

Teachers Mannual

HYDROPOWER ENGINEERING

For

Diploma Level Courses

**For Department of Technical Education
Govt. of Uttarakhand**



**ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE**

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PREFACE

Lecture notes for the proposed Engineering Diploma Level Elective Course for the branches in Electrical, Instrumentation and Electronics Engineering is in accordance with the approved syllabus. These note have been prepared by Prof. O. D. Thapar on the following basis chapter 1 and 2 are mostly on the basis of lecture notes on Short term training Course on the subject organized by Alternate Hydro Energy Centre I.I.T. Roorkee in July 2007 by experts as mentioned in the text. Government notification on the subject as per AHEC Publication entitled ‘Small Hydropower Installations and Private Sector Participation – 3rd edition, Indian Electricity Act 2003 etc. Chapters 3 and 4 are mostly written by Prof. O.D. Thapar.

(ARUN KUMAR)
Head, AHEC, IIT, Roorkee

FOR ENGINEERING DIPLOMA LEVEL ELECTIVE COURSE**For the branches in Electrical, Instrumentation, Electronics Engg.****1. Course Title: Hydropower Engineering****2.* Contact Hours: L: T: P:****3.* Examination Duration (Hrs.): Theory: Practical:****4.* Relative Weightage : CWS PRS MTE ETE
PRE****5.* Credit: 6.* Semester:**
Autumn Spring Both**7. Pre-requisite: NIL****8. Details of Course:**

Sl. No.	Particulars	Contact Hours
1.	Introduction to Hydro Power Energy: Introduction to non-conventional energy. Types of energy – solar energy, wind energy, biomass energy, ocean & geothermal energy and hydrogen energy etc. What is hydropower energy? Need for hydropower energy and its power estimation. Law of conservation of energy, Route of energy conversion.	4
2.	Types of Hydro Projects, Planning & Management: Government Hydropower policies, environmental issues, SWOT-(Strength weakness opportunity threatening) of hydropower projects, type of clearance required for Hydropower project, master plan, topography, catchments area, types of streams, allotment of site-(Open bid, Mou, Joint venture). Survey & investigation, PFR-(Pre-feasibility report), DPR (Detailed Project Report), Process of development of site (announcement, allotment, clearance, agreement, commissioning).Types of survey- Topographical, metrological, hydrological, ecological, geological. Arial Rainfall Measurement, Type of flow measurement Devices-(Notch, weir, flume), dilution method, and Flow duration curve (important), flood – discharge estimation kripitech formula, dickens formula, English formula, hydrograph, unit hydrograph. Financial institution, SOI Map, Cost / Estimation – wheeling charges, Banking, Moratorium, PPA-(Power purchase agreement), SERC-(State electricity regulatory commission) Hydrological cycle.	9
3.	Description of main parts of Hydropower Station: Block diagram of Small Hydro Power Station. Dam, Details of desilting tank. Storage & Balancing reservoir. Pen Stock, Pipe Line & Tunneling. Surge Tank, Valve House, Turbines. Synchronous Generator. Protection & Control equipment. Governors (Mechanical, electro-mechanical). Synchronous Generator & its Construction, Types of Synchronous Generator -Self excited, separately excited, self-excited with carbon brush, self excited brush less. Operational principle of Synchronous Generator. Speed frequency relationship.	10

** These are to be decided by the respective University/Board*

Sl. No.	Particulars	Contact Hours
4.	Earthing and grounding: e.m.f. equation for generator, Characteristics of Synchronous Generator (V-I Characteristics). Voltage regulation, open circuits charges, Short circuits charges, phase diagram short circuit ratio, parallel operation of generator or synchronizing of generators (Dark & Bright lamp and Synchronoscope method) synchronizing-Current, Torque, Power, Load sharing between two alternator running in parallel, Effect of change in excitation on terminal voltage. Induction generator – Construction & Working Principle, slip speed, Self-excited Induction generator or standalone generator. Power factor-pf, Most economical power factor, Real power factor, operant power factor, leading & lagging power factor, pf correction methodologies. Switchyards- A Transformer – its types, construction, rating, Star & Delta Connection, parallel operation, phase group of 3 Φ transformer. B Protection -Circuit Breakers, Short circuit current, Base KVA, Method of short circuit current, KVA calculation, fuse element, current carrying capacity of fuse element, Instrumental transformer, Current transformer, Basic Principle of operation of circuit breaker, types of circuit breaker, oil circuit breaker, oil less circuit breaker, relay-its types – electromagnetic induction type, electromagnetic attraction, thermal, moving, static, Directional, Over Voltage & Over Current. C Power transformer – differential protection, over current earth fault protection, SCADA- Supervisory control and data acquisition, ICCS- Integrated computer control system.	14
5.	Costing & Estimation	5

Suggested Readings:

1. Bisht Tara Datt, Electrical Machine II, Asian Publishers Muzzaffarnagar.
2. Chakrabarti & Halder, Power System & Analysis - Operation & Research, PHI Pvt. Ltd., New Delhi.
3. Gupta & Singhal, Electric Machines, New Age International (P) Ltd, Publishers New Delhi.
4. Kumar Murugesh K., Basic Electrical Science & Technology, Vikas Publishing House Pvt Ltd, New Delhi.
5. Nag, P. K., Power Plant Engineering, TMH Publication, New Delhi.
6. Ravindranath & Chander, Power System Protection & Switch Gear, New Age International (P) Ltd, Publishers New Delhi.
7. Varshney, R.S., Hydro Power Structures, Nem Chand & Brothers.

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CHAPTER –1

INTRODUCTION TO HYDROPOWER ENERGY

1. FORMS OF ENERGY

There is an important principle stating that the total amount of energy in a closed system remains constant. Energy may change from one form to another, but the total amount in any closed system remains constant. This principle, known as 'Conservation of energy' is extremely important for understanding a variety of phenomena.

- (a) Kinetic energy
- (b) Potential energy
- (c) Chemical energy
- (d) Electrical energy
- (e) Heat energy
- (f) Radiant energy
- (g) Nuclear (Mass) energy

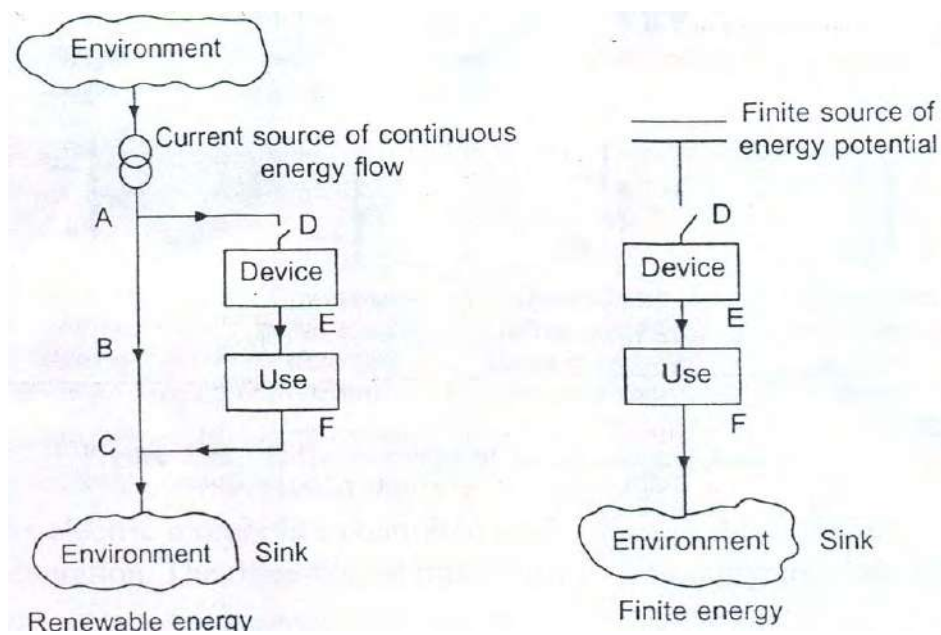
1.1 DEFINITIONS

- a) Renewable energy is the energy obtained from regenerative or virtually inexhaustible sources of energy occurring in the natural environment like solar energy, wind energy etc. This is also referred as non-conventional sources of energy.
- b) Nonrenewable energy is the energy obtained from static stores of energy that remain bound unless released by human interaction. Examples are fossil fuels of coal, oil and natural gas and nuclear fuels. This type of energy is also called finite energy or conventional sources of energy.

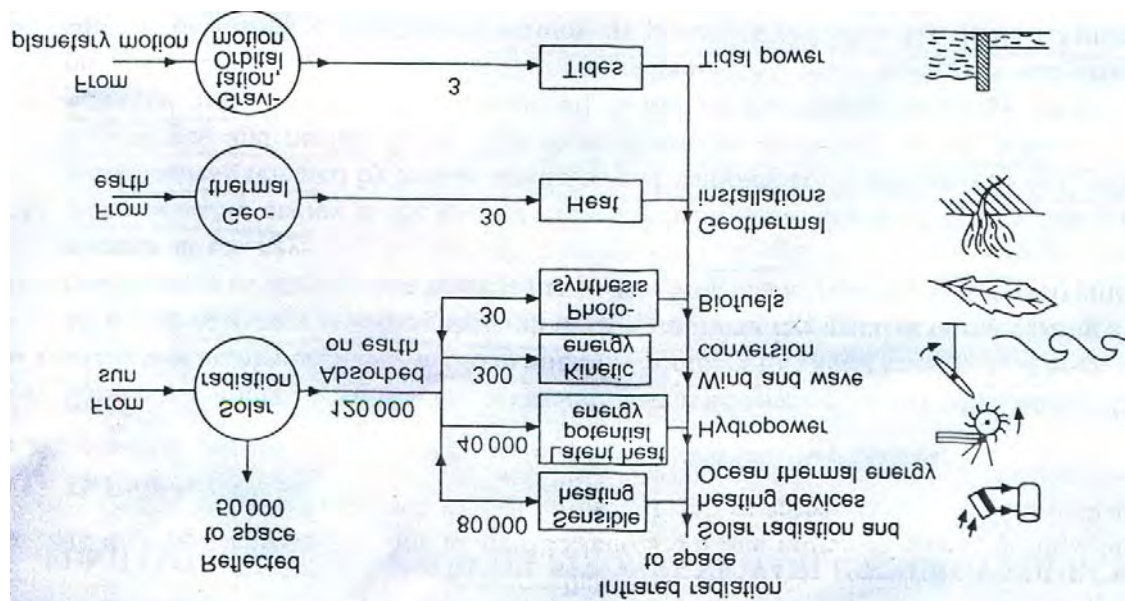
1.2 ENERGY SOURCES

There are six ultimate sources of useful energy:

- (1) The sun;
- (2) The motion and gravitational potential of the sun, Moon and earth;
- (3) Geothermal energy from cooling, chemical reaction and the radioactive decay inside the earth;
- (4) Nuclear reactions on the earth;
- (5) Chemical reactions from mineral sources; and
- (6) Fossil fuel (Petroleum product and gases).



Comparison between renewable and finite energy supplies. Environmental energy flow ABC, harnessed energy flow DEF.



Natural energy currents on earth, showing renewable energy systems. Units terawatts (TW) (10^{12})

1.3 ENVIRONMENTAL AND SOCIAL PROBLEMS OF FOSSIL FUELS

- Water pollution.
- Hazardous air pollutants
- Ambient air quality.
- Maritime pollution
- Solid waste disposal
- Land use and siting impact.
- Acid rain
- Stratospheric ozone depletion
- Global climate change(greenhouse effect)

Renewable energy achievements in India during the last four years

S. No.	Programmes	As on 12.10.1999	As on 12.10.2003
A	Grid Connected Systems (installed capacity in MW)		
1.	Wind power	1022.00	2002.00
2.	Small Hydro Power	1218.00	1530.00
3.	Biomass/Cogeneration Power	171.00	571.00
4.	Urban and industrial waste power	2.00	26.00
5.	Solar photovoltaic power	1.00	3.00
	Total	2414.00	4132.00
B.	Decentralized systems		
6.	Biogas plants (Nos. in lakh)	28.80	35.50
7.	Community/ Institutional/ Night-soil based biogas plants (Nos.)	2673.00	3902.00
8.	Improved chulha (Nos. in lakh)	250.00	350.00
9.	Solar home lighting systems (Nos.)	64000.00	260000.00
10.	Solar street lighting systems (Nos.)	32920.00	43470.00
11.	Solar lanterns (Nos. in lakh)	2.22	4.42
12.	SPV pumps (Nos.) (solar photovoltaic)	2160.00	6400.00
13.	Solar water heating systems (lakh sq. meter collector area)	5.70	7.00

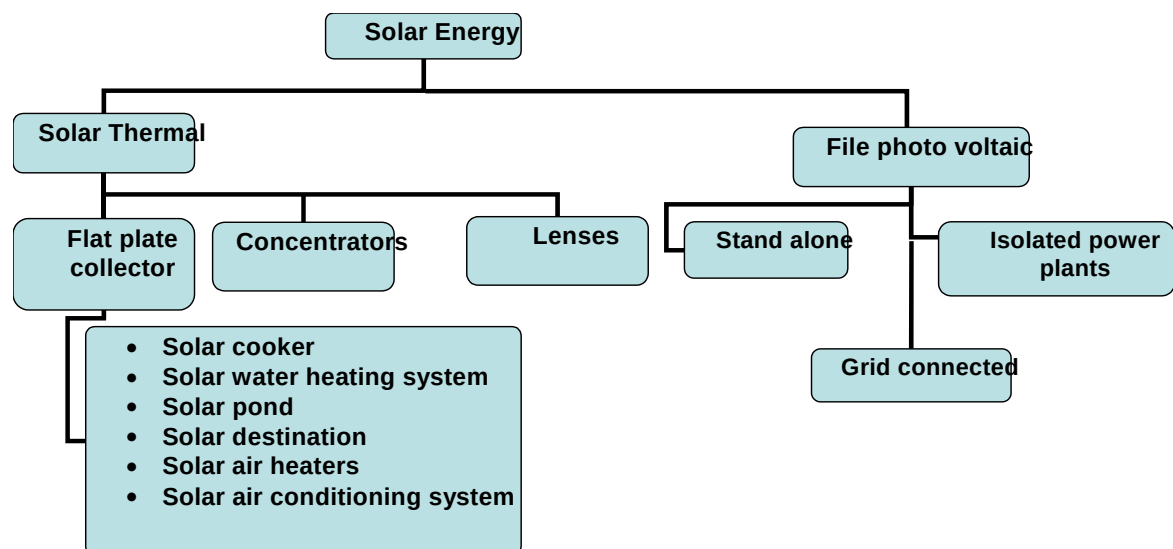
1.3.1 Important Renewable Energy Resources and Technologies for Sustainable Development

- i) They have much less environmental impact compared to other sources of energy.
- ii) Renewable energy sources cannot be depleted unlike fossil fuel and uranium resources.
- iii) They favour power system decentralization and locally applicable solutions more or less independent of the national network, thus enhancing the flexibility of the system and the economic power supply to small isolated settlements.

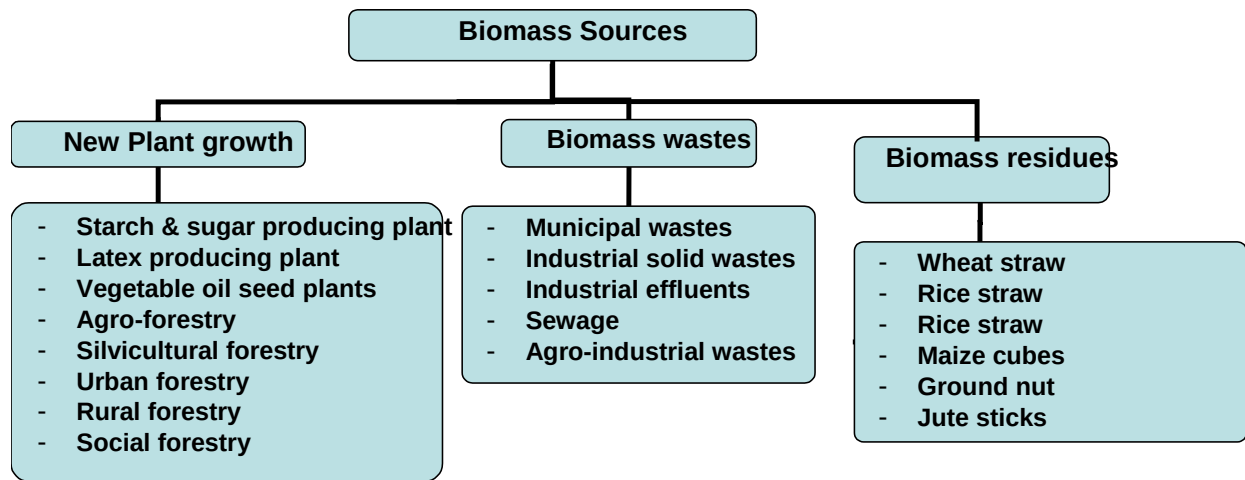
1.3.2 Essential Factors for sustainable Developments

- i) Public awareness
- ii) Information
- iii) Environmental education and training
- iv) Innovative energy strategies
- v) Promoting renewable energy resources
- vi) Financing
- vii) Monitoring and evaluation tools

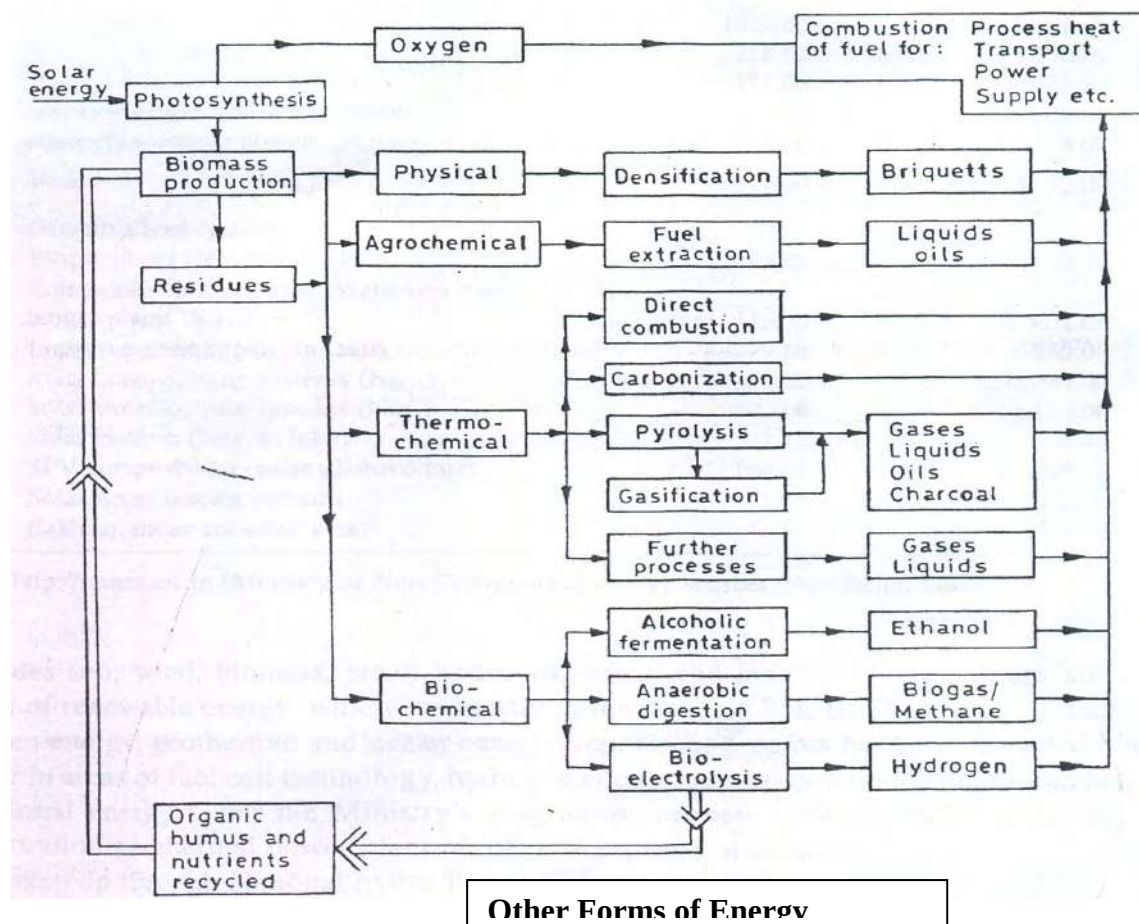
1.3.3 Direct Forms of Solar Energy



1.3.4 Indirect Forms of Solar Energy



Biomass Energy Sources



1.4 WIND ENERGY CONVERSION SYSTEM

Wind generated electricity has been used in three different modes

- below 4kW capacity have been used as battery chargers
- Wind electric generators in the range of 50 to 300 kW capacities have been used in grid connected wind farms
- Wind electric generators in the middle range of 50 to 300 KW capacities have been used in grid connected wind farms.
- Wind electric generators in the middle range of 20 to 100 kW have been used in stand alone model supplemented by power from diesel-generator sets. Many such locations in India are Lakshadweep, Bet-Dwarka, Leh etc. where small local grid operated by diesel generator and wind electric generators connected to this grid can be used in saving the consumption of diesel.

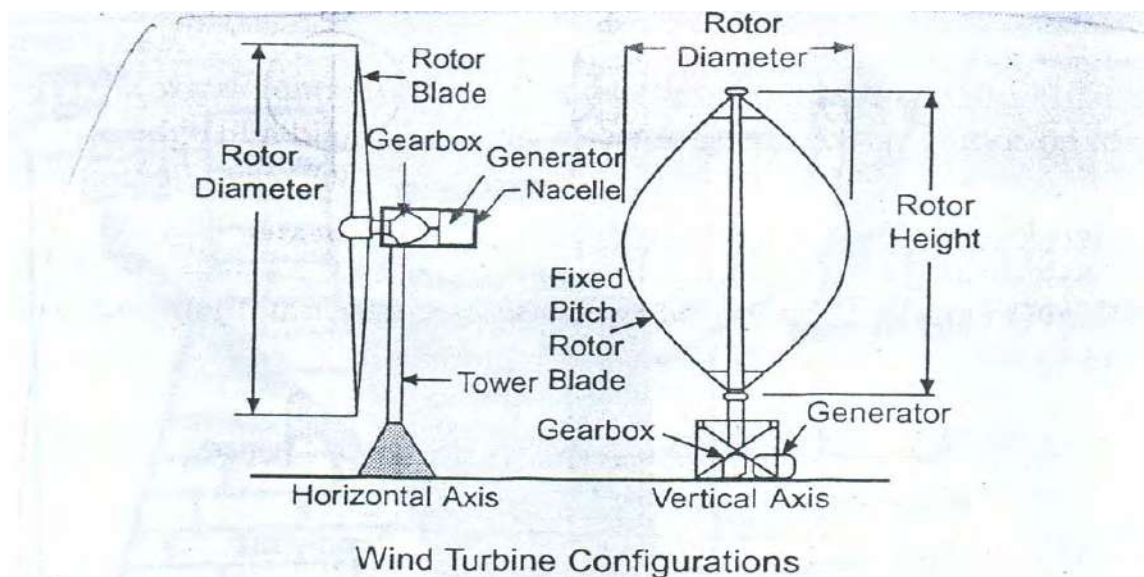


Fig. 1.4.1 – Configuration of horizontal axis and vertical axis wind turbines

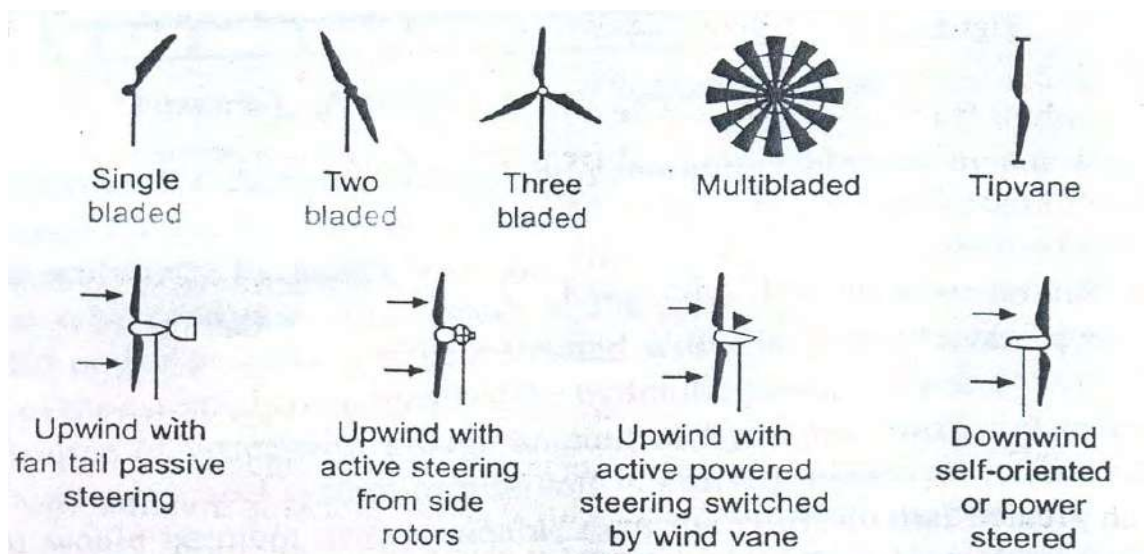


Fig. 1.4.2 Different design of horizontal axis wind turbine

1.5 HYDROPOWER

Hydro-energy is known as traditional renewable energy source. It is based on natural circulating water flow and its drop from higher to lower land surface that constitutes the potential. In order to convert this potential to applicable electric energy, water flow should be led to and drive a hydraulic turbine, transforming hydroenergy into mechanical energy, the latter again drives a connected generator transforming the mechanical energy into electric energy. As hydroenergy exploitation and its utilization are completed at the same time. I.e. the exploitation of first energy source and the conversion of secondary energy source occur simultaneously, unlike the coal power generation which should have two orders; first order is exploitation of fuel, second order is generation, so hydropower has the advantages over thermal power generation.

Mankind has used the energy of falling water for many centuries, at first in mechanical form and since the late 19th century by further conversion to electrical energy. Historically, hydropower was developed on a small scale to serve localities in the vicinity of the plants. With the expansion and increasing load transfer capability of transmission networks, power generation was concentrated in increasingly larger units and to benefit from the economies resulting from development on a larger scale.

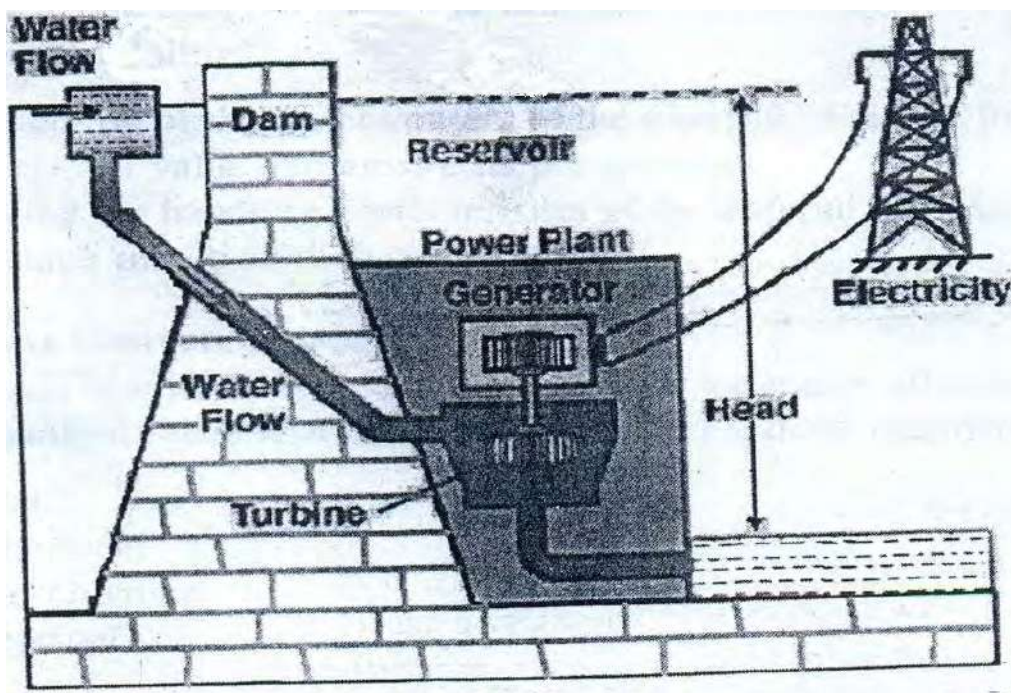


Fig. 1.5.1 General Layout of a dam based hydroelectric plant

Sites selected for development tended to be the most economically attractive; in this regard, higher heads and proximity to load centers were significant factors. For this reason, development was not restricted to large sites, and hydro stations today range from less than 1 MWe capacity to more than 10,000 MWe. The efficiency of hydroelectric generation is more than twice that of competing thermal power stations.

Water impounded in dam for storage and released in phased manner to generate power and further used for irrigation is shown in (figure 1.5.1).

1.5.1 Power Estimation

The potential electric power of the water in terms of flow and head can be calculated from the following equation.

$$KW = 9.81 \times Q \times H \times \eta$$

Where,

kW = electric power in kW

Q = quantity of water flowing through the hydraulic turbine in cubic meters per second. Discharge (quantity of water) flowing in a stream and available for power generation has daily and seasonal variation. Optimum discharge for power generation is determined on the basis of energy generation cost.

H = Net available head in meters (gross head – losses)

η = overall efficiency of the hydro power plant. For general estimation purposes, η is normally taken as 0.85

Example

A hydropower station has a gross head of 8.2 meter. Head loss in water conductor system is 0.5 meters. Optimum discharge in cumecs is 267 cubic meter per second.

$$KW = 9.81 \times 267 \times 8.2 \times 0.85$$

$$KW = 18256.3$$

According 2 units of 2 x 9000 kW can be installed.

Energy generation E = average power x 24 x 365 in (kWh) units

1.5.2 Power Potential

Major river system of India are shown in figure 1.5.2. Basin wise identified hydroelectric potential as per reassessment studies in 1978 – 87 is shown in table 1.5.1. and undeveloped potential statewise in the Himalayan region is shown in table 1.5.2.

MAJOR RIVER SYSTEMS OF INDIA

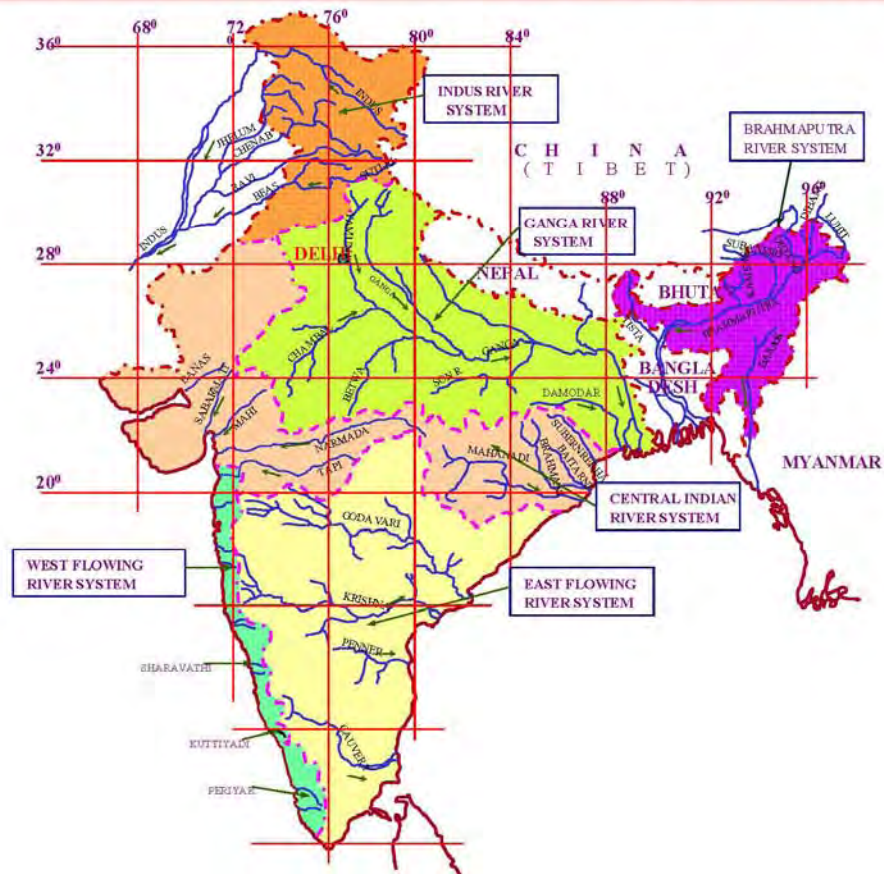


Fig. 1.5.2

Table 1.5.1

**BASIN-WISE IDENTIFIED HYDROELECTRIC POTENTIAL
REASSESSMENT STUDIES - 1978 - 1987**

S. No.	Basin	Potential in MW
1	Indus	33832
2	Ganga	20711
3	Central Indian	4152
4	West Flowing	9430
5	East Flowing	14511
6	Brahmaputra	66065
Total		148702

CHAPTER – 2

2.1 TYPES OF PROJECT

Capacity, unit size and selection of Equipment, their Characteristics and Specifications for design of hydro power station depends upon type of hydroelectric development and classification with respect to head and size. There are three main types of hydropower schemes that can be categorized in terms of how the flow at a given site is controlled or modified. These are:

1. Run-of-river plants (no active storage); and
2. Plants with significant storage
3. Pumped storage

In a run-of-river project, the natural flow of the river is relatively uncontrolled. In a storage project, the filling and emptying of the impounded storage along with the pattern of the natural stream flow controls the flow in the river downstream from the storage impoundment.

Run-of-river plants can be located at the downstream end of a canal fall, open flume, or pipeline diverting the stream's flow around a water supply dam or falls. The available flow governs the capacity of the plant. The plant has little or no ability to operate at flow rates higher than that available at the moment.

In a conventional plant, a dam, which stores water in a reservoir or lake impoundment, controls the river flows. Water is released according to electric, irrigation, water supply, or flood control needs. Constructing a dam and storage reservoir can increase the percentage of time that a project can produce a given level of power. Base load plants—those operated at relatively constant output—may have either a small capacity relative to the river flow or may have a significant storage reservoir. Storage reservoirs can be sized for storing water during wet years or wet seasons. Alternatively, they can be sized to provide water for weekly or daily peak generation. A storage reservoir allows using available energy that might otherwise be wasted as spill.

Plants with storage at both head and tailrace are pumped storage project.

2.1.1 Run of the River Schemes or Diversion Schemes

This type of development aims at utilizing the instantaneous discharge of the stream. So the discharge remain restricted to day to day natural yield from the catchments; characteristics of which will depend on the hydrological features. Diurnal storage is sometime provided for optimum benefits. Development of a river in several steps where tail race discharges from head race inflows for downstream power plants forms an interesting variation of this case and may require sometimes special control measures.

Small scale power generation also generally fall in the category and may have special control requirement especially if the power is fed into a large grid.

2.1.2 Storage Schemes

In such schemes annual yield from the catchment is stored in full or partially and then released according to some plan for utilization of storage. Storage may be for single purpose such as power development or may be for multi purpose use which may include irrigation, flood control, etc. therefore, design of storage works and releases from the reservoir will be governed by the intended uses of the stored water. If the scheme is only for power development, then the best use of the water will be by releasing according to the power demand. Schemes with limited storage may be designed as peaking units. If the water project forms a part of the large grid, then the storage is utilized for meeting the peak demands. Such stations could be usefully assigned with the duty of frequency regulation of the system.

2.1.3 Pump Storage Scheme

Principle

The basic principle of pumped storage is to convert the surplus electrical energy available in a system in off-peak periods, to hydraulic potential energy, in order to generate power in periods when the peak demand on the system exceeds the total available capacity of the generating stations.

By using the surplus scheme electrical energy available in the network during low-demand periods, water is pumped from a lower pond to an upper pond. In periods of peak demand, the power station is operated in the generating mode i.e. water from the upper pond is drawn through the same water conduit system to the turbine for generating power.

There are two main types of pumped storage plants:

- i) Pumped-storage plants and
- ii) Mixed pumped-storage plants.

Pump-storage plants: In this type only pumped storage operation is envisaged without any scope for conventional generation of power. These are provided in places where the run-off is poor. Further, they are designed only for operation on a day-to-day basis without room for flexibility in operation.

Mixed pumped-storage plants: In this type, in addition to the pumped storage operation, some amount of extra energy can be generated by utilizing the additional natural run-off during a year. These can be designed for operation on a weekly cycle or other form of a longer period by providing for additional storage and afford some amount of flexibility in operation.

2.2 CLASSIFICATION OF HYDROPOWER PLANTS

As such there are no hard and fast rules to classify Hydro power plants. Some of the basis are as follows:

- Based on Hydraulic Characteristics
- Based on Head
- Based on Capacity

- Based on Turbine Characteristics
- Based on Load Characteristics
- Based on Interconnection

2.2.1 Hydropower Project based on Hydraulic Characteristics:

- (i) Run off river plant (Diversion plant)
- (ii) Storage plant (Impoundment plant)
- (iii) Pumped storage plant
- (iv) Tidal plant

2.2.1.1 Run off River Plant (Diversion Plant)

- ❖ In some areas of the world, the flow rate and elevation drops of the water are consistent enough that hydro electric plants can be built directly in the river.
- ❖ The water is utilized as it comes in the river.
- ❖ Practically, water is not stored during flood periods as well as during low electricity demand periods, hence water is wasted.
- ❖ Run off river plant may be without pondage or with pondage.
- ❖ The plants with pondage are provided with a barrage to store the water, to take care of daily variation.
- ❖ During good flow conditions – can supply base load and during low flow conditions - can supply peak load
- ❖ Seasonal changes in river flow and weather conditions affect the plant's output, hence it is in limited use unless interconnected with grid.

flows that occur in the stream at the intake and flows downstream of the powerhouse are virtually identical to pre-development flows.

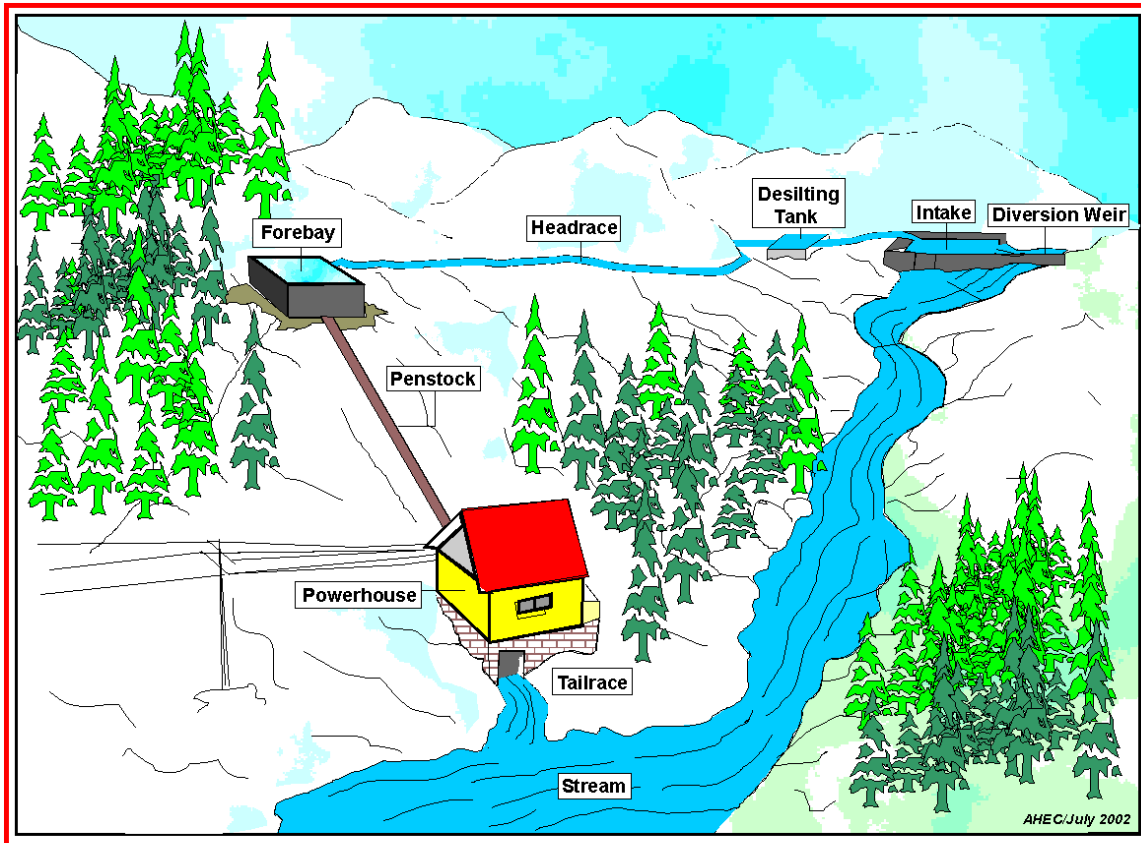
- Run-of-river facilities use low dams to provide limited storage of water– at most daily pondage.
- In a run-off river SHP scheme, through a diversion structure water is diverted to water conductor system to the powerhouse.

A typical scheme is shown in figure 2.1 and 2.2.

2.2.1.2 Canal based sites

- A Canal based scheme utilises the drops on existing/proposed irrigation canals.
- The energy generated by water flowing through the canal fall (located in the canal) is tapped for power generation.
- Powerhouse is located at the main canal or a bye pass canal is constructed where the powerhouse can be located.

A typical scheme is shown in figure 2.3



Typical Arrangement of Small Hydro Power Station

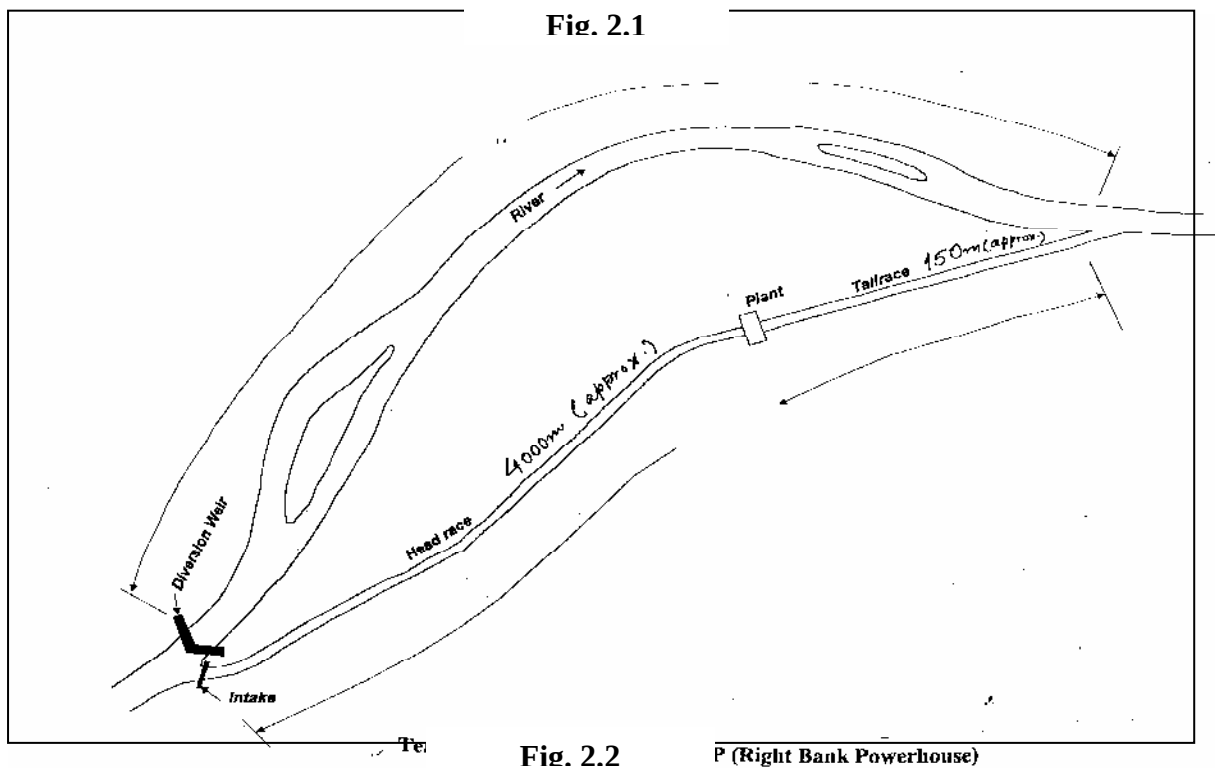
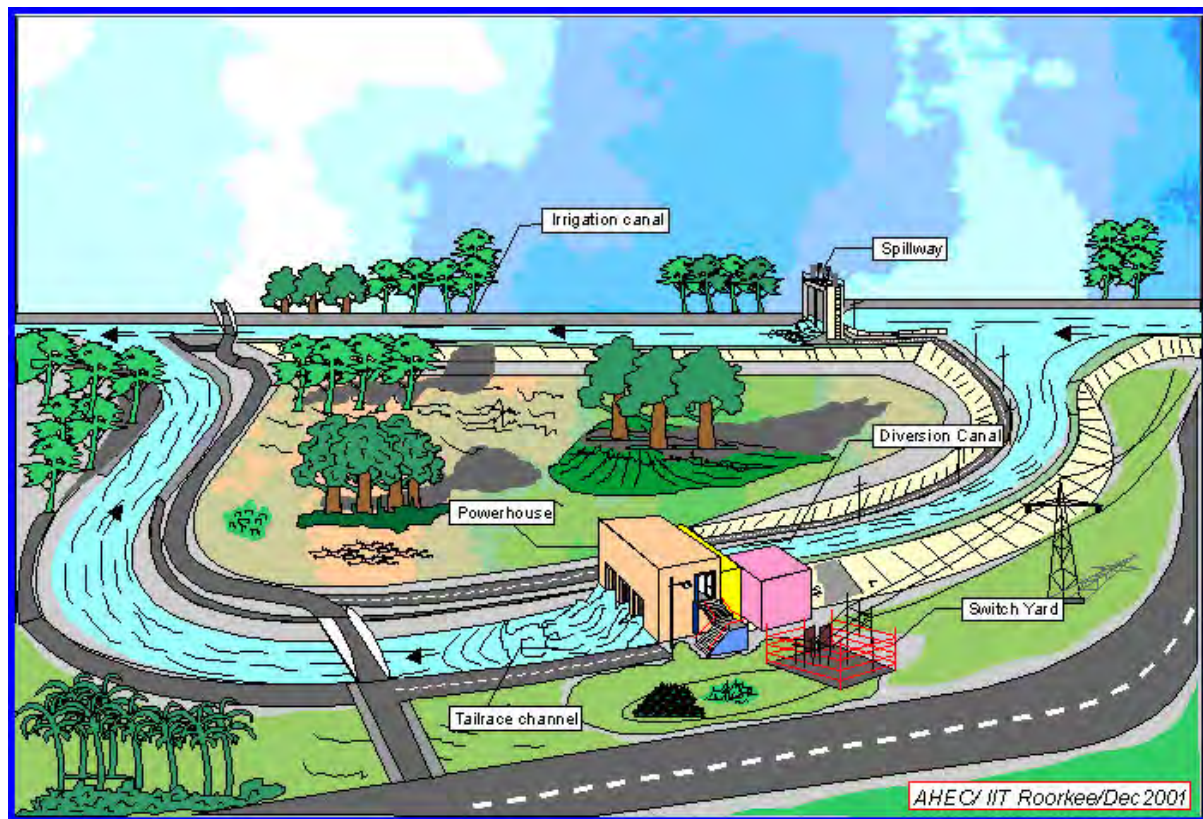


Fig. 2.2

P (Right Bank Powerhouse)

Run of the River Scheme



Typical Arrangement of Canal Fall Small Hydro Power Station

Fig. 2.3

2.2.1.3 Storage Plant (Impoundment Plant)

- ❖ A common type of hydro power plant.
- ❖ This plant has storage reservoir provided by constructing a dam across the river.
- ❖ It is generally preferred in mountainous regions.
- ❖ The storage of water takes care of fluctuations of water supply during flood and draught period as well as during load fluctuations, hence it can supply electricity more constantly than any other plants
- ❖ Suitable for both base load and peak load.
- ❖ Other benefits of this plant are:

Flood control	Irrigation	Drinking water
Improved navigation	Improved fish breeding etc.	

- The dam provides the means to regulate the flow of water, and can add to the height of the source of water thereby effectively increasing the head (H).
- Reservoir created by the dam may store and regulate stream flows to make them more timely for power production, and to serve other purposes for water resource development.
- Powerhouse is located at the toe of the dam and it utilizes the discharge release through sluice primarily meant for irrigation and the head available (water level difference between upstream and downstream of reservoir) for power generation.

A typical scheme is shown in figure 2.4

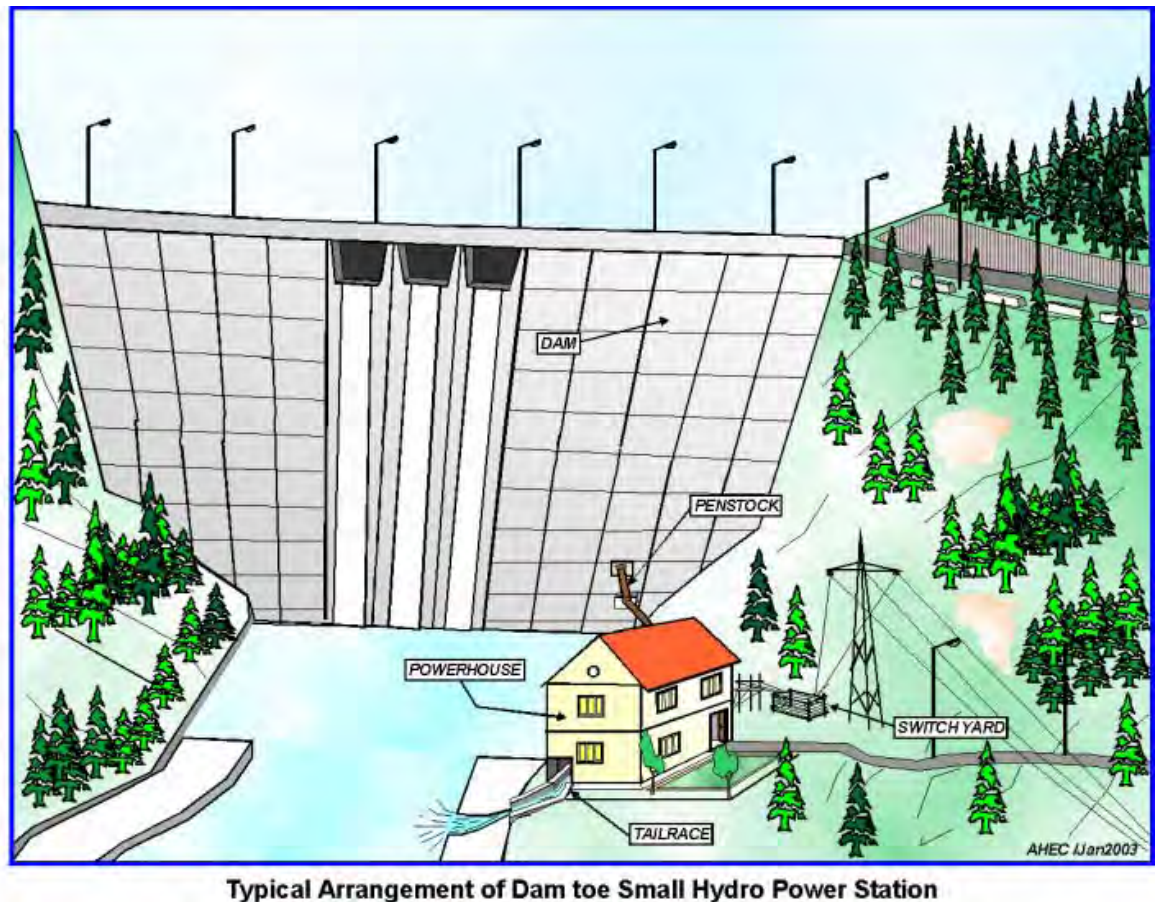


Fig. 2.4

2.2.1.4 Pumped Storage Plant

- ❖ Water is utilized for generation of power during peak demand, while same water is pumped back in the reservoir during off peak demand period, when excess power is available for this purpose.
- ❖ If turbine is reversible, it can be used as a pump to supply water back to reservoir, otherwise separate pump can be used.
Based on operating cycle it can be classified as:
 - (a) **Plant with a daily cycle:** water is pumped up from mid night to early morning as well as near lunch time.
 - (b) **Plant with a weekly cycle:** water is pumped up during weekend.
 - (c) **Plant with a seasonal cycle:** water is pumped up in the winter continuously for several days to be utilized for a continuous power generation in the high demand summer period.

Figure 2.5 shows a typical layout.

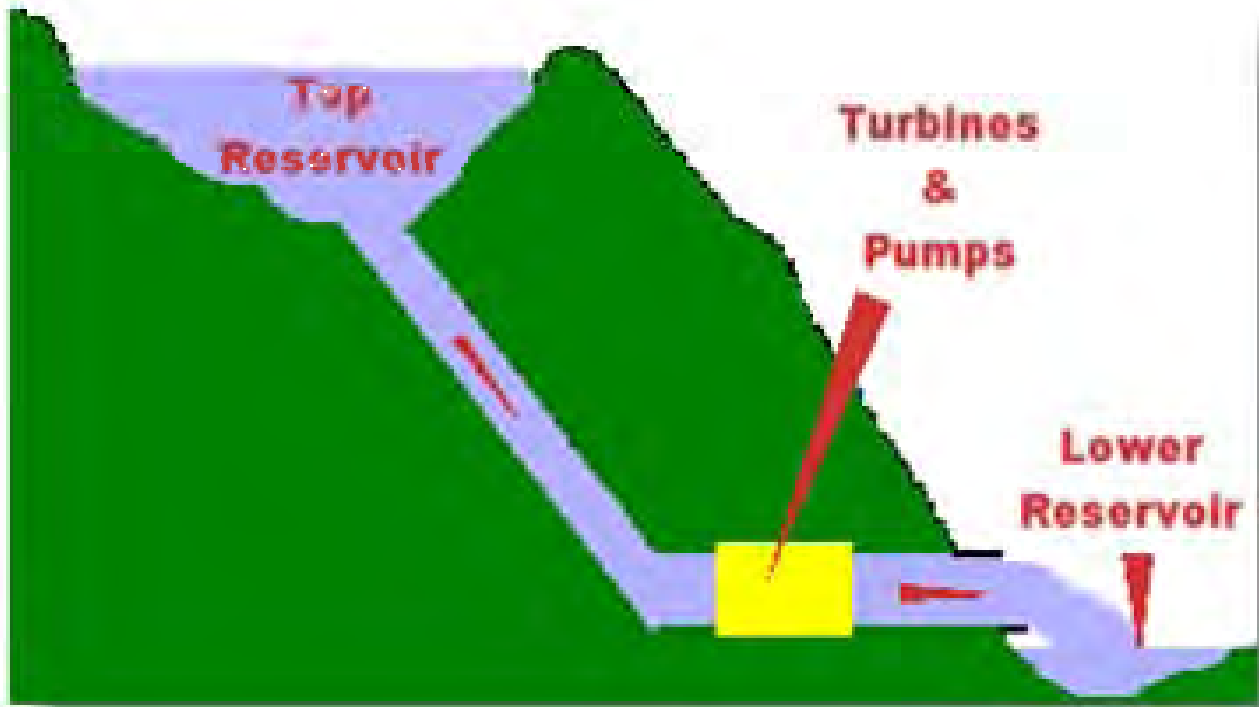


Fig. 2.5 Pumped Storage Plant

2.2.1.5 Tidal Plant

- . Tide is a periodic rise and fall of water level of the sea due to gravitational attraction between moon and earth and sun and earth.
Regions which comes nearer to moon are subjected to high tide and regions which are away from moon are subjected to low tide.
- ❖ The level difference between high tide and low tide is called **Range of Tide**, which is responsible for power generation.

2.2.2 Hydropower Projects based on Head

Head

- | | | |
|-------|-------------------|---------------------|
| (i) | Low head plant | upto 30 m |
| (ii) | Medium head plant | between 30 to 300 m |
| (iii) | High head plant | more than 300 m |

2.2.3 Hydro Projects based on Turbine Characteristics (i.e. *Specific speed)

	<u>Specific Speed</u>	<u>Type of Turbine</u>
(i) Low specific speed	between 10 to 60	Axial flow propeller turbine
(ii) Medium specific speed	between 60 to 300	Francis turbine
(iii) High specific speed	between 300 to 1000	Impulse (pelton) turbine

[***Specific speed** is the speed of a turbine which is similar to the actual turbine but of such a size that it will develop unit power when working under unit head.]

2.2.4 Hydro Projects Based on Load Characteristics

- **Base load plant:**
 - ❖ Operates continuously and generate constant power throughout the year. e.g. Storage plant, Run off river plant without pondage.
- ⑩ **Peak load plant:**
 - ❖ Which supply the power during the peak hours only. e.g. Pumped storage plant, Run off river plant with pondage.

2.2.5 Based on Interconnection

- **Isolated plants:**
 - ❖ If a power station works independently it is referred as an isolated plant.
 - ❖ Generally installed in industries (i.e. Captive power plant)
- ⑩ **Interconnected plants:**
 - ❖ If a power station is connected with **grid**, it is called interconnected plant.

Some typical illustration of different types of hydro electric development are shown in figure 2.6 to figure 2.25.

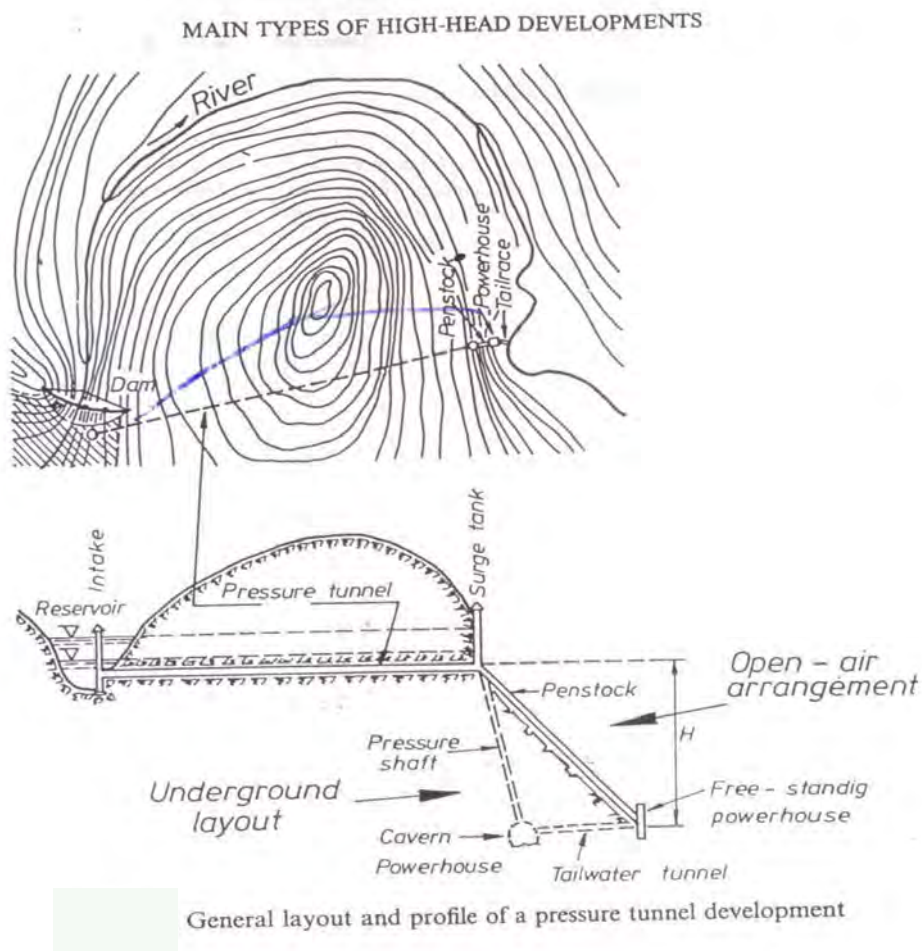


Fig. 2.6

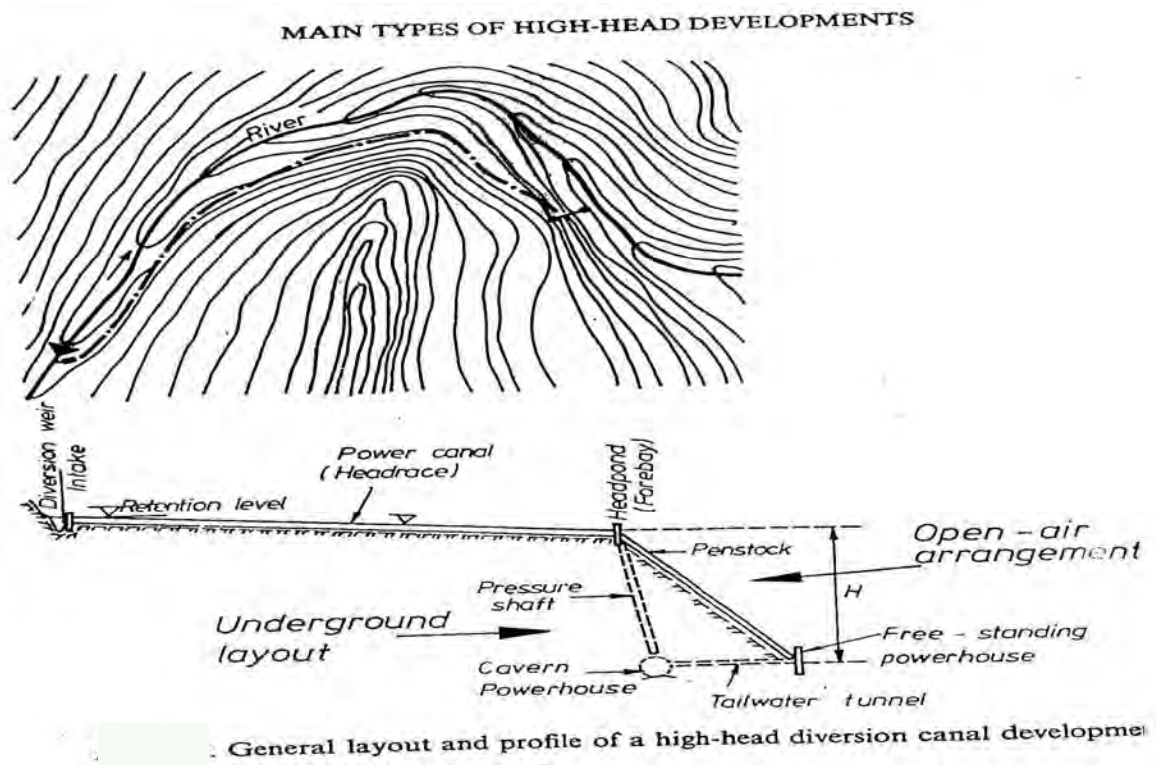


Fig. 2.7

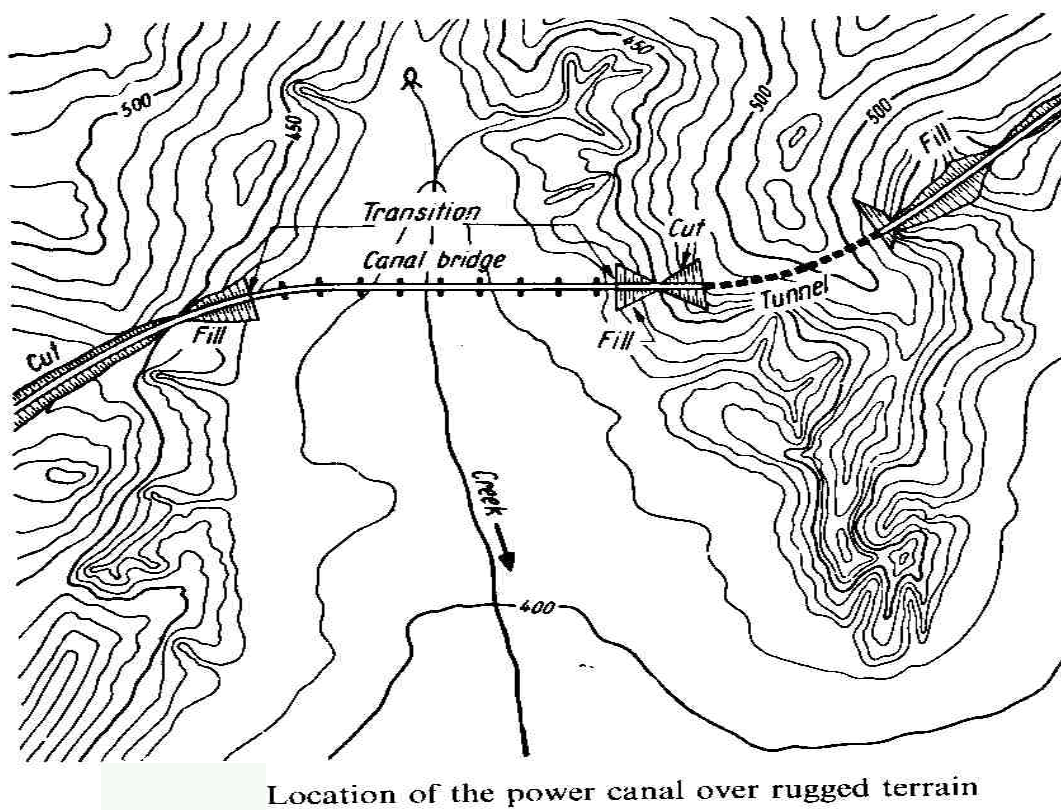
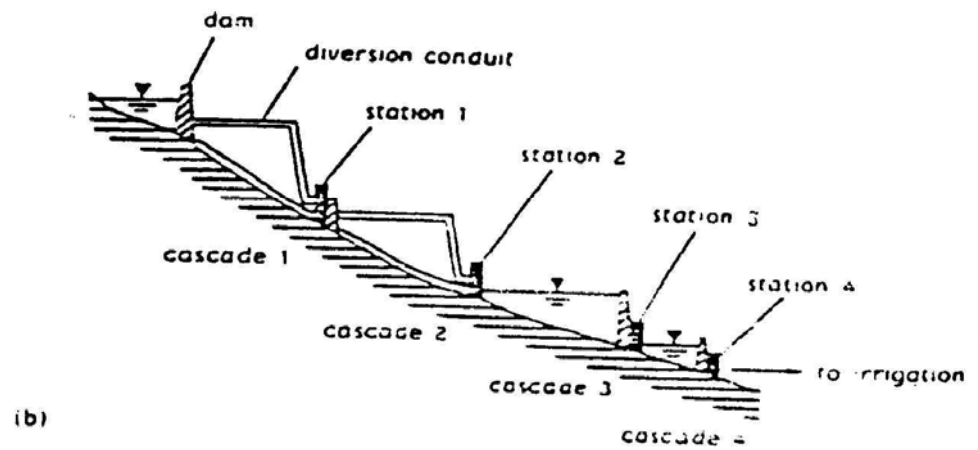
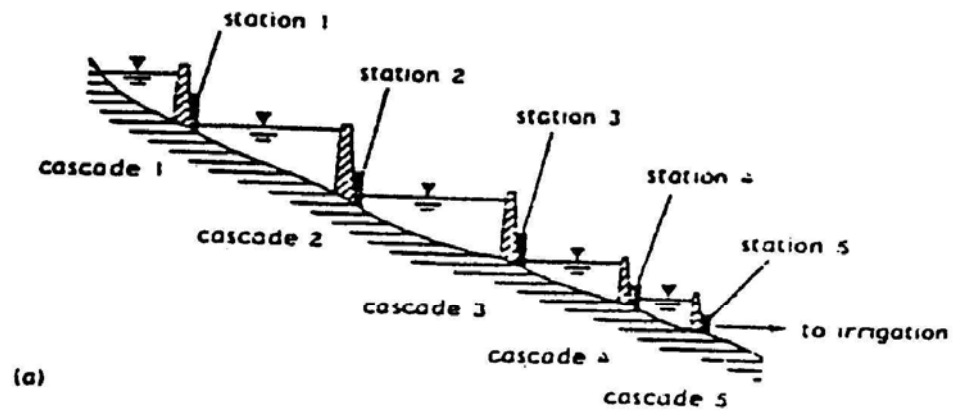


Fig. 2.8



Cascade development

Fig. 2.9

"Non-diversion" Development



"In river" Layout

Diversion Development

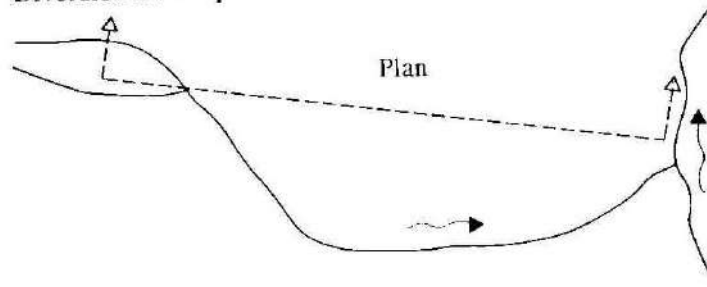
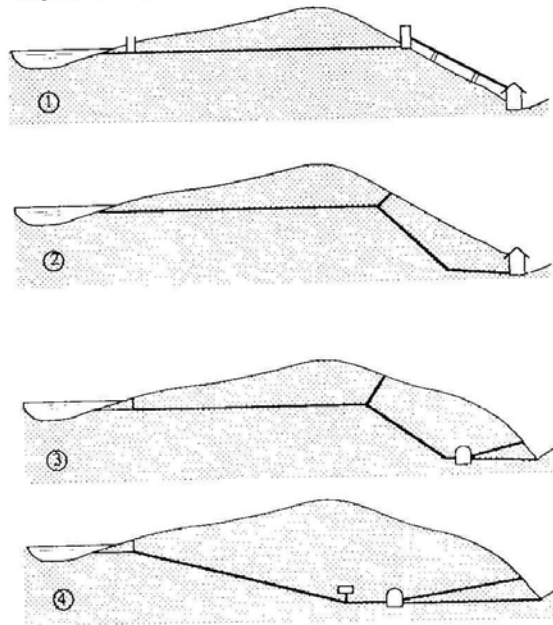


Fig. 2.10

Layout Concepts



Above ground developments

1. Penstock / surge tank.
2. Pressure shaft / surge shaft.

Underground developments

3. Pressure and surge shafts.
4. Pressure tunnel and air cushion surge chamber.

Fig. 2.11

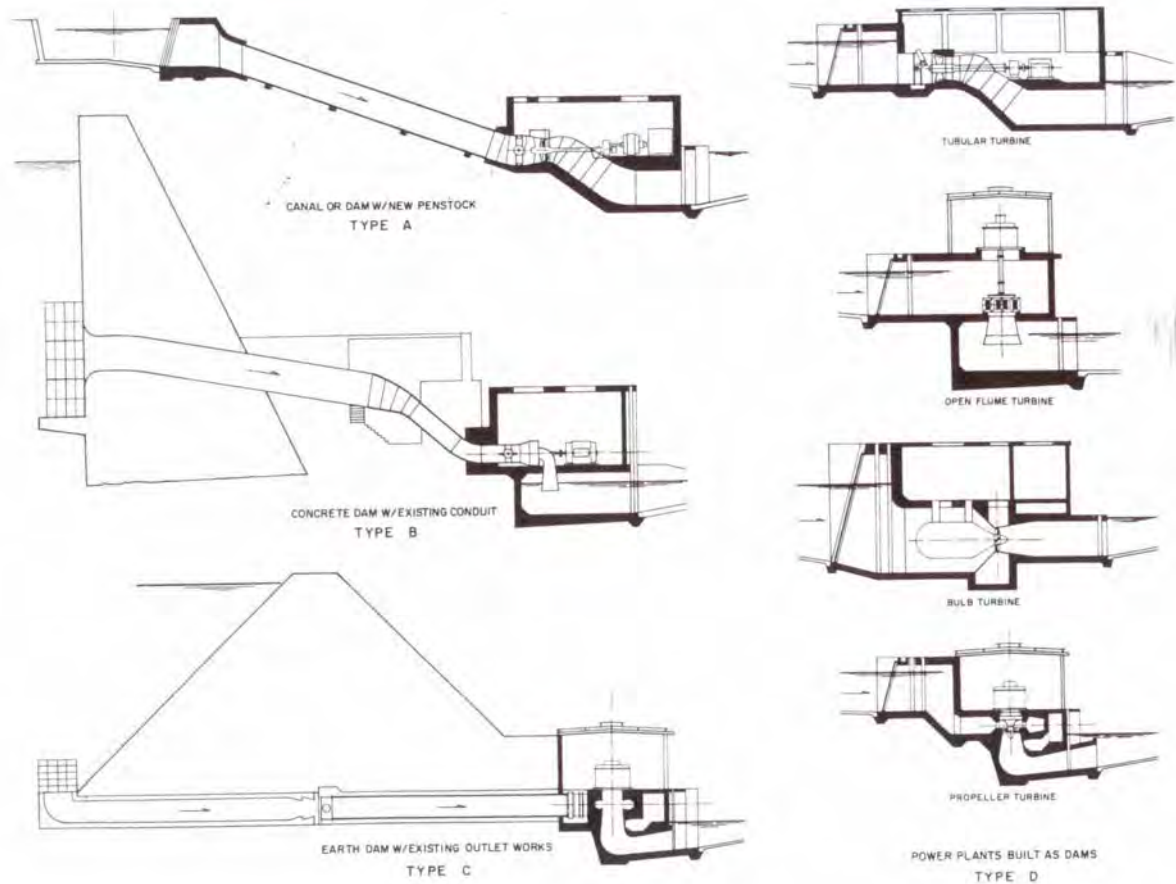
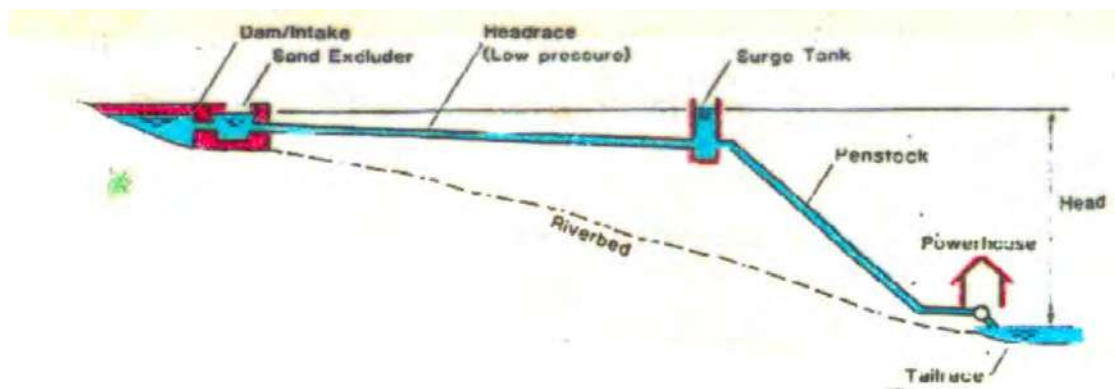


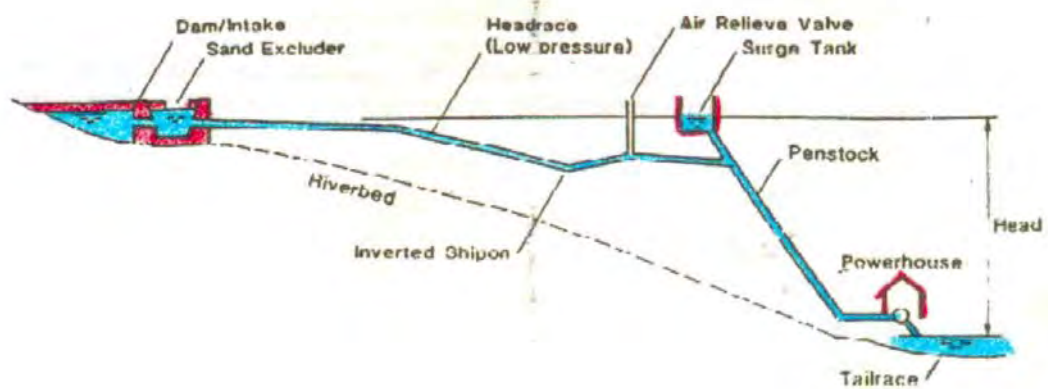
Fig. 2.12



General Layout, Alternative 1.

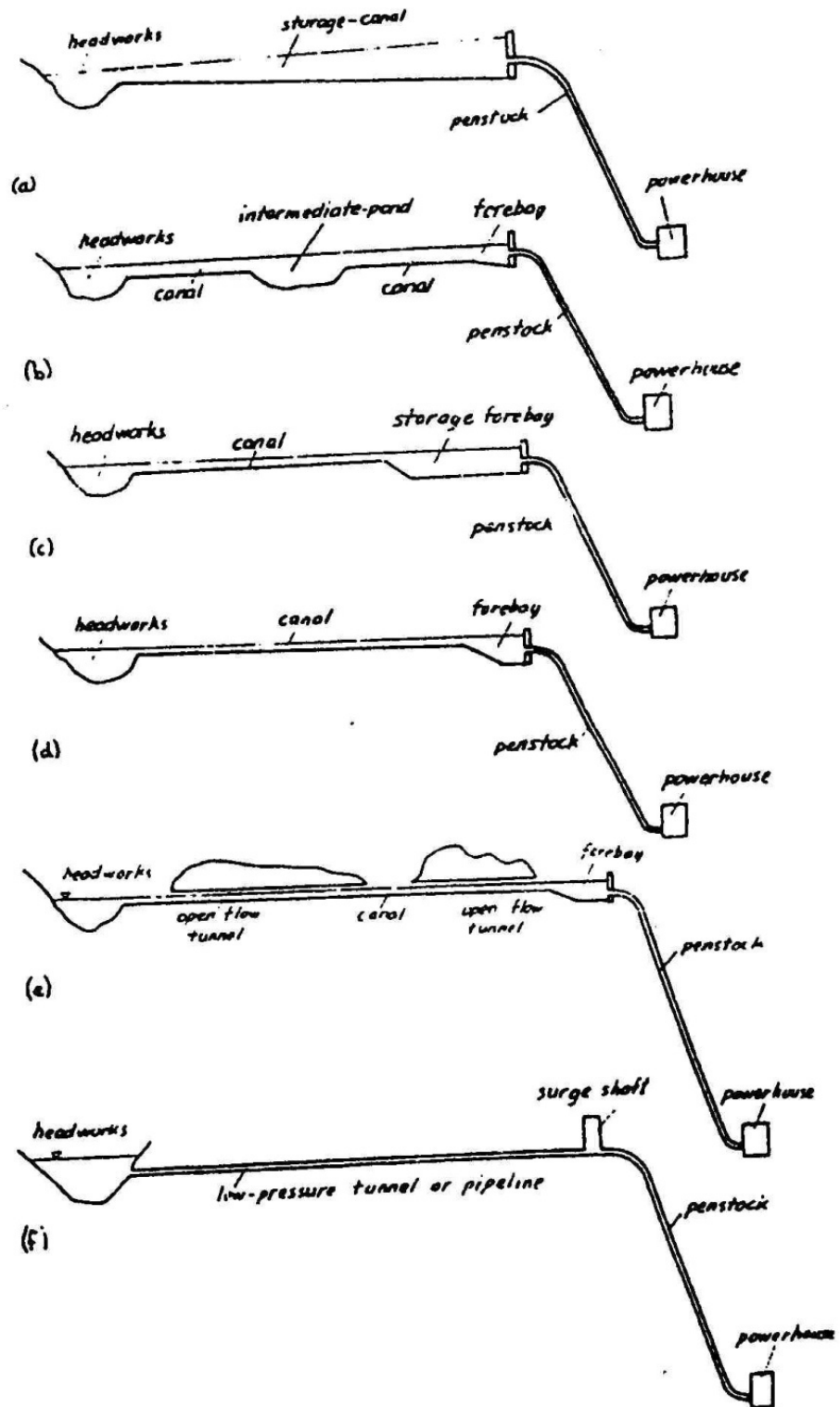


General Layout, Alternative 2.



General Layout, Alternative 3.

Fig. 2.13



Diversion-type scheme. (a) storage-canal type; (b) intermediate pond type; (c) storage-forebay type; (d) non-pondage type; (e) Open flow tunnel type; (f) low pressure conduit type.

Fig. 2.14

UNDERGROUND POWER STATIONS

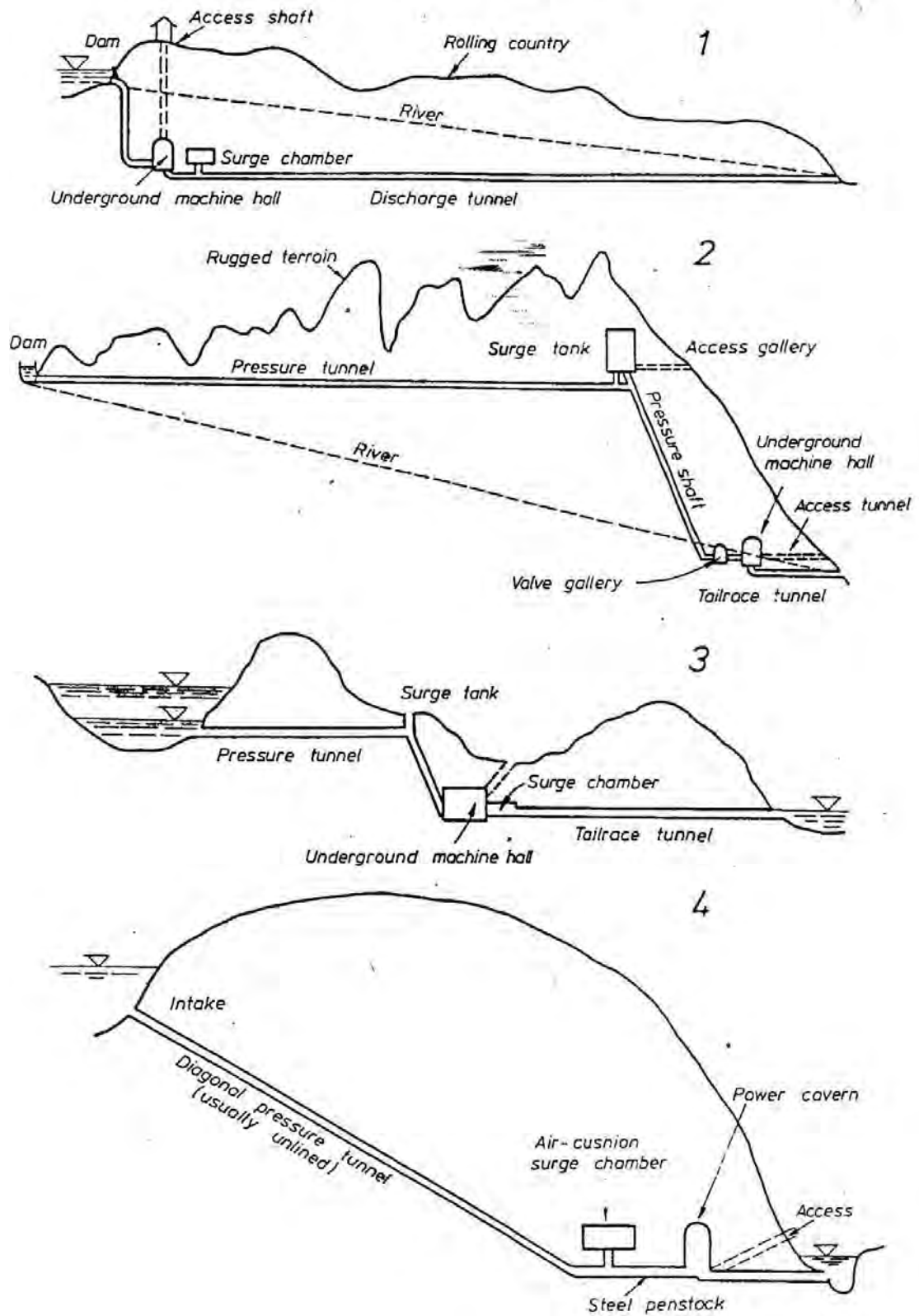
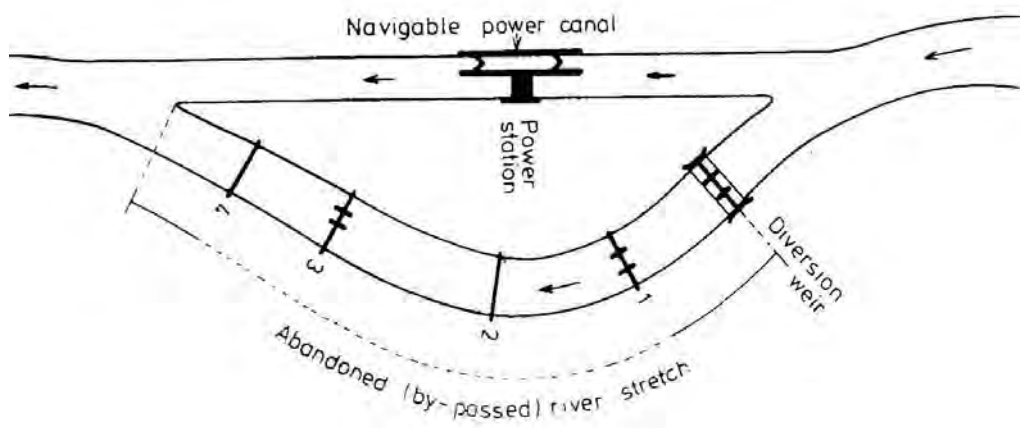
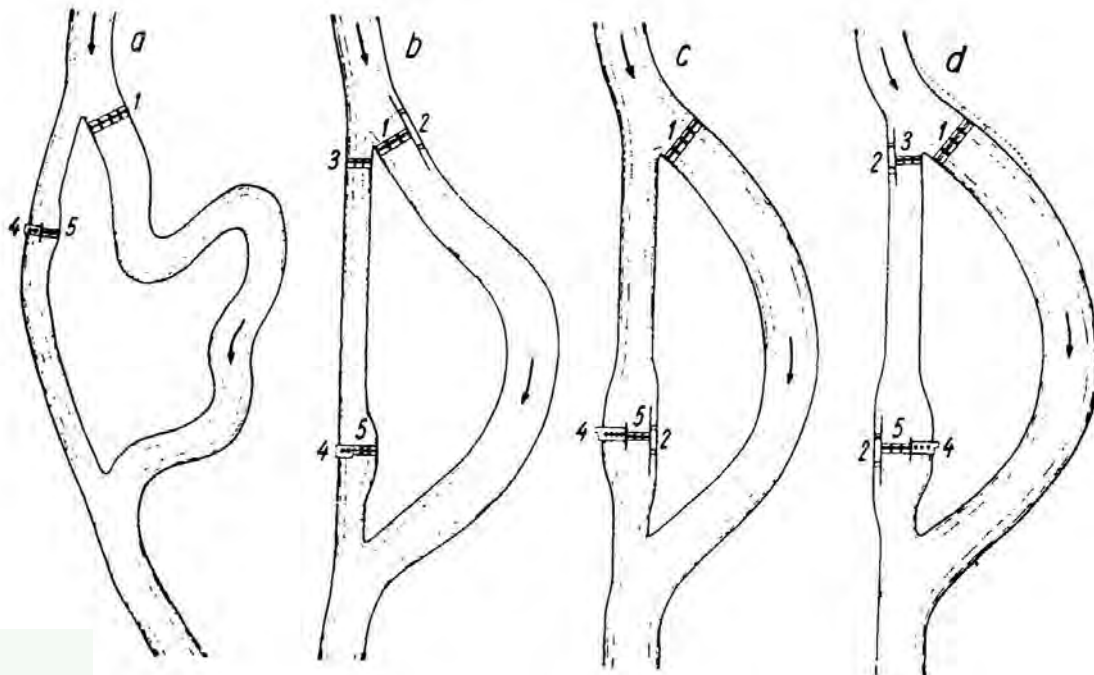


Fig. 2.15



2,4=control sills
1,3=control weirs

18. Sketchy representation of an abandoned river stretch where e.g. two sills and two weirs are required for groundwater control and possibly for other purposes too.



Alternatives for diversion canal type layouts: 1. weir, 2. navigation lock, 3. intake, 4. power station, 5. spillway and bottom outlet

Fig. 2.16

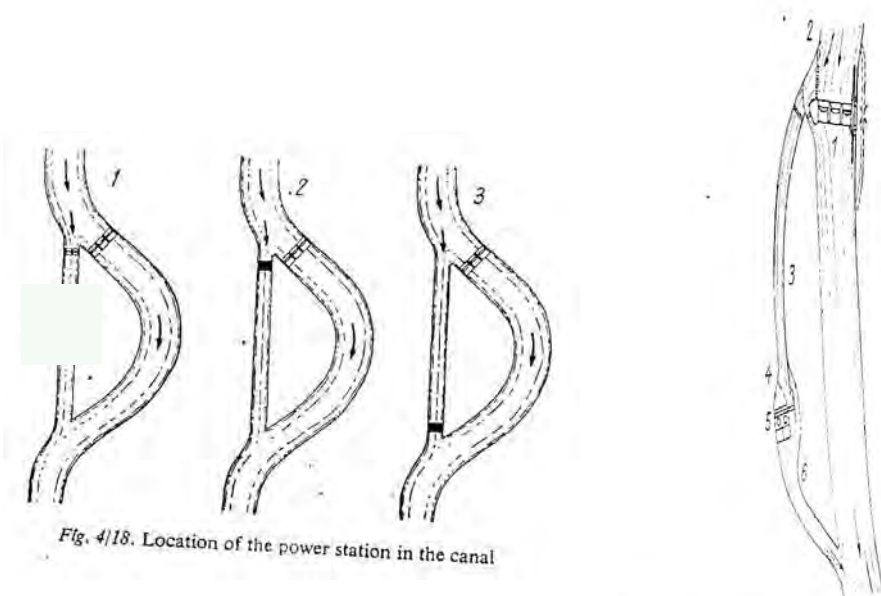
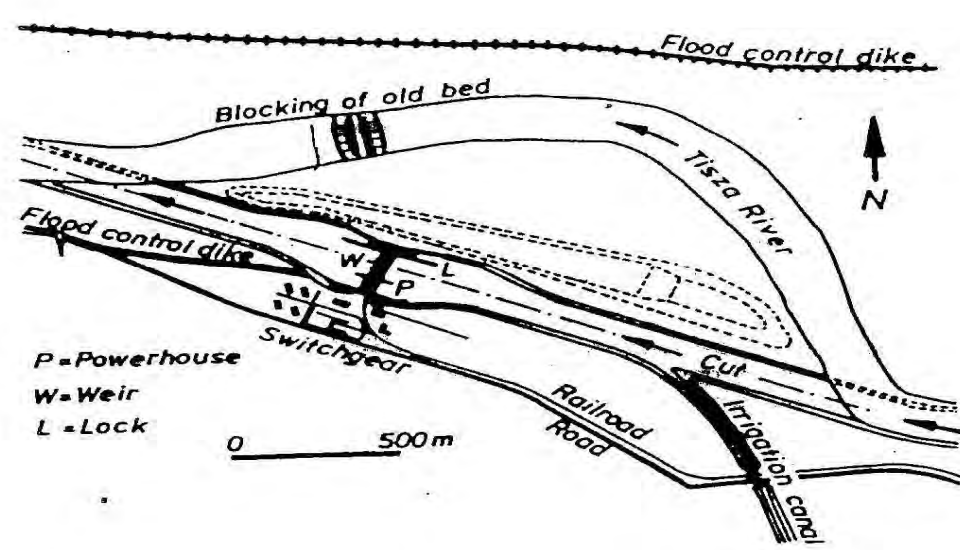


Fig. 4/18. Location of the power station in the canal

Fig. 1/18. General layout of diversion canal type plant. 1. Weir, 2. bypass, 3. powerhouse, 4. forebay, 5. powerhouse, 6. tailrace

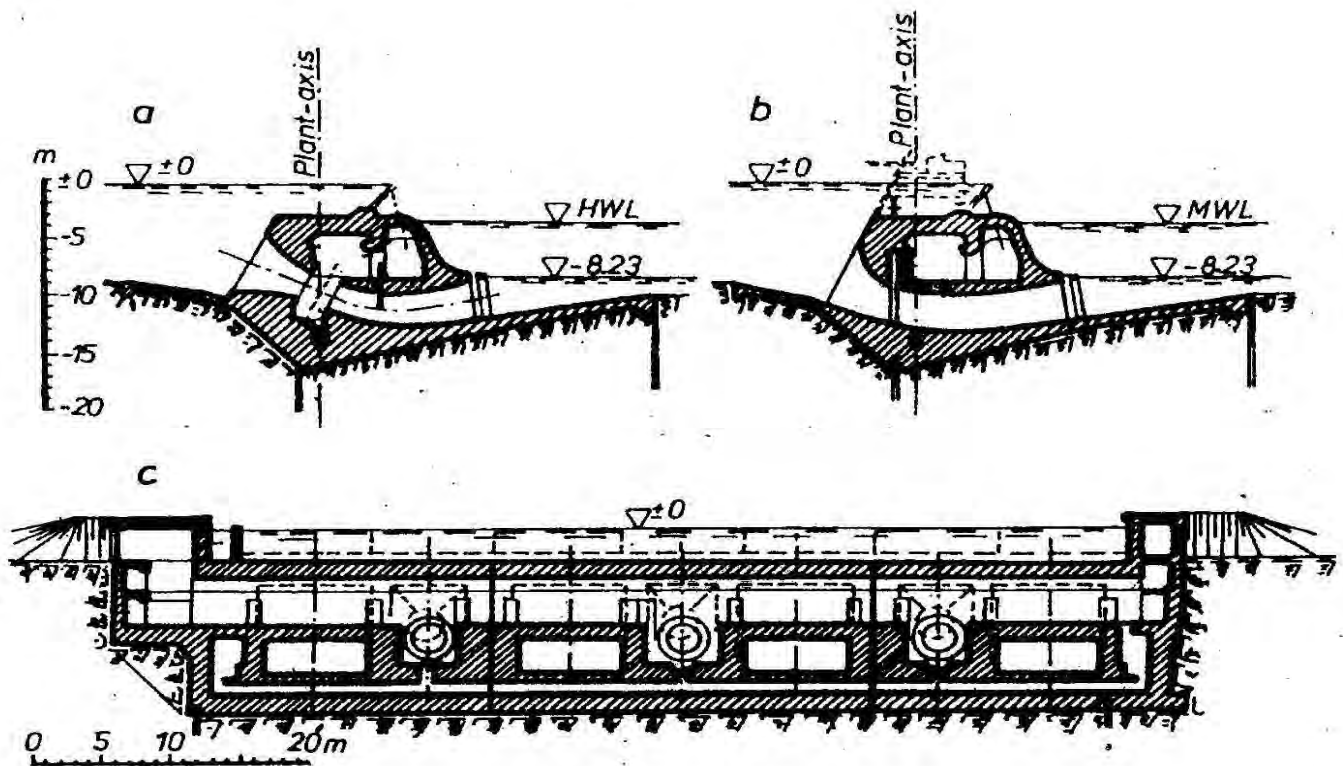
Fig. 2.17

WATER POWER DEVELOPMENT



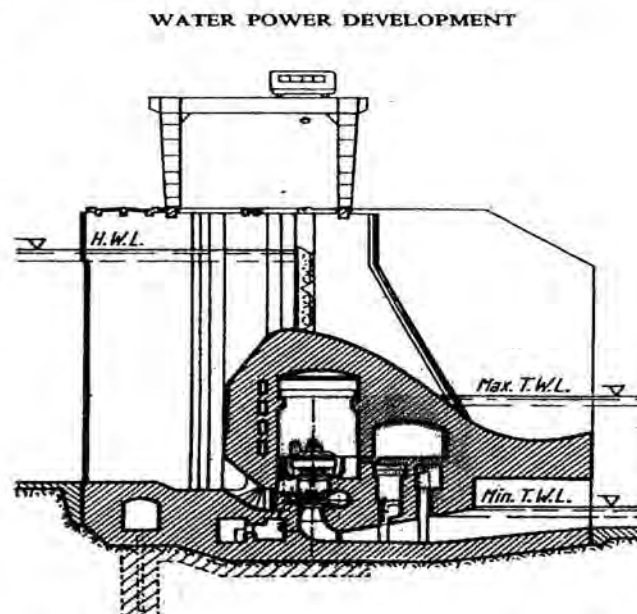
River barrage located in a cut of the river channel; Tisza, Hungary, 1953, 300 m³/s, 0-7.5 m, 12 MW.

Fig. 2.18



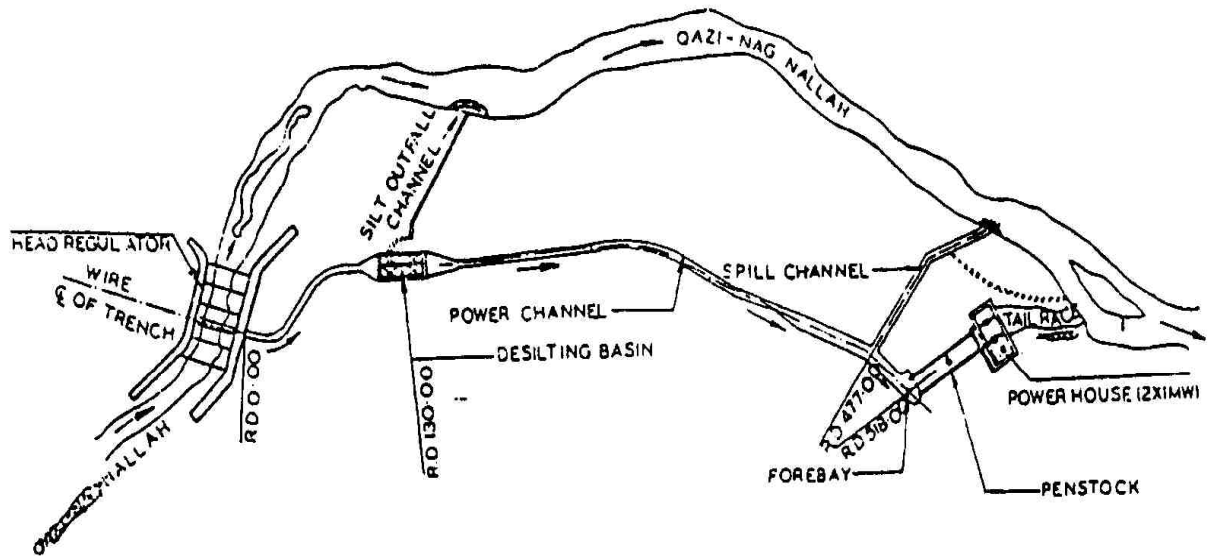
Early development of submersible plant equipped with rim-generator propeller turbines: (a) section through turbine; (b) bottom outlet; (c) longitudinal section; Rott-Freilassing, Saalach, FRG, 1951, $60 \text{ m}^3/\text{s}$, 8.5 m, 4100 kW.⁴⁵

Fig. 2.19

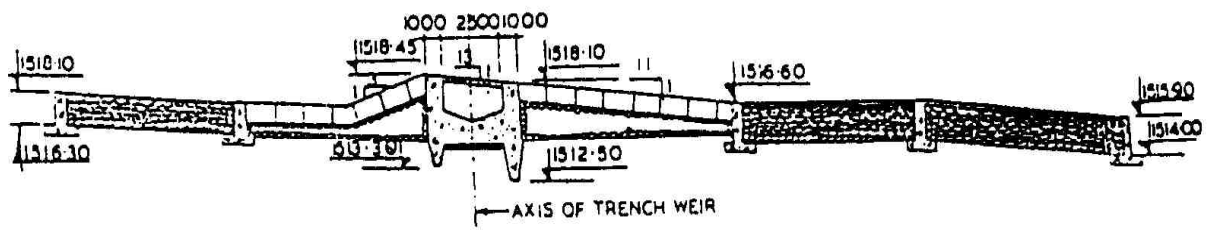


Submersible station with conventional Kaplan units located within the weir body; Pavlovsk, USSR.⁴⁶

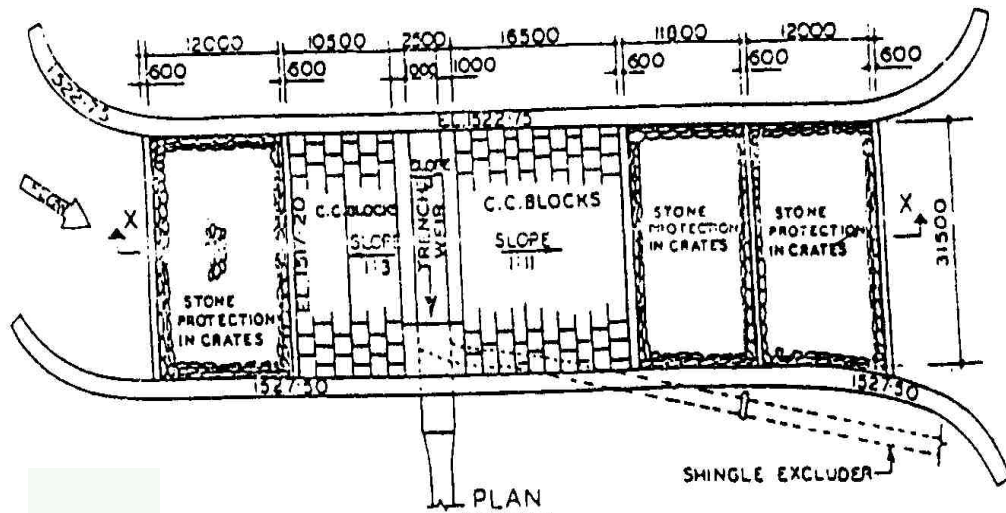
Fig. 2.20



KARNAH H.E. PROJECT-LAYOUT PLAN



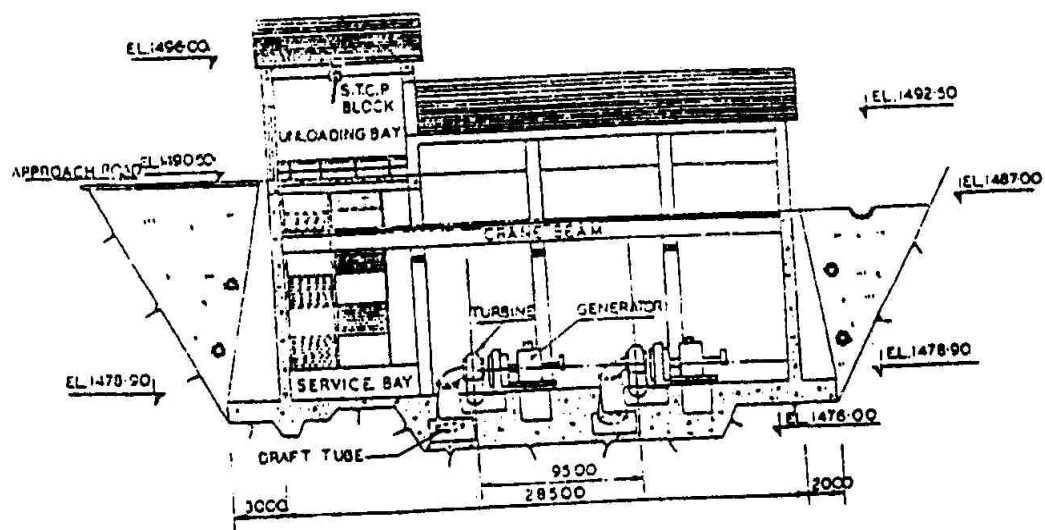
SECTION X-X



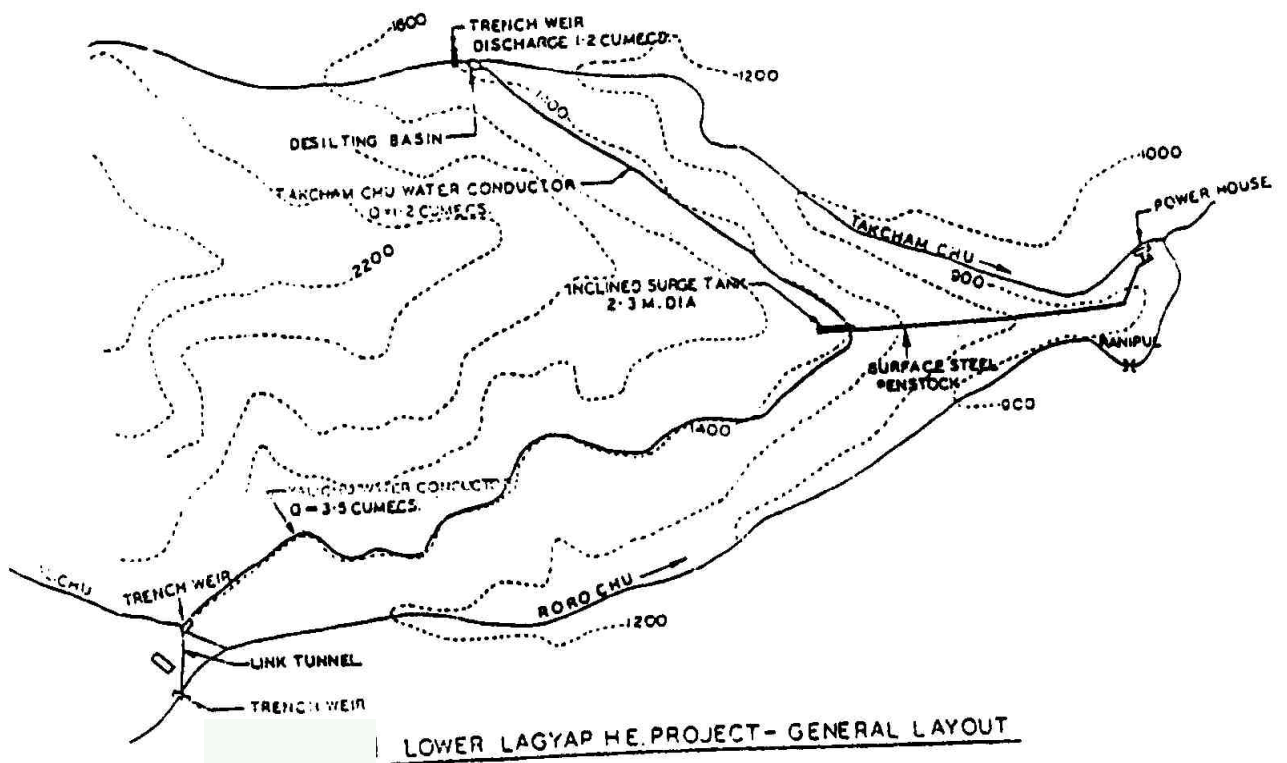
PLAN

KARNAH H.E. PROJECT-PLAN AND SECTION OF TRENCH WEIR

Fig. 2.21



KARNAH H.E. PROJECT-POWER HOUSE L- SECTION



LOWER LAGYAP H.E. PROJECT- GENERAL LAYOUT

Fig. 2.22

2.3 PLANNING AND MASTER PLAN

2.3.1 General

For a systematic, development of hydropower time bound, duly shared between Government, Social and Private Sectors, master plan are required.

- It is an inventory of all possible sites.
- Provides priority or ranking for speedy development.
- Provides cluster approach.
- Provides financial requirement.
- Provides – grid network strengthening.

2.3.2 Master Plan

- Assessment of SHP potential of existing irrigation dams and canals.
- Assessment of potential as run off river schemes
- Assessment of potential sites for rural electrification.
- Compilation of the above mentioned activities with prioritization of identified SHP sites.
- Creating of spatial database using Geographic Information Systems (GIS) for the state incorporating various themes including identified SHP sites.

2.3.3 Source of Information for Master Plan

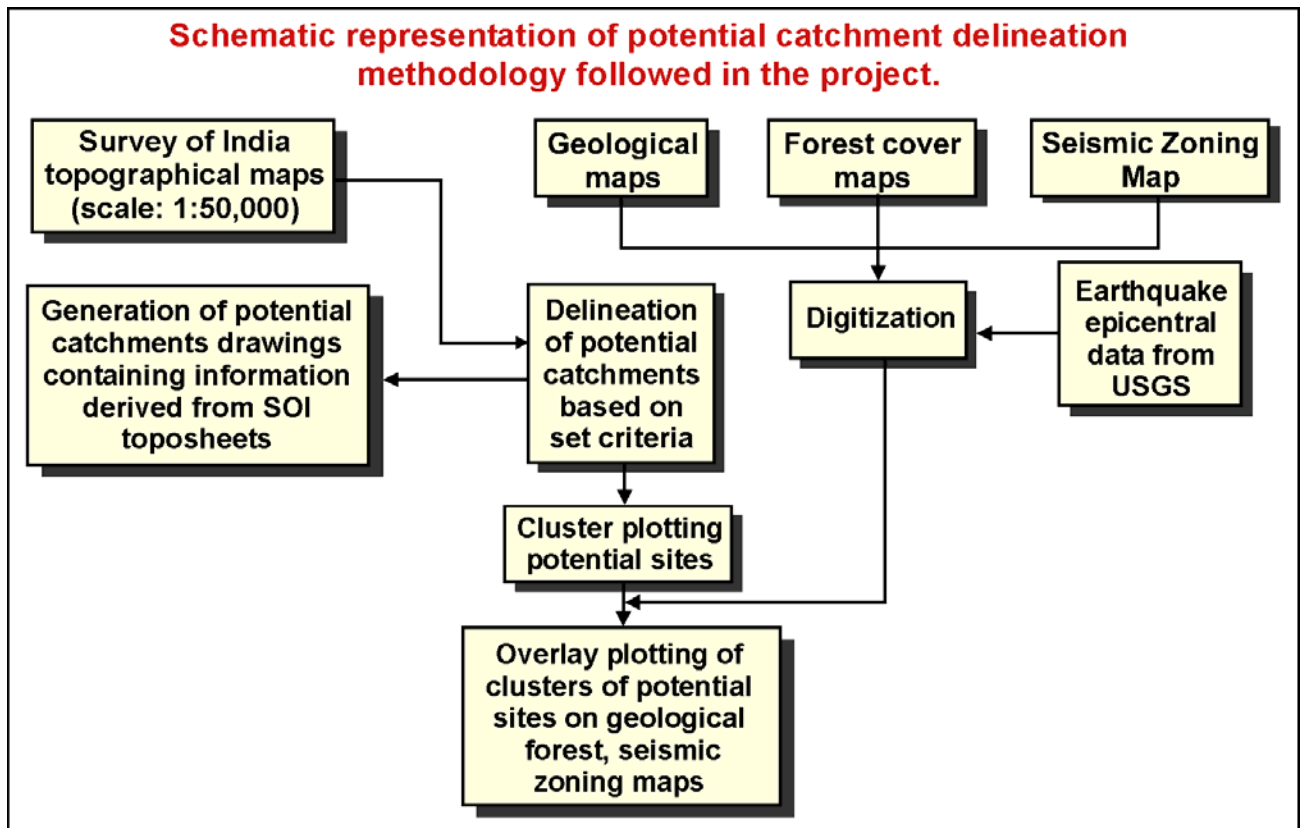
- State Nodal Agencies for renewable energy in states
- State Electricity Boards, Deptt. of Power of states
- Central Government MNES, CEA, CWC, NHPC etc. Individuals having background in such data calculation
- Survey of India including Digital Mapping Centre
- Forest Survey of India, Dehradun
- Indian Institute of Remote Sensing, Dehradun
- Regional Centre for Remote Sensing, Dehradun
- NATMO, Calcutta

2.3.4 Schematic representation of potential catchments delineation methodology followed in the project

2.3.5 Identification of potential catchments for small hydropower generation

The following criteria may be adopted as in one study

- Catchment should have an area of at least about 10 km²
- Channel should be perennial in nature (in Survey of India (SOI) toposheets perennial streams are marked with blue colour).
- Main channel should have a length of about 7-8 km.
- Availability of head should be at least 20 m as lower head and discharge does not yield significant power potential.



MNES - Ministry of Non-conventional Enrgy Sources, Govt. of India
 CEA - Central Electricity Authority, ministry of power, Govt. of India
 CWC - Central Water Commission, Ministry of Water
 NHPC - National Hydropower Corporation
 SOI - Survey of India

2.3.6 Information associated with individual catchments were also extracted from the toposheets

- SOI toposheets references Number Name of the stream Name of the river basin
Catchment area (in km²) Length of main channel (in km) Catchment perimeter (in km)
Highest point elevation of the catchment Elevation at stream meeting point with the major river
- Stream meeting point with the main river Latitude and Longitude
- Information about the snow/glacier/rain fed
- Name of the state
- Name of the district
- Major contour lines crossing the stream
- Major road network available
- Locations of villages and town were also marked
- Latitude and longitude grid on all sides of the drawing were also marked.

2.3.6 Computation of Head

- Head is the important parameter to work out the Small Hydro power Potential in a catchment.
- To compute this information, the points on the main channel where the elevation contours cross the channel were marked on the catchment drawing.
- In each catchment, lower two-third length of the channel was considered for the determination of head (drop)
- This part of the channel carries maximum discharge.
- The Head thus, obtained was used to calculate the power potential for each site

2.3.7 Hydropower Potential

- Discharge be also verified by spot measurement.
- Local inquiry to be made for flow conditions throughout the year.
- For each catchment, hydropower potential has been computed. This need to be verified in the field.
- The Hydro Power Potential may be calculated for 50%, 75%
- And 90% dependable flows for all sites.

2.3.8 Ground Verification of SHP Sites

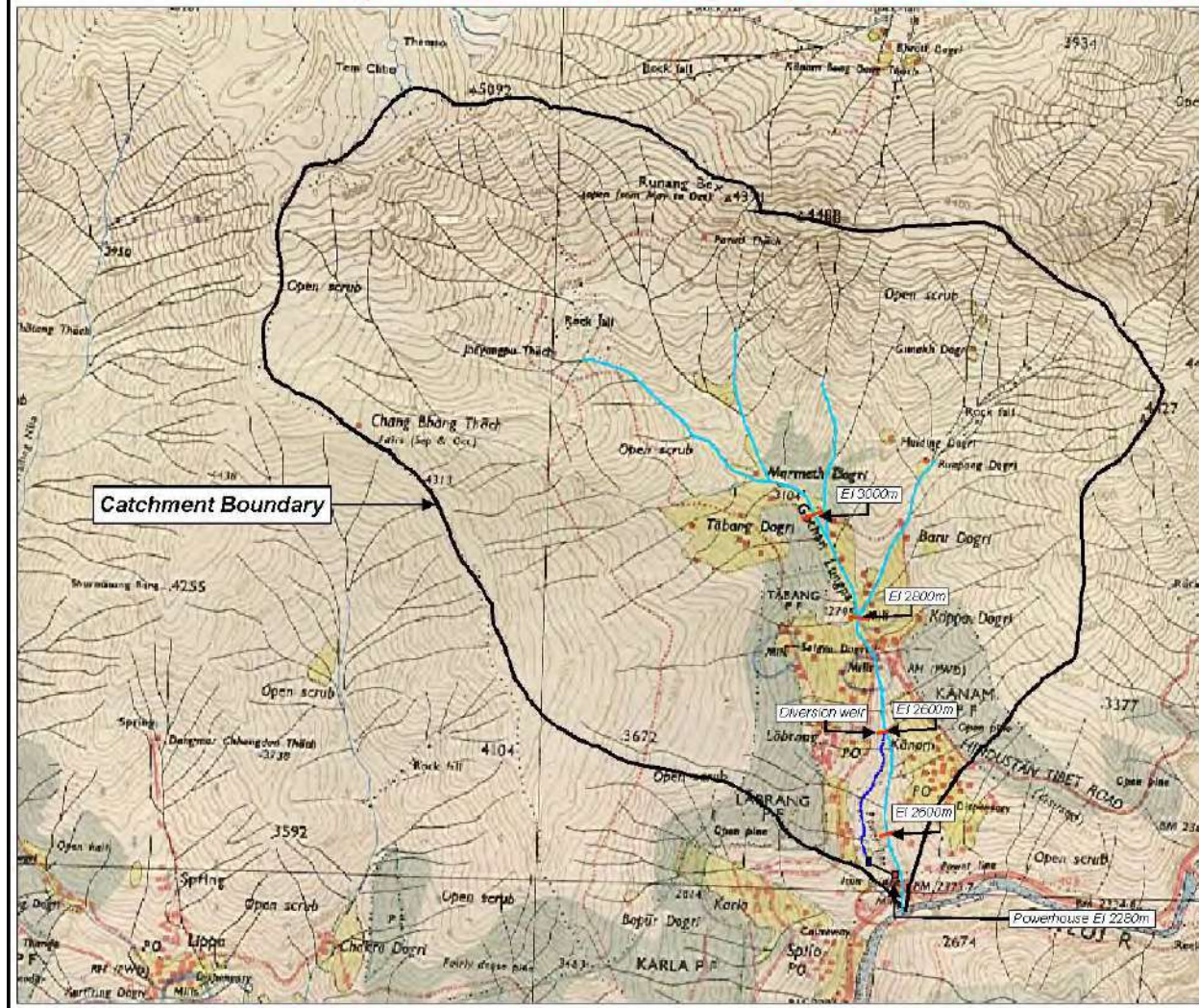
Since, the identification of SHP site has been done on toposheet therefore there was a need to ground verify the various component like,

location of powerhouse,
diversion weir,
availability of Head.
discharge available

Discharge measurements are to be taken so as to ensure the dependable flow estimated from empirical model.

In addition local enquiry has to be made to know the stream flow conditions through out the year

**Shows delineation of potential catchment on
Survey of India toposheet (source scale 1:50,000).**

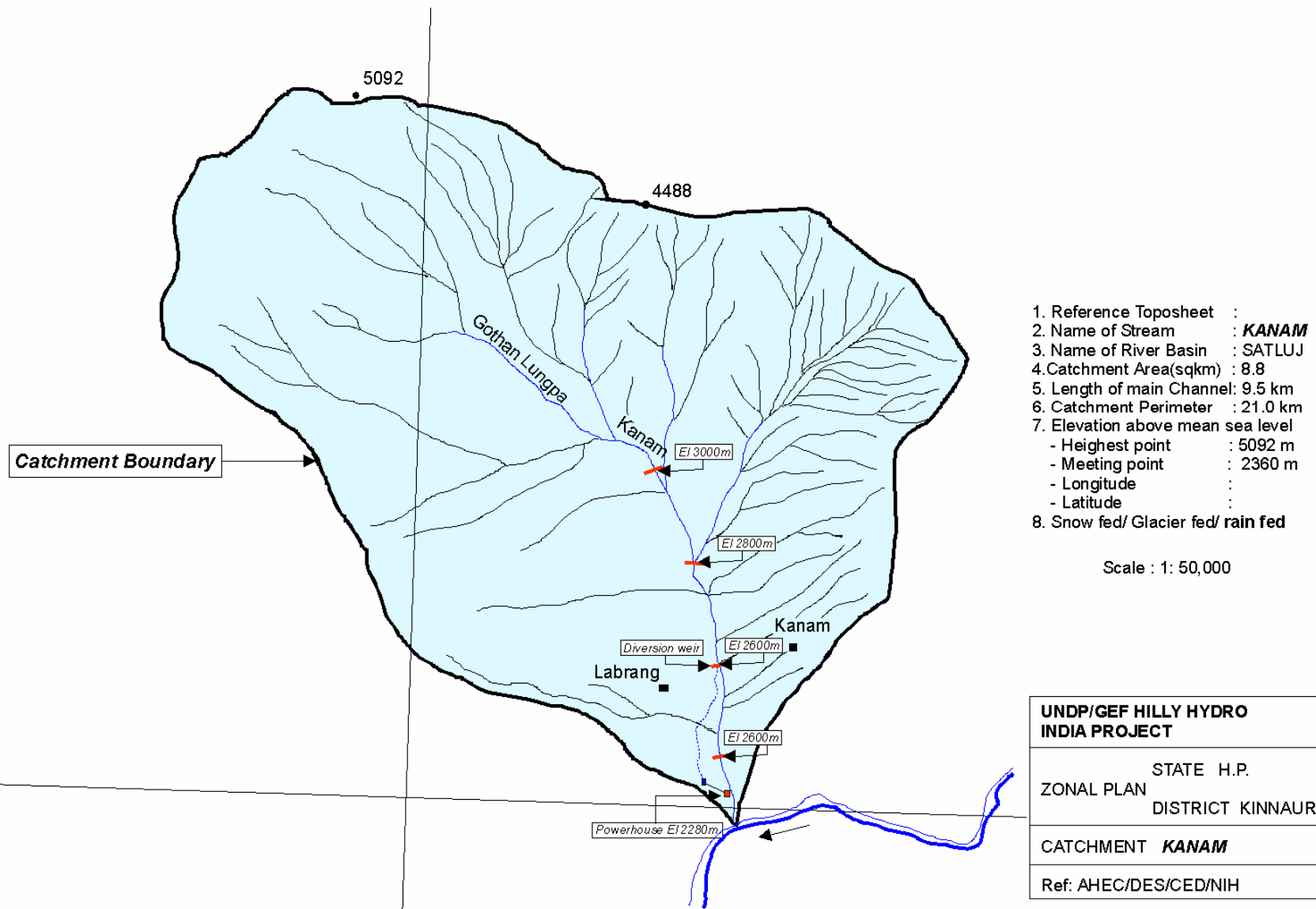


1. Reference Toposheet : **KANAM**
2. Name of Stream : **KANAM**
3. Name of River Basin : **SATLUJ**
4. Catchment Area(sqkm) : **8.8**
5. Length of main Channel: **9.5 km**
6. Catchment Perimeter : **21.0 km**
7. Elevation above mean sea level
 - Highest point : **5092 m**
 - Meeting point : **2360 m**
 - Longitude :
 - Latitude :
8. Snow fed/ Glacier fed/ **rain fed**

Scale : 1: 50,000

UNDP/GEF HILLY HYDRO INDIA PROJECT	
STATE	H.P.
ZONAL PLAN	DISTRICT KINNAUR
CATCHMENT	KANAM
Ref. AHCC/DES/CED/NIH	

Illustrates potential delineated catchment and other relevant information derived from Survey of India toposheet.



2.4 GOVERNMENT HYDROPOWER POLICIES

2.4.1 Government of India Policy on Hydropower Development - Announced by Ministry of Power Govt. of India Aug. 1998* (“as per AHEC Publication Small Hydro Power – Installations and Private Sector Participation – 3rd Edition”)

2.4.1.1 Need for a Hydel Policy

Hydropower is a renewable economic, non polluting and environmentally benign source of energy. Hydro power stations have inherent ability for instantaneous starting, stopping, load variations etc. and help in improving reliability of power system. Hydro stations are the best choice for meeting the peak demand. The generation cost is not only inflation free but reduces with time. Hydroelectric projects have long useful life extending over 50 years and help in conserving scarce fossil fuels. They also help in opening of avenues for development of remote and backward areas.

Our country is endowed with enormous economically exploitable and viable hydro potential assessed to be about 84,000 MW at 60% load factor (1,48,700 MW installed capacity). In addition, 6781.81 MW in terms of installed capacity from small, mini and micro hydel schemes have been assessed. Also, 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified. However, only 15% of the hydroelectric potential has been harnessed so far and 7% is under various stages of development. Thus, 78% of the potential remains without any plan for exploitation.

Despite hydroelectric projects being recognised as the most economic and preferred source of electricity, share of hydro power has been declining steady since 1963. The share of hydro power has been continuously declining during the last three decades. The hydro share has declined from 44 percent in 1970 to (25 75:23:2 percent in 1998). The ideal hydro thermal mix should be in the ratio of 40:60. Because of an imbalance in the hydel thermal mix especially in the Eastern and Western regions, many thermal power stations are required to back down during off peak hours. The capacity of the thermal plants cannot be fully utilized resulting in a loss of about 4 to 5 percent in the plant load factor. Even if the share of hydro power is to be maintained at the existing level of 25 percent, the capacity addition during the 9th and 10th Plan would work out to 23,000 MW. If the share were to be enhanced to 30 percent, it would require a further addition of 10,000 MW of hydro capacity

The constraints which have affected hydro development are technical (difficult investigation, inadequacies in tunnelling methods), financial (deficiencies in providing long term financing), tariff related issues and managerial weaknesses (poor contract management). The hydro projects are also affected by geological surprises especially in the Himalayan region where underground tunnelling is required), inaccessibility of the area, problems due to delay in land acquisition, and resettlement of project affected families, law & order problem in militant infested areas.

2.4.1.2 Objectives

The programmed capacity addition from hydel projects during the 9th Plan is 9815 MW, of which Central Sector and State Sector will contribute 3455 MW and 5810 MW respectively and the balance 550 MW will be contributed by the Private Sector. Sanctioned and ongoing schemes under implementation will enable a capacity addition of 6537 MW

during the 10th Plan, of which 990 MW, 4498 MW and 1050 MW will be the contribution of Central, State and Private Sectors respectively. In addition, 12 projects (5615 MW) have been identified for advance action in the 9th Plan for benefits in the 10th Plan.

The Government of India has set the following objectives for accelerating the pace of hydropower development: -

(i) Ensuring Targeted capacity addition during 9th Plan:

The 9th Plan programme envisages capacity addition of 9815 MW from hydel projects in the total capacity addition of 40245 MW. The Central Sector hydel projects would contribute 3455 MW, State Sector would add 5810 MW and Private Sector 550 MW. Keeping in view that the achievement in 8th Plan had been dismal, the Government is determined to ensure that no slippage is allowed to occur and the targeted capacity addition in the 9th Plan is achieved in full.

(ii) Exploitation of vast hydroelectric potential at a faster pace :

The Government would initiate advance action for taking up new hydro projects since the ongoing projects will contribute a very small percentage of the desired capacity addition envisioned for 10th Plan and beyond. Towards this end, Government would take up for execution all the CEA cleared projects, and take steps to update and obtain clearances for pending DPRs. Measures for vigorously starting survey and investigations for new green field sites would also be implemented shortly. In addition, Government is keen to restart and activate the hydro projects which are either languishing for want of funds or are remaining dormant due to unresolved inter-State issues.

(iii) Promoting small and mini hydel projects

Small and mini hydel potential can provide a solution for the energy problems in remote and hilly areas where extension of-grid system is comparatively uneconomical and also along the canal systems having sufficient drops. The small hydro potential could be developed economically by simple design of turbines, generators and the civil works. Small and mini hydel capacity aggregating to about 340 MW is in operation, and Government is determined to provide thrust for developing the assessed small hydel potential at a faster pace henceforth.

(iv) Strengthening the role of PSUs/SEBs for taking up new hydel projects

In view of the poor response of the private sector so far in hydro development which may persist for some more years, the involvement of public sector in hydel projects would not only have to continue but will also have to be enlarged. There are categories of projects such as multi-purpose, projects involving inter-State issues, projects for peaking power and those involving rehabilitation and resettlement which may be taken up and implemented more easily in public sector. Similarly, mega hydro projects in the North and North Eastern region would also have to be executed by CPSUs in case the State or the private sector is not in position to implement these projects.

(v) Increasing private investment:

Even though public sector organisations would play a greater role in the development of new schemes, this alone would not be adequate to develop the vast remaining hydro potential since it will require huge investments which are difficult to be supported from the budget/plan assistance in view of competing demands from the various sectors. A greater private investment through IPPs and joint ventures would be encouraged in the coming years and required atmosphere, incentives and reliefs would be provided to stimulate and maintain a trend in this direction.

2.4.1.3 Policy Instruments

To achieve the above stated objectives for faster development of hydro potential, the Government proposes to take the following steps and measures : -

(i) Funding

All the ongoing Central Sector hydroelectric projects namely Nathpa Jhakri (1500 MW), Tehri Stage I (1000 MW), Ranganadi State I (405 MW), Dulhasti (390 MW), Dhauliganga (280 MW), Doyang (75 MW) and Rangit (60 MW) would be provided with full budgetary support till completion. Government of India will also provide budgetary support for the new projects to be taken up by the CPSUs during the 9th Plan. The actual utilisation of the funds on the ongoing Central Sector hydro projects has been Rs. 1616.87 crores in 1997-98 and the budget provision for 1998-99 has been increased to Rs. 2070 crores. Therefore the remaining three years of the 9th Plan would require about Rs. 5896 crores on the ongoing Central Sector projects (excluding NEC projects). Having regard to the large capacity addition envisaged in the State Sector (5810 MW) it is necessary to (a) provide a mechanism for funding hydro projects by earmarking funds in the plan allocation of the State Governments by the Planning Commission ; and (b) organising supplementary funding of hydel projects where more than 50 percent of the expenditure has already been incurred. The monitoring of all the ongoing projects will be intensified and a task force would be constituted for this purpose. The progress of important projects in the State and Central Sector would be reviewed at the level of Minister/Secretary (Power) and all measures will be taken so that there is no slippage in the schedule for completion of the ongoing projects.

(ii) Power Development Fund

The survey and investigation of hydro projects have been discontinued since long in the States due to paucity of funds. As a result, there are not enough projects right now that could be taken up in the next 2 to 3 years and get completed in the 10th Plan or early 11th Plan. It is necessary to carry out survey and investigations continuously and prepare a shelf of projects of execution over a decade and more.

In case fully investigated projects with Detailed Project Reports are offered to private developers, their response could be more favourable. If pre-construction activities and enabling works could be completed and these sites offered to IPPs the chances of IPPs opting to invest in these projects would further improve. Further this would reduce the gestation period which would make investment in hydro projects more attractive.

The above approach is possible and successful only if a dedicated fund is available for this purpose.

It is proposed to levy a Power Development Cess at 10 paise per kWh of electricity consumed in the country. The levy of cess was recommended by the Sub Committee of the NDC Committee on power which gave its report in January, 1994. The cess would be levied on the electricity billed by SEBs/Electricity Departments/Bulk licensees/Distribution licensees. The State/UT Governments would be responsible for the collection of the cess. The amount would thereafter be credited to a "National Power Development Fund. It is expected that about Rs. 3000 crores per annum can be realised by levying a cess of 10 paise per kWh.

It would be necessary to establish a legal and organisational frame work for levy of a cess. Electricity being a Concurrent Subject, the Central Government is empowered to legislate on all aspects of electricity including the levy of cess, the proceeds of which is to be utilised for power development. In order to levy a power development cess, it would be necessary for parliament to enact a legislation on the subject. The cess will be imposed on the consumption of electricity throughout the country. The State Electricity Boards will be the responsible agencies for the collection of cess. The proceeds of the cess will be shared with the State/UT governments and the Central Government. Two-thirds of the amount realised from the State/UT Government will be allocated to the respective government to be utilised for power development. This amount would be released from the National Power Development Fund for financing schemes/projects recommended by the State Government. The remaining one-third will be utilised by the Central Government for promoting hydel projects in the Central Sector and for investment in transmission lines for evacuation of power from mega hydel projects which will benefit more than one State.

(iii) Basin-wise Development of Hydro Potential

The assessment of hydro potential in 845 identified conventional hydro projects and 56 pumped storage projects is on the basis of desk studies using toposheets and discharge data. Further, detailed studies to firm up the parameters of the projects as identified by CEA would be taken up on the basis of development of hydro potential in a basin as a whole for maximising benefits and prioritising execution of projects. These studies will be done in close co-ordination with CWC and in harmony with Planning Commission and development for other uses of water like irrigation, drinking water etc. While CEA would carry out these studies, CPSUs/other Central Government Organisations and State authorities would do the investigations and prepare the detailed project reports, by adopting an integrated approach towards planning and development of the various projects, evacuation arrangement and environmental impact assessment. This would enable an optimal harnessing of hydro potential in each river basin.

(iv) Advance Action for Capacity addition in the 10th Plan and beyond

Government will take immediate steps to tie up funding, execution agencies and convey investment decision for schemes already accorded techno economic clearance of CEA. as far as Central Sector is concerned, NHPC would take up Chamera Stage II (300 MW), Parbati Stage-II (800 MW), HP and Kol Dam (800 MW) in HP; Teesta Stage V (510 MW) in Sikkim, Loktak Downstream (90 MW) in Manipur and NEEPCO will take up Tuivai (210 MW) in Mizoram, Lower Kopili (150 MW) in Assam, Kameng (600 MW) and Rangadi Stage II (160 MW) in Arunachal Pradesh (after the consent of the State Govt. has been

obtained). In addition THDC would take action to start activities on Tehri Stage II (1000 MW) and Koteswar (400 MW) in UP Similarly NJPC would also take up Rampur Project (535 MW) in HP. These projects would require budgetary support of about Rs. 2000 crores in the 9th Plan.

(v) Survey & Investigations

As a long term strategy efforts will be made to ensure that DPRs which are under various stages of processing for accord to TEC by CEA are finalised and cleared so that a start could be made on these projects in the next one or two years. Survey and investigation of the potential hydro sites on an advanced scientific basis would be essential requirement for the future. The progress on this front has been dismal given the funds constraint and outdated technology. The funding agencies like World Bank and ADB have shown their interest towards funding the survey and investigation activities for hydroelectric projects. Concerted efforts would be made towards availing the funds quickly. This would not only help in preparation of the bankable DPRs for large hydroelectric projects but would also bring in advanced technology by involving reputed international consultants. The central organisations like CWC, Brahmaputra Board, NEEPCO and NHPC, besides SEBs would be provided with funding support from the proposed power development fund for the purpose of carrying out survey and investigations and preparation of bankable DPRs.

Since the private sector has so far been hesitant and cautious to invest in hydro projects, it is proposed that new projects will initially be taken up by CPSUs/SEBs for investigations, updation of DPRs, obtaining the necessary clearances and pre-construction activities. After these stages, the projects could be offered to the private sector for execution either on 'stand alone' basis or for joint venture participation with the CPSU/SEB. The expenditure incurred by CPSUs/SEBs on these activities would be adjusted in the project cost to be recovered from the executing agency to be decided at a later stage. The Government expects that more private investment would be possible with this approach. In case for a particular project no such private investment is forthcoming, it will be executed entirely by the concerned CPSU/SEB which initiated its development.

(vi) Inter-State Projects

A substantial hydel power potential has remained locked up and many mega hydel projects could not be taken up for implementation, even though these projects are well recognised as attractive and viable, because of unresolved Inter-State issues. Govt. of India recognises the need for evolving an approach to ensure that the available hydro-electric potential is fully utilised without prejudice to the rights of the riparian States as determined by the awards of the Tribunals/Agreements arrived at among the party States for a given river basin with regard to water sharing. The selection and design of project would be based on integrated basin wise studies, so as to arrive at an optimal decision and care will be taken that such projects do not in any way prejudice the claims of basin states or affect benefits from the existing projects, a consensus would be evolved amongst the basin states regarding the location of such project, basic parameters involved and mechanism through which each project would be constructed and operated. As far as possible, there would be preference to take up simple run-of-the-river schemes that do not involve any major storage or consumptive uses.

(vii) Renovation, Modernisation & Upgrading

Renovation, Modernisation & Upgrading of old hydro power plants is being accorded priority as it is a faster and cheaper way of capacity addition than installing new capacity. As per recommendations of National Committee set up in 1987 and based on the subsequent reviews, 55 hydro schemes with an aggregate capacity of 9653 MW were identified for RM&U. Out of these, 20 hydro schemes have been completed providing a benefit of 971.5 MW and work on 27 schemes is in progress. In order to provide a greater thrust for RM&U, Government would set up a Standing Committee, to identify the new schemes and for tying up technology, funding and executing agencies.

(viii) Promoting Small and Mini Hydel Projects

The Ministry of Non-Conventional Energy Sources (MNES) deals with all matters related to Small Hydel projects (upto 3 MW Capacity). These projects are being provided with the following incentives.

- (a) Incentives for detailed survey & investigation and preparation of DPR.
- (b) Incentives during the execution of the project in the form of capital/interest subsidy.
- (c) Special incentives for execution of small hydro projects in the North Eastern Region by the Government departments/SEBs/State agencies.
- (d) Financial support for renovation, modernisation and upgrading of old small hydro power stations,

The small hydel projects are site specific and depending on the hydrology, typically the plant load factor varies from 40 to 60%. The Small Hydel Projects upto 25 MW will also be transferred to MNES in order to provide greater thrust for its development. Government of India proposes to provide soft loans to these projects (upto 25 MW) through IREDA/PFC/REC and other financial institutions and Ministry of Non-Conventional Energy Sources would announce a suitable package of financial incentives for the accelerated development of Small Hydel Projects upto 25 MW station capacity. The State Government and Central and State Hydro Corporations like NHPC/NEEPCO etc. would be encouraged to take up a cluster of small/mini hydel schemes on Build, Operate and Transfer basis, and other suitable

(ix) Simplified Procedures for Transfer of Clearances

As stated in the foregoing, the CPSUs and the private sector would need to play a greater role in hydro development. The immediate requirement would be to transfer the clearances already accorded to non-starting hydro projects in the State Sector in favour of CPSU/IPP/Joint Venture of IPP and CPSU. Government would evolve a simple procedure so that the transfer of CEA's techno economic clearance would be facile as only updation of project estimate would be examined by CEA. In the case of Environment and Forest clearances these could be transferred to CPSU/IPP etc. within a prescribed time limit on acceptance of conditionalities stipulated in the MOEF clearance accorded for execution in the State sector by the above executing agencies. Another inhibiting factor discouraging IPPs is the need for notification of the scheme as per Section 29 of ES Act in newspaper and Gazette afresh even if this was done earlier for execution by SEBs. Government intends to do away

with this requirement. The simplified procedure as proposed would be an encouraging factor of IPP to evince greater interest in hydro development. Government would initiate action right away towards this end.

2.4.2 Policy For The Development Of Small Hydropower Upto 25 Mw In Uttaranchal Issued Vide State Government Notification No. 1611/NEW-3-U/2002 Dated Oct. 19, 2002 “*as per AHEC Publication Small Hydro Power – Installations and Private Sector Participation – 3rd Edition”

2.4.2.1 Scope For Small Hydropower Development In Uttaranchal

Uttaranchal has a hydropower potential of the order of 15,000 MW against which only about 1100 MW has been harnessed so far. The Government of Uttaranchal (GOU) has decided to encourage generation of power through small hydropower sources of energy, and has framed a policy so that the development of this sector serves as an engine to achieve the objective of promoting the all round development of the region.

This policy shall be in operation from the date of its publication as notified by Government Order. All projects awarded within this period under this policy will be governed by this policy for their entire duration.

All Hydropower projects/stations estimated to have an installed capacity of upto 25 MW shall be eligible under this policy. The identified potential at present for further small hydropower (SHP) projects ranging in capacity upto 25 MW is about 254 MW at 47 identified locations as at Annexure "A"(See notification).

2.4.2.2 Participation & Prequalification

Uttaranchal invites any non-GOU agency to bid for identified projects for the development of this sector. These will be termed as Independent Power Producers (IPP). There shall be a prequalification by the GOU of the bidders for the projects in the state. Based on the balance sheets, annual reports and other reported evidence of financial and technical capacity, the applicants will be graded and listed. The weightage to be given to financial capacity, technical capability, past experience and other relevant attributes of the applicants, the sub-categories of these attributes to be evaluated and their inter-se weightage, the guidelines for evaluation and the passing score on attributes/in aggregate required for pre-qualification shall be specified in the bid documents inviting bids for pre-qualification.

2.4.2.3 Projects

- i) The list at annexure "A" identified projects available for development with indications-of estimated capacities, and for which development of pre-feasibility studies is in progress. The Uttaranchal Jal Vidyut Nigam Ltd. (UJVNL) will undertake to prepare the pre-feasibility studies in a time bound manner. The evacuation requirements including details of nearest sub-station will be specified in the pre-feasibility studies.
- ii) The projects shall be offered for a period of forty years from the date of the award at the end of which they shall revert to the Government of Uttaranchal or extended

further on mutually agreed terms, as per the decision of the Government of Uttaranchal.

2.4.2.4 Process Of Allotment

- i) The projects shall be advertised in order to seek bids. Applications in response to the advertisement should be accompanied by a non-refundable draft of Rs. 1,00,000/- payable to UJVNL.
- ii) All bidders will be subject to pre-qualification as provided in Paragraph 2.4.2.2.
- iii) All pre-qualified bidders will be provided with the pre-feasibility studies prepared by the UJVNL.
- iv) Bids shall be invited for premium payable upfront to the Government of Uttaranchal per MW in the case of each project/site, subject to a minimum threshold premium of Rs.5 lakhs per MW bids received beneath the threshold premium will be rejected.
- v) Projects will be allotted to the bidders making the highest bids. The successful bidder shall be required to deposit the premium/other amount due within a reasonable period of receiving intimation regarding his bid being successful. The exact time period shall be specified in the bid documents for invitation of bids. The successful bidder may be permitted to provide 50% of the bid amount in excess of the threshold as a bank guarantee encashable at the time of actual or scheduled financial closure, whichever is earlier.
- vi) If more than one bidder bids the identical premium per MW for any site/station, a gradation list based on pre-qualification criteria described above shall be the basis for alignment,
- vii) In case any projects fails to attract any acceptable bid despite being bid out at least twice, the GOU may consider allotting the site to a GOU agency.

2.4.2.5 Sale Of Power

The IPP/bidder can contract to sell power to any HT consumer within Uttaranchal, to local rural grids within Uttaranchal which are not connected to UPCL's main grid, to rural power distribution entities (i.e. those which sell power to predominantly rural areas), to any consumer outside the state, or to the Uttaranchal Power Corporation Ltd. (UPCL). Sales to the UPCL will be mutually negotiated. All sales will be approved, as may be required, by the Regulator.

2.4.2.6 Wheeling Charges

- i) The infrastructure and facilities of UPCL will be made available to all IPPs for wheeling the generated energy.
- ii) Wheeling charges for wheeling the generated energy to third party consumers or outside the State will be as determined by the ERCU. However, for those projects which are bid out prior to the determination of this rate by the ERCU, the wheeling charge (for the entire concession period) would be 1.0% of net energy supplied at the interconnection point.
- iii) No wheeling charges are applicable in cases of sales to the UPCL or for sale to rural power distribution entities or local rural grids within Uttaranchal.

- iv) The UPCL will prepare a standard wheeling and banking agreement draft consistent with this policy statement. This will be made available prior to any bidding for projects.

2.4.2.7 Grid Interface/Transmission Line

The IPP shall be responsible for laying lines for connectivity to the nearest grid sub-station at the appropriate voltage, which will normally be 132 KV or 33 KV depending on the capacity of the power station and the distance from the power station to the Grid sub-station. The UPCL will determine the specifications of the evacuation facilities required, including the inter-connection point and voltage and the same would be specified in the project information document provided with the application form. On specific request from the IPP, the UPCL will carry out the implementation of evacuation facilities at charges to be mutually negotiated.

2.4.2.8 Banking

Developers can avail of the facility of banking of energy within fixed period spans of 2 months, which would be specified in the standard wheeling and banking agreement. The energy banked into the grid by the IPP shall be mentioned at "the average pooled purchase prepaid by UPCL" during the month of banking-in (into the UPCL system). The points of linking-in would be the interconnection point at which the developer would feed in the energy into UPCL system. The amounts so credited to the developer for the banked-in energy would be set off against the monetised value of the banked out energy. The monetisation of the banked out energy shall be reckoned on the basis of the average pooled purchase price of electricity by the UPCL during the months of banking-out (of UPCL system). However, in addition, the loss incurred by UPCL on account of over-drawal during peak hours compared to input the system during the peak hours will be compensated by charging the IPP the average differential between the rate for HT consumers in the State for peak and non-peak hours for the net overdrawal against peak power banked. The banked out energy shall be deemed to have been delivered at the interconnection point. The developer would be required to pay the difference between monetised value of the banked-in and the banked-out energy and the peak period differential adjustment within a period of 30 days failing which a penal interest will be levied on the outstanding amount. Similarly in case of a balance to the credit of the developer, it shall be payable by UPCL within 30 days with a provision of penal interest on overdue settlement.

2.4.2.9 Despatch

Priority will be accorded for dispatch into the grid by these IPPs ahead of merit order and any other source of supply, subject to any overall restrictions on the proportion of power that may be bought from such sources, which may be imposed by the Government/Regulator in the interest of keeping the overall cost of power purchase within reasonable limits.

2.4.2.10 Royalty

- i) On all projects governed by this policy, royalty payment for the first 15 years of operation would be exempted in all cases of sale of power outside the State or to the UPCL or to consumers in rural areas not served or inadequately served by the concerned existing distribution licensee. In case of sales to other parties, a royalty

of 12% of net energy wheeled (after deducting wheeling charges) or supplied directly without wheeling would be charged. Beyond the 15th year of operation, a royalty of 18% of net energy wheeled or supplied directly without wheeling will be made available to the GOU free of charge by all IPPS.

- ii) In the event of third party sale, electricity duty as per law will apply.
- iii) No further levies, taxes, charges other than those stipulated in this policy would be levied by the State Government and its agencies or the Regulator on the IPPs governed by this policy, for a period of ten years from the date of this policy.

2.4.2.11 Incentives By State Government

No entry tax will be levied by the State Government on power generation, transmission equipment and building material for projects.

2.4.2.12 Transfer Of Allotment

Free transfer of shares will be permitted in the companies allotted projects as per the procedure laid down in this document.

2.4.2.13 Time Limit For Executing The Project

- i) IPP shall prepare and submit the detailed project reports and all other information and make the necessary applications for obtaining the statutory clearances and approvals of the state and central government and the regulator (as applicable) after carrying out the required confirmatory surveys and investigations as prevailing regulations/norms within 32 months from the date of allotment. The IPP shall be responsible for ensuring completeness of all submissions to concerned authorities. Failure to do so within the stipulated time frame shall be treated as non-compliance with the requirement stipulated in this paragraph.
- ii) The IPP shall achieve the financial closure within 12 months from the date of receipt of all statutory approvals and clearances given by the State and Central Governments. Financial closure would imply firm commitments for financing the entire project, with all pre-disbursement conditions having been fulfilled and the loan documentation being complete.
- iv) The project shall be made operational within 48 months from the date of receipt of all statutory approvals and clearances by the IPP. Incentives for early commissioning will be extended.
- v) The failure to reach any of the two milestones mentioned in 13.1 & 13.2 above will result in automatic cancellation of the allotment of the site, and forfeiture of upfront premium amounts. No compensation would be payable to the IPPs in such instance.
- vi) Failure to reach to milestone as in 13.3 above would result in a liability to pay penalty by the IPP to the GoU, computed at the equivalent royalty revenue that would have been payable to the GoU had the project met the milestone. In case the project enjoys an exemption from royalty in the initial years, the duration of royalty exemption would be reduced by the period of delay.
- vii) The IPP may surrender the allotment back to GOU if on completion of the DPR, within the stipulated time-frame, it has grounds to establish that the project is not techno-economically viable. On such surrender, the bank guarantees provided by the IPP in lieu of upfront premium would be released and any premium amount

paid in excess of the threshold premium of Rs.5 lakhs/MW, would be refunded to the IPPs by the GOU.

2.4.2.14 Roll of UPCL and UJVNL

The UPCL will be responsible for preparing the standard wheeling and banking agreement draft (Para 2.4.2.6), determination of evacuation requirements (Para 2.4.2.7), and overseeing banking, dispatch, and royalty arrangements (Paras 2.4.2..8, to 10).

The UJVNL will be responsible for preparation of pre-feasibility studies, carrying out the bidding process (Para 4) and monitoring of the development of allotted project delivery as per time schedules (Para 2.4.2.13).

The UJVNL will not participate in the bidding process. However, after allotment, upon request from the IPP, the UJVNL may consider participating as a minority partner (with less than 0% shareholding interest) or perform certain tasks for the bidder on a consultancy basis. Such participation would be independently negotiated between UJVNL with the IPP and is — mandatory on the part of UJVNL.

2.4.2.15 Regulatory Oversight

Aspects of this policy that require Regulatory approvals from the concerned regulatory authority would be subject to such approvals being given and would apply in the manner approved by the Regulator.

2.4.2.16 Due Diligence

The applicant/IPP shall be responsible for carrying out due diligence with regard to his compliance responsibilities under various applicable Central/State/other laws, rules and regulations, and ensure compliance with the same.

2.4.2.17 Power To Resolve Difficulties

In the event of a dispute, the interpretation of these guidelines made by the Government of Uttaranchal shall be final. In all such matters, to the extent practicable, an opportunity shall be given to affected stakeholders to be heard before the Government takes any decision.

2.4.3 Extracts of Electricity Act. 2003 as regards generation is given below:

Part III Generation of Electricity

Generation company and requirement for setting up of generating station	7.	Any generating company may establish, operate and maintain a generating station without obtaining a licence under this Act if it complies with the technical standards relating to connectivity with the grid referred to in clause (b) of section 73.
Hydroelectric	8(1)	Notwithstanding anything contained in section 7, any generating

generation	company intending to set-up a hydro-generating station shall prepare and submit to the Authority for its concurrence, a scheme estimated to involve a capital expenditure exceeding such sum, as may be fixed by the Central Government, from time to time, by notification. (2) The Authority shall, before concurring in any scheme submitted to it under sub-section (1) have particular regard to, whether or not in its opinion, (a) the proposed river-works will prejudice the prospects for the best ultimate development of the river or its tributaries for power generation, consistent with the requirements of drinking water, irrigation, navigation, flood-control, or other public purposes, and for this purpose the Authority shall satisfy itself, after consultation with the State Government, the Central Government, or such other agencies as it may deem appropriate, that an adequate study has been made of the optimum location of dams and other river-works; (b) The proposed scheme meets, the norms regarding dam design and safety. (3) Where a multi-purpose scheme for the development of any river in any region is in operation, the State Government and the generating company shall co-ordinate their activities with the activities of the person responsible for such scheme in so far as they are inter-related.
Captive Generation	9(1) Notwithstanding anything contained in this Act, a person may construct, maintain or operate a captive generating plant and dedicated transmission lines: Provided that the supply of electricity from the captive generating plant through the grid shall be regulated in the same manner as the generating station of a generating company. (2) Every person, who has constructed a captive generating plant and maintains and operates such plant, shall have the right to open access for the purposes of carrying electricity from his captive generating plant to the destination of his use: Provided that such open access shall be subject to availability of adequate transmission facility and such availability of transmission facility shall be determined by the Central Transmission Utility or the State Transmission Utility, as the case may be: Provided further that any dispute regarding the availability of transmission facility shall be adjudicated upon by the Appropriate Commission.
Duties of Generating Companies	10.(1) Subject to the provisions of this Act, the duties of a generating company shall be to establish, operate and maintain generating stations, tie-lines, sub-stations and dedicated transmission lines connected therewith in accordance with the provisions of this Act or the rules or regulations made there under. (2) A generating company may supply electricity to any licensee in accordance with this Act and the rules and regulations made there

		under and may, subject to the regulations made under sub-section (2) of section 42, supply electricity to any consumer.
	(3)	Every generating company shall -
	(a)	submit technical details regarding its generating stations to the Appropriate Commission and the Authority;
	(b)	co-ordinate with the Central Transmission Utility or the State Transmission Utility, as the case may be, for transmission of the electricity generated by it.
Direction to Generating Companies	11(1)	The Appropriate Government may specify that a generating company shall, in extraordinary circumstances operate and maintain any generating station in accordance with the directions of that Government.
		Explanation. - For the purposes of this section, the expression “extraordinary circumstances” means circumstances arising out of threat to security of the State, public order or a natural calamity or such other circumstances arising in the public interest.
	(2)	The Appropriate Commission may offset the adverse financial impact of the directions referred to in sub-section (1) on any generating company in such manner as it considers appropriate

2.5 ENVIRONMENTAL ISSUES

2.5.1 General

Environmental issues generally involved in Hydropower project are as follows:

- Rehabilitation
- Deforestation
- Submergence
- Quality of water
- Flood mitigation
- Aquatic life
- Green house emission

All hydroelectric projects require environment impact assessment report and clearances as generally given in Para 2.7. Information required by Govt. of India Ministry of Environment and Forest is given below.

2.5.2 Clearances

1. (a). Name and address of the project proposed.
- (b) Location of the project
Name of the place
District, Tehsil
Latitude/Longitude
Nearest Airport/Railway Station
- (c) Alternate sites examined and the reasons for selecting the proposed site
- (d) Does the site conform to stipulated land use as per local land use plan

2. Objectives of the project

3. (a) Land Requirement

Agriculture land
Forest land and density of vegetation
Other (specify)

- (b) i) Land use in the catchment within 10 kms radius of the proposed site
ii) Topography of the area indicating gradient, aspects and altitude
iii) Erodibility classification of the proposed land

- (c) Pollution sources existing in 10 km radius and their impact on quality of air, water and land
(d) Distance of the nearest National Park/Sanctuary/Biosphere Reserve/Monuments/heritage site/Reserve Forest
(e) Rehabilitation plan for quarries/borrow areas.
(f) Green belt plan
(g) Compensatory afforestation plan

4. Climate and Air Quality

- (a) Max/Min/Mean annual temperature
(b) Frequency of inversion
(c) Frequency of cyclones/tornadoes/cloud burst:
(d) Ambient air quality data
(e) Nature & concentration of emission of SPM, Gas (CO, CO₂, NO_x, CH₄ etc.)

5. Water balance

- (a) Water balance at site
(b) Lean season water availability;

Water requirement
(c) Source to be tapped with competing users (river, lake ground, public supply)
(d) Water quality
(e) Changes observed in quality and quantity of groundwater in the last years and present charging and extraction details
(f) i) Details of reservoir water quality with necessary catchment treatment plan

6. Noise and Vibrations

- (a) Source of noise and vibrations
(b) Ambient noise level
(c) Noise and vibration control measures proposed
(d) Subsidence problem, if any, with control measures

7. Power requirement indicating source of supply: Complete environmental details to be furnished separately, if captive power unit proposed.

8. Peak labour force to be deployed giving details of:
 - Endemic health problems in the area due to waste water/air/soil borne diseases:
 - Health care system existing and proposed
9. (a) Number of villages and population to be displaced
 (b) Rehabilitation master plan

10. Risk Assessment Report and Disaster Management Plan

Report prepared as per guidelines issued by the Central Government in the MOEF from time to time:

11. (a) Environmental impact assessment
 (b) Environment management plan
 (c) Detailed feasibility report
 (d) Duly filled in questionnaire

2.5.3 A typical environmental impact assessment for Mukerian SHP (2 x 9000 kW) is given below.

1. Mukerian small hydel stage-II scheme envisages the power generation from existing canal and this development is without any additional pondage. Small hydel development projects, while sharing all the benefits of hydro electric generation, harnesses a renewable source of energy in extremely environmentally benign manner.

Social cost therefore are almost nil to even an environmental conscious state. Being small it does not involve any additional submergence or violation of the sanctity of forests.

2. The location of power house is so taken that it requires minimum width and at a safe distance from the existing canal system from the safety point of view during excavation of power house foundation. It does not cause any environmental and ecological imbalance of the area.
3. Availability of reliable electrical energy is expected to reduce dependence on depleting fuel and saving of petroleum products like diesel and Kerosene for power generation.
4. The magnitude of construction activity will not induce migration of labour to this area, as sufficient local labour is available in the area, and thus local ecology will not be pressurised.
5. In addition, it is proposed to do plantation in the scheme area wherever possible.
6. The water will be passing through turbines for power generation and will be discharged in the river Beas through tailrace channel. The surplus water will be taken care by spillway proposed in the diversion channel.

7. Provision has been made to cover fuel arrangements for labour, afforestation in the project area, restoration of construction area by levelling and filling of borrow pits and providing vegetation on exposed slopes etc.
8. Population of two nos. villages (village Tarkiana in Hohiarpur district & village Kathana in district Gurdaspur) may be affected with the construction of this Power House. Provision for adequate compensation to the affected population has been proposed.

2.6 SWOT – STRENGTH, WEAKNESS, OPPORTUNITY AND THREATENING OF A HYDROPOWER PROJECTS

2.6.1 Strength

- Environmental friendly, clean renewable
- High degree of flexibility
- Part of multi purpose project with additional benefits.
- Pumped storage for optimal integrate operation of grid
- Least operational and maintenance cost
- Additional benefits of Flood control, Tourism, fishery.
- Well recognized for obtaining financial support.

2.6.2 Weakness

- Mainly depends on rainfall/snowmelt.
- Run of river not for peaking
- High capital intensive.
- Remotely located
- Gestation period is very large.
- Relatively smaller units.
- Non standard occurrence.

2.6.3 Opportunities

- Vast potential untapped
- Requirement for power peaking
- Greater concern towards increasing pollutions on land, water and in air causes leading inclination towards hydro
- Depletion of fossil fuels.

2.6.4 Threats

- Ambitious plan for thermal/nuclear programme for power.
- Growing concern of environment.
- Prone to natural calamities.
- Submergence of land and displacement of population
- Apprehension on seismic disturbance
- Over emphasis of other renewable energy sources development.

2.6.5 Institutional Arrangements

- The Ministry of Power responsible for policy and programmes and all matters in the sector of Power.

- The Ministry of New and Renewable Energy is responsible for all matters of new and renewable energy including hydropower development.
- The Central Electricity Authority (CEA) is the technical wing of the ministry.
- Central Electricity Regulatory Commission is to regulate the tariff of generating companies, to regulate interstate transmission of electricity, to issue licenses to function as transmission licensees, to adjudicate upon disputes involving distribution companies or transmission licensee, to specify grid code etc.
- Central Transmission Utility is a government company to undertake transmission of electricity through the interstate transmission system.
- Power Grid Corporation of India Limited (PGCIL), which is a Government of India company, is entrusted with the responsibility of creating a national transmission grid.
- The PTC is to purchase power from the identified private projects and sell it to the identified State Electricity Boards or supply power directly to a 'cluster'.
- Rural Electrification Corporation, a Government of India company to assist the Departments of Energy and Power of various State Governments, State Electricity Boards in the development and financing of programmes of rural electrification.
- Power Finance Corporation, a central public sector undertaking, to assist various electricity Boards in the power sector.
- Central Water Commission is an autonomous Commission under the Ministry of Water

Other organizations Include

Professional organizations like

- Central Power Research Institute,
- Power Engineers Training Society,
- Energy Management Center etc.
- Central Board of Irrigation and Power,
- Council of Power Utility,

2.6.6 Other Stake holders

- Power Trading companies
- Private developers
- Regulatory commission
- Financial Institutions
- Manufacturers
- Consultants
- EPC contractors and construction firms
- NGOs

2.6.7 Sources of Information (e.g. in India)

- **State Nodal Agencies for renewable energy in states**
- State Electricity Boards, Deptt. of Power of states
- Central Government MNES, CEA, CWC, NHPC etc. Individuals having background in such data calculation
- Survey of India including Digital Mapping Centre
- Forest Survey of India

- Indian Institute of Remote Sensing, Dehradun
- Regional Centre for Remote Sensing, Dehradun
- NATMO, Calcutta

2.6.8 Matrix of States and Key Factors Relevant For SHP projects

A matrix of 8 States and key factors which may be taken into consideration for decision has been prepared and is reproduced below:

States →		J & K	Arunachal Pradesh	Sikkim	H.P	Uttara - khand	Karnataka	Maharashtra	Meghalaya
↓	Issues								
Policy		Good	Good	Fair	Good	Good	Good	Good	Not yet
Availability of sites		Good	Good	Good	Good	Poor	Fair	Fair	Fair
Infrastructure		Poor	Poor	Fair	Fair	Fair	Good	Good	Fair
Working environment		Poor	Fair	Fair	Good	Good	Good	Good	Fair
Law and order		Poor	Fair	Good	Good	Good	Good	Good	Fair

2.6.9 CLEAN DEVELOPMENT MECHANISM

Under the Clean Development Mechanism (CDM), energy projects lowering the carbon intensity of the electricity grid can generate additional revenues from carbon credits.

- India's committed to the protection of the global environment.
- 124 Indian projects have been registered with the executive board.
- Host country approval for 21 projects has also been accorded by National CDM authority established under the Ministry of Environment and Forest.
- The central electricity authority has published the CO₂ base line data for the Indian Power Sector and also user guide version 1.1 dated Dec. 2006. These are available on the website of CEA.

2.6.10 PROCEDURE FOR SHP DEVELOPMENT

- Small Hydro is a state government subject and hence state government allots the sites.
- Site may be ready with investigations, report or may not be with any data

- Sites are allotted to private sector on MOU, advertisement based by state government through nodal agency.
- All SHPs are dealt and approved techno-economical at state level
- Implementation agreement, power purchase agreement is drawn between IPP and state utility.
- State Electricity Regulatory Commission approves the price
- Environment clearance not required for projects below and upto 25 MW

2.6.11 Risks in SHP

<i>Risks-Types</i>	<i>Mitigation</i>
Hydrology Failure	Long term data
Geology Failure	Detailed Investigations
Power Evacuation	Disciplined grid
Delayed Payment by State Utility	Discipline/ Escrow account
Natural Calamities	Insurance

2.6.12 Barriers to small hydropower development

Policy, Legislative and Institutions Related Problems

- High premium and free sale by State Govt.
- Land acquisition problems
- Obtaining clearance for new projects from environmental and forest viewpoints
- High cost of compensatory afforestation & physical infrastructure
- Geological surprises in Himalayas; Consequently high risk
- Long gestation period and non priority of FIs
- Inadequate coverage of country with transmission network
- Local opposition
- Variation in water flows resulting in energy uncertainty.
- Law and order problems
- Apportionment of Project Cost Among Various Agencies
- Time taken for Allocation of Projects for Development
- Storage vs. Run-off-River Projects
- A large number of regulatory agencies are involved in such projects and there is a lack of proper coordination.
- Shortage of local trained labour and manpower, local contractors and local quality assurance.
- Problem of remote location of site and evacuation of power

2.6.13 Problems being faced in execution of hydro PROJECTS

- General Problems in Executing Hydro Electric Projects in India
- Competition
- Lack of cooperation from local population
- R&R issue
- Environment
- Forest clearances

- Political (change of parties)
- Delay in issuing licensee like blasting, stone crushers, quarrying of river
- Lack of liaison & coordination (with multiple cooperation)
- Delay in design drawings
- Political insurances
- Insurance for replacement values
- Labour laws
- Lack of involvement of local people
- Shortage of local labour, local contractors, quality assurance, manpower

Risk	Mitigation
Hydrological Risk	✓Long term data ✓Good quality rainfall- run off modeling ✓Sustainable Water shed management ✓Good availability of resource data, maps
Geological Risk	✓Detailed investigations ✓Catchments treatment ✓Good design
Constructions Risk	✓Insurance ✓Tern key contract ✓Performance guarantees ✓Liquid damages on non-performance ✓Due diligence process ✓Good engineering design ✓Good supervision
Performance Risk	✓Insurance ✓Warrantees ✓Out sourcing of O&M ✓Trained manpower ✓Availability of spares and others
Risk	Mitigation
Power evacuation risk	✓Disciplined grid ✓Stable grid
Financial Risk	✓Long term financing ✓To have better understanding by FIs
Delayed disbursement	
Delayed receipts from sale	
Delayed receipt of insurance	
Short duration PPAs	
Market fluctuation	

2.7 PROCESS OF SITE DEVELOPMENT

2.7.1 Stages in a Hydro Project

- 1) Administrative – including advertising to offer sites to Power Producers; Allotment of Site and Signing of Agreement as detailed in Para 2.9.
- 2) Pre-implementation
- 3) Implementation
- 4) Post Commissioning

Details are as follows:

2.7.2 Pre-Implementation Activities

- i .Detailed Investigation & surveys
- ii. Pre feasibility Report (PFR)
- iii. Detailed Project Report (DPR)
- iv. Approval of DPR
- v. Land Acquisition – Forest Land Acquisition – Civil Land Acquisition - Private
- vi. Clearance for Environment
- vii. Power purchase agreement
- viii. Clearance from different
- ix. Preparation of plan for Resettlement & rehabilitation
- x. Financing

Time Taken

Activities V to X can be done in parallel. The most time consuming is Preparation of Resettlement and Rehabilitation Plan which may take 12 to 24 months.

2.7.3 Implementation & Post Commissioning Activities

- i. Construction License
- ii. Engineering design & construction drawings
- iii. Equipment supply
- iv. Civil works construction
- v. Resettlement & rehabilitation of project affected families
- vi. commissioning
- vii. Post commissioning
- i. Receipt of payment from utility / trading / user
- ii. Refund of borrowing to FIs

Activities		Large & Medium HP	Small HP
A. Administrative			
Advertisement		Few times	Yearly
Allotment		6 months to one year	6 months to one year
Signing of implementation agreement	of	2-3 months	1-3 months

B. Pre- implementation			
Detailed Investigation & surveys		6 months – 2 years	4 months – 2 years
Pre feasibility Report (PFR)		3-6 months	1-3 months
Detailed Project Report (DPR)		6-12 months	3-6 months
Approval of DPR		4-6 months	4-6 months

Activities		Large & Medium HP	Small HP
Land Acquisition – Forest		6-18 months concurrently	6-
Land Acquisition – Civil		6-12 months concurrently	4-12 months
Land Acquisition - Private		4-12 months concurrently	4-12 months
Clearance Environment	for	6-12 months concurrently	4-12 month concurrently
Power agreement	purchase	3-6 month concurrently	2-4 month concurrently
Clearance from different		Twelve months concurrently	6 months concurrently
Preparation of plan for Resettlement & rehabilitation	of plan for &	12 to 24 months concurrently	Normally not involved
Financing		4-12 month concurrently	3-6 month concurrently

Activities	Large & Medium HP	Small HP
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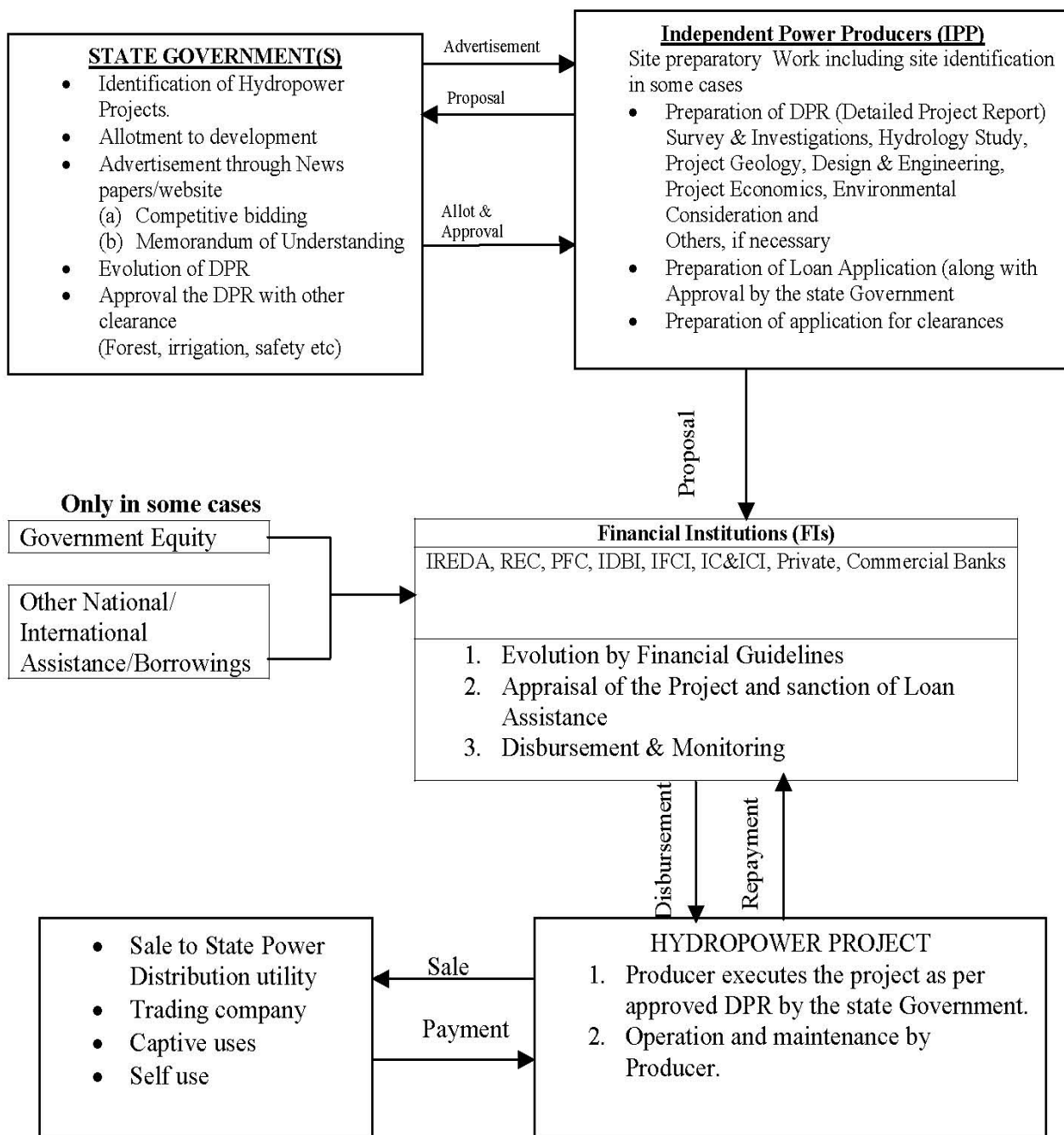
C. Implementation

Construction License	2-6 month	2-3 months
Engineering design & construction drawings	4-18 month concurrently	3-6 month concurrently
Equipment supply	12-24 month concurrently	8-16 month concurrently
Civil works construction	24-48 month concurrently	10-18 months concurrently
Resettlement & rehabilitation	36 to 60 months concurrently	Normally not involved
commissioning	36-60 months concurrently	12-24 months concurrently

D. Post commissioning

Receipt of payment from utility / trading / user	1 month	1 month
Refund of borrowing to FIs	As per Schedule	As per schedule

Independence Power Producer Hydropower Development Flow Chart



2.8 TYPE OF CLEARANCES

List of Clearances required for hydropower projects Extracted from AHEC Publication Small Hydro Power – Installations and Private Escort Participation – 3rd Edition

S. No.	Item	Agency	Remarks
Statutory Clearances			
1.	Cost Estimates		
	Any power project involved capital expenditure exceeding the limit by Govt. needs to be scrutinized by CEA for examination of salient features and benefits which may accrue there from.	CEA* ¹	Required under section 29 of electricity (supply) Act. 1948.
2.	Techno-Economic Clearance/Concurrence of CEA by CEA after examination		
	i) River works/dams to be put up for hydro ii) Greatest possible economic output of electric power iii) Transmission lines and systems iv) Reasonableness of the scheme v) Site location distance from load centers, transportation facilities, water availability and environmental considerations.	CEA	Under Section 30 Electricity (supply) Act. 1948. SEBs, State Govts, Concerned Ministries of Coal, Petroleum & Natural Gas, Railways, Surface Transport involved.
3.	Publication		
	Schemes to be published in the official local newspaper as the generating company may consider necessary along with a notice of at least two months and modification if any consequent to public representation.	State Govts.	Section 29 clause gazette/(2), (3), (4) and (6) E (S) Act, 1948. State Govts.
4.	Water Availability	1. State Govts.	Interaction between state Govt. Deptts. & CWC required
5.	CWC		Relevant irrigation Act of the State & Central Water Commission
6.	SEB Clearance	1. SEB* ² 2. State Govt.	Sec. 44, E (S) Act, 1948 Water (Prevention & control of Pollution) Act,

7.	Pollution Clearance Water and Air	State/Central pollution control board	1947 Air (prevention & control of pollution) Act. 1981.
8.	Forest Clearance	1. State Govt. 2. Min. of E & F* ³	Coordination with state forest Deptt./Min. of Environ. & Forest (MOE&F) regarding forest (conservation) Act. 1980.
9.	Environment & Forest Clearance	- do -	As per item (6) & (7) & Govt. policy in force
10.	Registration of company	Registrar of Companies	Under Indian Companies Act. 1950
11.	Rehabilitation & Resettlement of Displaced Families, by land Acquisition	1. min. of E&F 2. State of Govt.	
12.	Hydro-Projects (Mini-Micro)	M/o Water Resources	Under relevant acts
13.	Equip. Procurement	DGTD, CCI & E* ⁴	Import & export acts
<u>Non Station Clearances</u>			
1.	Land Availability	State Govt.	
2.	Financing	CEA, Deptt. Of power Deptt. Of Eco. Affairs Financial Institutions	
3.	Transportation of Fuel	Deptt. Of Coal/M/o petroleum & Natural Gas, Ministry of railways, Shipping & Surface transport	

CEA*¹ - Central Electricity Authority
SEB*² - State Electricity Board
Min. of E & F*³ - Ministry & Environment and Forest - Govt. of India
DGTD, CCI & E*⁴ -

2.9 JOINT VENTURES AND ALLOTMENT OF HYDROPOWER SITES

2.9.1 Joint Ventures (Govt. of India Policy)

With a view to bring in additional private investment in the hydel sector there would be a greater emphasis to take schemes through the joint ventures between the PSUs/SEBs and the domestic and foreign private enterprises. The joint venture company will be an independent legal entity to be registered under Companies Act and would act as an independent developer. The joint venture agreement between the two partners will bring clearly the extent of participation by each pattern and sharing of risks relating to implementation and operation of the project. It will also provide for agreement in such cases where the joint venture pattern would not be associated with the operation and maintenance of the project. While the selection of a joint venture partner would be in accordance with the policy of the Government, there would be an option for the PSU to either select the joint venture partner wherein the EPC contract is decided by both the partners after they have

formed the joint venture company. The associated transmission lien connected with the scheme will be constructed by the power grid corporation of India. The power from joint venture hydel projects will be purchased by the power trading corporation (PTC) proposed to be formed with equity participation from government/CPUs/financial institution. The security for payment of power purchased from the joint venture projects would be through a LC to be provided by the SEBs and resources to the State's share of Central Plan Allocation and other revolution. This security package would enable to raise for these projects as far as the new schemes to be developed under the joint venture route are concerned, the power sharing formula as applicable to the Central Sector Projects shall not apply and joint venture company would be totally guided by the commercial interest. The State government (home state/states) will be compensated by way of 12% free power as per the present policy applicable for central sector hydel projects.

2.9.2 Potential Sites and Guidelines for Allotment

To develop hydro project, State Government identify potential sites, prepare Pre-Feasibility Report (PFR) and declare hydro policy which gives the guideline for allotment of sites to public and private investors or companies.

2.9.3 Prequalification of Allotment

Qualification	Weightage
• Financial capacity	(60-80)%
• Technical capacity	(20-30)%
• Past experience	(10-15)%
• Local factor	(5-10)%

2.9.4 Method of Allotment of HP Sites

There are two methods for allotment of HP site:

1. By signing MOU (memorandum of understanding).
2. By inviting bid.
3. Joint ventures

2.9.5 Procedures of Allotment of HP Sites

- The projects are advertised in order to seek bid of possible sites.
- All bidder will be subjected to pre-qualification.
- Applications from bidders in response to the advertisement should be accompanied by a non-refundable upfront premium.
- Upfront will be per MW for each project, subjected to a minimum threshold premium. If bids received beneath the threshold premium will be rejected.
- Projects will be allotted to the bidder making highest bid. The successful bidder shall be required to deposit the premium within a reasonable period of receiving bid document.

- If more than one bidder bids the identical premium, a gradation list based on pre-qualification criterion is made and allotted to highest priority bid.
- In case there is no bid for any site in two times the site is allotted to govt. agency.

2.9.6 Sale of power

The bidder can contract to sell power to any HT consumer, to local rural grids, main grid to rural power distribution entities, to any consumer outside the state. All sale is approved by SRC, or CRC in case inter-state matter.

2.9.7 Wheeling charges

Wheeling charges for wheeling the generated energy to third party consumers or outside the State will be as determined by the SRC (see Para 2.4.2.6).

No wheeling charges are applicable in cases of sales to the state govt. or for sale to rural power distribution entities or local rural grids within state.

2.9.8 Grid interfacing/transmission line

The IPP shall be responsible for laying lines for connectivity to the nearest grid substation at the appropriate voltage, depending on the capacity of the power station and the distance from the power station to the Grid sub-station. The state govt. will determine the specifications of the evacuation facilities required, including the inter-connection point and voltage. and the same would be specified in the project information document provided with the application form. On specific request from the IPP, the state govt. will carry out the implementation of evacuation facilities at charges to be mutually negotiated.

2.9.9 Royalty

On all projects governed by policy, royalty payment for the first 15 years of operation would be exempted in all cases of sale of power outside the State or to the state or to consumers in rural areas not served or inadequately served by the concerned existing distribution licensee. In case of sale to other parties, a royalty of 12% of net energy wheeled (after deducting wheeling charges) or supplied directly without wheeling would be charged.

Beyond the 15th year of operation, a royalty of 18% of net energy wheeled or supplied directly without wheeling will be made available to the Govt. free of charge by all IPPs.

2.9.10 Incentive by State Govt.

The State Government will levy no entry tax on power generation, transmission equipment and building material for projects.

2.9.11 Time for executing the project

IPP shall prepare and submit the detailed project reports and all other information and make the necessary applications for obtaining the statutory clearances and approvals of the State and Central Governments and the Regulator (as applicable) after carrying out the

required confirmatory surveys and investigations as per prevailing regulations/ norms within 32 months from the date of allotment.

2.9.12 Time for executing the project

The IPP shall be responsible for ensuring completeness of all submissions to concerned authorities. Failure to do so within the stipulated time frame shall be treated as noncompliance with the requirement stipulated in this paragraph.

The IPP shall achieve the financial closure within 12 months from the date of receipt of all statutory approvals and clearances given by the State and Central Governments. Financial closure would imply firm. Commitments for financing the entire project, with all pre-disbursement conditions having been fulfilled and the loan documentation being complete.

The project shall be made operational within 48 months from the date of receipt of all statutory approvals and clearances by the IPP. Incentives for early commissioning will be extended.

The failure to reach any of the two milestones mentioned in above two will result in automatic cancellation of the allotment of the site, and forfeiture of upfront premium amounts. No compensation would be payable to the IPPs in such instance.

Failure to reach the milestone as in III above would result in a liability to pay a penalty by the IPP to the Govt., computed at the equivalent royalty revenue that would have been payable to the Govt. had the project met the milestone. In case the project enjoys an exemption from royalty in the initial years, the duration of royalty exemption would be reduced by the period of delay.

The IPP may surrender the allotment back to Govt. if on completion of the DPR, within the stipulated time frame, it has grounds to establish that the project is not techno-economically viable. On such surrender, the bank guarantees provided by the IPP in lieu of upfront premium would be released and any premium amount paid in excess of the threshold premium of Rs.5 lakhs/MW would be refunded to the IPPs by the Govt.

2.10 INVESTIGATIONS, FLOW MEASUREMENTS , FLOW DURATION CURVE, PFR AND DPR

2.10.1 General Scope

Data collection or investigation is a very important fundamental work for the project design. Comparing with large and medium hydropower projects, data collection for small hydro has the characteristics of being much simplified, fast, economic and appropriate. However, these features of data collection are not to imply that data collection of SHP can be carried out carelessly. But it implies that its method adopted must correspond with the project scale and function and do not copy indiscriminately the experience of large scale hydro power projects.

The main problems caused by insufficient investigations, encountered in implementing SHP development are;

1. Due to inaccurate calculation of the annual run off or improper adoption of water flow for generating power, the installed capacity of power station become abnormally large or small, so it cause to either the utilization factor of equipment dropped below a certain level or hydro power potential had not been utilized effectively.
2. Due to under estimation of the flood on insufficient capacity of spillway, the flood over the dam crest may cause serious damage to the dam/intake structure and sometime power house may also be failed.
3. Due to neglecting the geological exploration work or failing is taking appropriate measures in design, some hydraulic structures had been damaged by piping of material from foundation, uneven settlement and serious downstream scouring (erosion).

Some people look down on SHP and omit the necessary investigations for SHP projects. For SHP, it becomes more important to go into a reasonable investigation as most of the time there will not be much available data and cost economics would not permit to go far longer duration investigation.

An evident from above it will be very important to carry out a series of field or site investigations. These investigations may entail the collection and recording of a wide range of information, possibly from an extensive area of the country and may invite the attention of a number of people over a considerable period of time. It is, therefore, be advisable at the very outset, to initiate a well considered programme of investigations at the site, so that the available time, personnel and equipment may be employed to the greatest advantage.

The scope and extent of the site investigations depend partly on the availability and reliability of existing published data, nature and size of proposed development and opportunities/difficulties presented by the existing topographical and geological features which in turn will effect the number of alternatives which have to be carried out. For these reason the various classes of site investigations cannot readily be tabulated in any invariable order or priority or importance.

It is, however, usual for both office studies and site investigations to be carried out in two stages- Preliminary and final.

Since small hydro projects are broadly of two types; the investigation type and time/money required to complete the investigations will be different.

- a) Projects in hills (basically run off river type) using the steep slopes of streams. These are of medium and high head.
- b) Projects on existing facilities such irrigation dams and canals fall structures. These are of low head.

While there are several types of investigations required to be carried out for the schemes in hills, the investigation for schemes on existing facilities are rather less as published or otherwise most of the data are available from the owners of these facilities.

2.10.2 Investigation Stages

For planning, which may be regarded as a 2 or 3 stage process, investigations also are done in stages progressively by increasing degree of reliability.

The following stages of investigation are commonly used.

1. Reconnaissance level (Preliminary) - Pre feasibility report (PFR)
2. Feasibility/Detailed Level (Pre-Investment) – (DPR)

2.10.2.1 Reconnaissance Level (Preliminary) – Pre Feasibility Report

At this level of investigations following should be determined.

- a) Technical feasibility of the project
- b) Identification of critical issues and their possible solutions
- c) First economic evaluation

The purpose of the preliminary investigations is to provide sufficient information to confirm the practicability of any proposed scheme of development to compare between alternative schemes or arrangement so that preliminary design and estimates can be prepared and recommendations made with reasonable confidence. These preliminary investigations generally include the following studies:

- a) **Hydrological Studies:** Overall rainfall, run off data, principal river flow data, flood characteristic etc. from records of Govt. deptts. Establishment of approximate figures on minimum, average and flood discharges.
- b) **Topographical Studies:** Tachometric Surveys and survey required depending upon the existing information and maps.
- c) **Geological Studies:** Overall geological characteristics and local features and some surface investigation, preliminary reconnaissance surveys for construction material etc.
- d) **Power load demand assessment:** Overall power demand scenario in the project nearby area and existing facilities/infrastructure for power evacuation.

With such study, it is expected a reconnaissance study will be planned and available for taking decision whether further detailed investigations are wanted. Such study is designed to reduce chances of a subsequent unfavorable funding.

- * Define power potential
- * Estimate power output
- * Assess market potential
- * Identify physical works needed
- * Develop project hydrology and hydraulics
- * Formulate and cost project

- * Develop power benefit stream
- * Determine economic feasibility
- * Identify critical issues, i.e. environmental and social
- * Assess legal/institutional issues
- * Assess site issues as land, construction material etc.
- * Assess facility integrity such as access and power evacuation arrangement.
- * Assess financial issues
- * Document findings

2.10.2.2 Feasibility/Detailed Level Investigations (Detailed Project Report)

The final investigations comprise the detailed exploration of the finally recommended site (or sites) so as to establish beyond doubt their complete suitability and to enable the final designs and contract documents to be prepared with the least chance of serious alteration after the contract has been let. The final investigations will generally be:

- a) **Hydrological:** The most complete and detailed extension possible of the preliminary hydrological studies.
- b) **Topographical:** Preparation of accurate large scale maps for the sites of all-important structures.
- c) **Geological:** detailed sub-surface investigations by excavation, boring etc. rigorous sampling and testing of materials, water tightness and grouting test etc.
- d) **Power load demand:** For grid connected projects, the investigation on location and facilities at the power evacuation project is required. For isolated projects the load demand in nearby area is to be forecasted based on the population, type of industries, distance from power house etc.

With above said investigations, it is expected that following will be achieved.

- * Formulate power features
- * Refine power output estimates
- * Recomputed the benefit streams
- * Cost project power features
- * Select project power features
- * Preliminary project components designs and specifications
- * Project cost estimates
- * Perform sequential power routing
- * Refine power features and performance characteristics
- * Complete project benefit cost analysis
- * Assess financial requirements
- * Application for permissions on load transfer, power evacuation etc.
- * Environmental factors require continuous evaluation at all study levels.

It determines whether or not the proposed development merits investment decision.

2.10.3 Investigations and Surveying

2.10.3.1 Hydrological Investigations

Available Flow Data: The most urgent hydrological investigation is to be undertaken to determine the run off or flow of water available for power. It often happens that more is known about the rainfall over large catchment areas than about the flow in individual streams and rivers and preliminary office studies are often based on analysis of rainfall gauging and comparisons of catchment characteristics. The most reliable method of determining run off is by accurate flow gauging of rivers preferably at the actual points proposed for interception.

Stage Discharge Data: Full range of hydraulic conditions for which various structures must be designed as correctly as possible. These investigations comprise principally the determination of natural water level corresponding to various discharge conditions of flow. The accuracy of this information affects the degree of safety or economy with which any individual structure must be designed.

Most of SHP stations are run-of-river or daily regulation type. There are several ways to approach the solution of hydrological problems to following data conditions:

1. There are flow data with long sequence of observation on site under study: this condition is very rare for small rivers.
2. There are flow data with short sequence of observations on site, supplemented by indirect data correlated with reference gauging stations.
3. Neither flow data at site nor that of reference station are available.

In the third condition, there are five main methods usually adopted to approach the solution: correlation analysis, hydrological analogy, regional synthesis, hydrological investigations and mixture of above methods.

For run-of-river schemes, especially for micro/mini projects, there might be only meager data available for assessing dependable flow. In such cases, discharge observations should be commenced immediately at appropriately located site. The data collected on this basis should be analysed for deriving a long term run-off-series based on rainfall to obtain as best a reliable correlation as possible. The rain gauges considered should preferably be located in the catchment in the vicinity of a particular scheme or in the absence of such location, the rain gauge stations of neighboring catchment should be considered for arriving at proper correlation between rain fall and run-off.

Discharge measurement in the vicinity of the site chosen for hydroelectric scheme should be taken in as accurate a manner as possible. Any of the following methods may be employed for discharge measurements, as considered appropriate for the particular location.

1. Flow measuring, structures such as notches, weirs and flumes (Ref. IS:1193-1959)
2. Velocity area method (Ref: IS:1192-1959): Use of current meters.
3. Slope area method (Ref : IS:2912-1964)

The discharge measurements should preferably cover a **minimum period of two lean seasons for SHP**. In addition to above following are also to be investigated

1. Suspended sediment
2. Tail water levels
3. Dissolved oxygen daily and average
4. Water temperature, daily and average

2.10.3.2 Topographical Investigations

The topographical maps available from respective government agencies such Survey of India and other state agency should be collected as far as possible in the first instance. In India the generally the maps of 1:50,000 scale with contour interval of 40 m and 1:25,000 with contour interval of 10 m are available for almost all of the area.

The topographical surveys should be conducted to fix the location of particular structures. The surveys should be connected to a GTs bench mark. In the absence of GTs bench mark at a reasonable distance from the project site, a suitably located permanent point within the project are may be chosen with a suitable value assigned to it to serve as datum for reference.

Survey plan for medium/high head scheme: The various requirements are as per table 1 enclosed.

Survey plan for low head schemes : Survey required for low head schemes are relatively much less. In the case of existing small dams, diversion structures, where penstock pipes are already embedded no survey would be required. In case penstock embodiment does not exist, water would be required to be led through suitable channel to the power house site and from there back to the existing canal system. If a powerhouse is to be located on an existing canal at a point where suitable fall is available, then bypass with similar arrangement as above would be necessary. Surveys would be done over a short stretch to fix the suitable channels/bypass etc. However, if a suitable fall is to be created in the existing run of a canal, remodeling of the existing canal would be necessary. As this might involve considerable length in re-alignment of the canal which would make the scheme rather costly.

Field surveys should include preparation of contour plans of the proposed arrangement covering sufficient area to a scale of 1:500 with a contour interval of 2 m. The L-section and Cross section of the canal should also be obtained.

2.10.3.3 Geological Investigations

Based on a geological traverse of the area the following minimum geological investigation shall be carried out: -

Diversion structure: It is desirable to ascertain the type of strata underlying the proposed structure by means of at least one borehole trial pit at a suitable location, as advised by the geologist, with geological logging. The report should also include the type of strata of the abutments.

Power channel: As the power channel in a micro/mini hydel scheme has comparatively small cross-section, detailed geological investigation by drill holes/test pits may not be required. However, the geological mapping of the hill slopes along the alignment is essential for assessing the stability of hill slopes, particularly the reaches where falling of the loose material in the canal is apprehended, should be identified in order to enable the designer to consider the remedial measures, like providing covered conduit or duct in these reaches.

Cross drainage works: A geological assessment of the strata, particularly of the abutments and bed of the drain at the proposed site of structure is required. Such a report would assist the designer to take care of the geological factors for the foundation of the abutment of the structure.

Penstock intake and penstocks: Geological mapping of the penstock slopes should be carried out. Particular attention should be given for geological sections at saddle and anchor block locations with indication of strata at the foundation level of the structure. One test pit at the location of intake and two or more test pits on the penstock slope with geological logging may be sufficient.

Power house: One test pit at power house site with geological logging should be carried out. In particular, geological mapping of the slopes of the power house excavation should be prepared, indicating the stability of the construction slopes and any adverse geological feature, so that this could be taken care of in the design for stability of slopes.

The geological investigation for small schemes on canal falls may include the geotechnical assessment of the site, indicating the type of rock, if available, or type of soil likely to be met at the foundation level of the power station by test pits. In case rock is not available at foundation grade, permeability tests should be carried out. These are given in table 2.

2.10.3.4 Load Demand Investigations

Load demand and market survey is required to assess the energy sale and financial analysis of the scheme. These may be of two types.

Grid Connected: The investigations will involve the details on the nearest sub station for trouble free power evacuation, its capacity, the length of transmission line required, land required etc.

Isolated Status: The daily, seasonal and annual consumption of domestic/commercial/community/industrial and irrigation needs are to be worked. The load curve will decide the size and number of units.

2.10.3.5 Socio Economic Investigations

Investigations on power consumers are important for determining the installed capacity of SHP. The design load for SHP is assumed in five years after commissioning of the plant i.e. under that load level the plant will be in full output.

Investigation of existent power stations such as existing SHP stations diesel electric stations and sub-stations is necessary in order to make the comparison between alternative of power sources.

Data relating to irrigation, urban and rural water supply and aquatic breeding concerning the multi purpose utilisation of project should be collected as well.

2.10.3.6 Environmental Investigations

1. Affect of foundation and submergence after the creation of reservoir.
2. Impact of deforestation.
3. Scaring or defacing of natural surrounding, especially in the region of borrow pits and quarry sites.
4. Preservation of cultural and ancient relics.
5. Affect on stream flow.
6. **Change of water quality/ (organise matter content, temperature, dissolved solids contents etc.)**

2.10.4 Flow Duration Analysis (Flow Duration Curve)

After measuring the discharge, a flow duration curve is plotted. This curve is the first basic analysis for designing a hydropower scheme. For plotting a flow duration curve, about 2 to 10 years data should be used. However in case of SHPs, less years' data can also be used.

A flow duration curve shows the percent of time that flow is equal to or less than or more than various rates during the period of study. The same data may also be plotted to show the percent of time of various flows are equaled or exceeded. A duration curve may be constructed on daily, monthly or yearly basis. As the length of time unit increases, the range of the curve decreases. The selection of the time unit depends upon the purpose of the curve. If a project for diversion without storage is under study, the time unit should be daily so that absolute minimum flows will be indicated. For reservoir design, the month or year may be sufficient depending upon reservoir size in relation to flow.

The main defect of the flow duration curve as a design tool is that it does not present flow in natural sequence. It is not possible to tell whether lowest flows occurred in consecutive periods or were scattered through out the record. Duration curves are most useful for preliminary studies and comparisons between streams. The exact storage requirements are dependent on the actual sequence of flow and can not be accurately estimated from duration curves.

The shape of the flow duration curve will mainly depend on the time unit selected (i.e. daily, monthly or yearly) and the type of stream (i.e. highly variable discharge, small flow variability, large flood plains, or considerable base flow).

The duration curve can be computed by (i) Rank ordered technique (ii) Class-interval technique.

2.10.4.1 Rank Ordered Technique

The data are ranked according to magnitude (in descending order) and the frequency of occurrence, F_x is given by;

$$Fx_m = m/n \times 100 \text{ (California formula)}$$

Where,

n	=	number of records, and
m	=	the order number in the rank (m = 1 for the highest ranked value)
Fx_m	=	Frequency of occurrence (percent dependable flow or the probability of flow being equaled or exceeded).

Table 3 gives monthly discharge data for one year at a site and Table 4 gives the computations of flow-duration curve using rank ordered technique.

2.10.4.2 Class Interval Technique

A useful first step is to plot the data as a frequency histogram. This is done by grouping the data into classes and then plotting a bar graph with the number of relative frequency of observations in a class versus the mid point of the class interval. The mid point of a class is called the class mark. The class interval is the difference between the upper and lower class boundaries.

Another method of presenting data is in the form of a cumulative frequency distribution. Cumulative frequency distributions show the frequency or events less than (greater than) some given value. They are formed by summing the relative frequencies and plotting the accumulated sum against the corresponding data value. If the ordinates are summed from the smaller (larger) data values to the larger (smaller) values, the resulting cumulative frequency refers to the frequency of observations less (more than) the corresponding data value. Points on the cumulative curve should be plotted on the right (left) boundary.

If the relative frequency of the i th class of the frequency histogram is denoted by fx_i , then one property of the histogram is

$$\sum_{i=1}^k n fx_i = 1$$

Where, k is the number of classes. Similarly if the cumulative relative frequency at the end of the i th class interval is Fx_i , then

$$Fx_i = Fx_i - Fx_{i-1}$$

$$\text{and } Fx_i = \sum_{j=1}^i n fx_j$$

Using the data of Table 1, the relative and the cumulative relative frequencies (duration curve) for a class interval of 5 cumecs are as given in Table 5.

A typical flow duration curve is shown in figure 2.10.4.

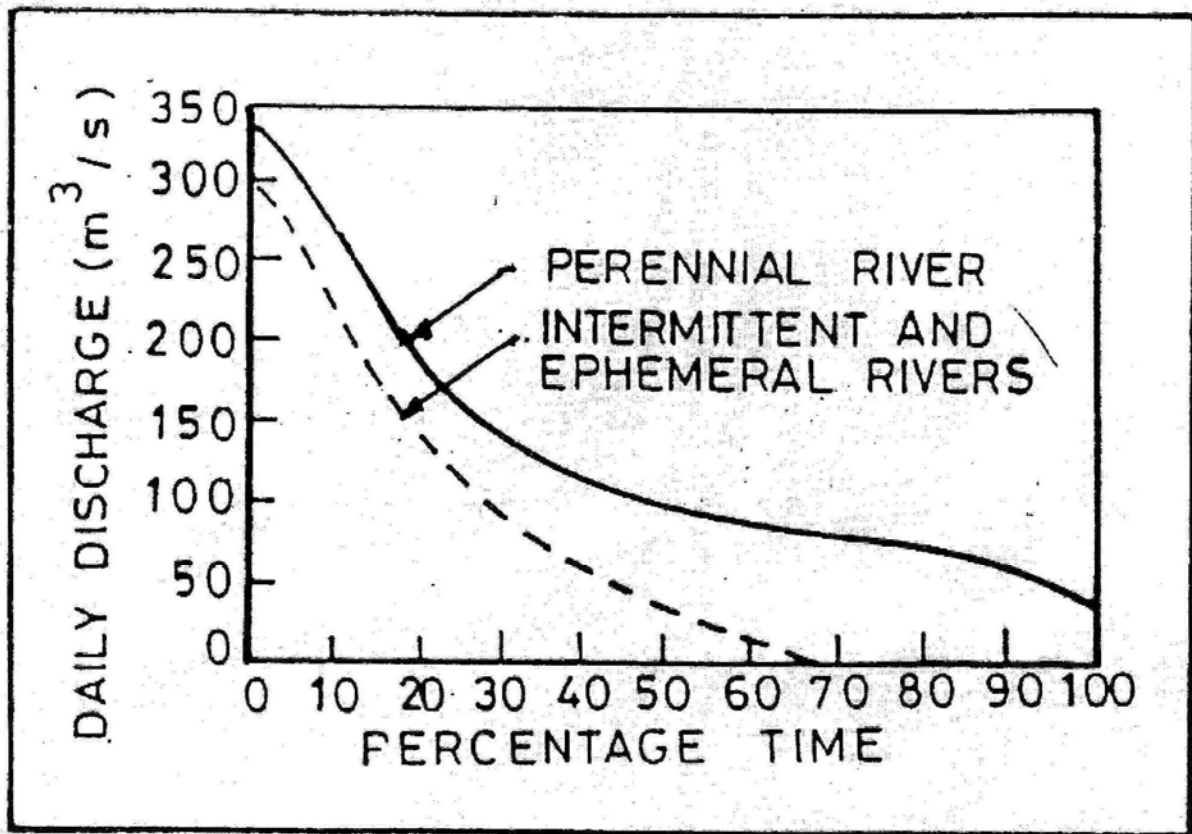


Fig. 2.26 Typical Flow Duration Curve

2.10.5 Conclusions

1. Data collection is indispensable to SHP design and construction. To some extent we can say that the failure and success of a SHP project mainly depend upon the failure or success of data collection.
2. The amount of work of data collection depends upon the project size and natural site condition. What affects data collection the most respects of amount of work and degree of difficulty are hydrological and geological investigations.
3. Hydrological investigation should be conducted in accordance with the requirements of design criteria of SHP such as flood standard, dependability of power output, the requirements put forward to the run off calculation and methods of hydrological analysis recommended by norms.
4. In region where there is no data available for hydrological analysis, some provisional gauging station should be set up at the very beginning of the investigations so as to get flow and precipitation data directly from the site under study, the observation period is at least 1-2 years.
5. Geological investigation for SHP differs that of large/medium hydro not only in amount of work and depends in research, but also exploration method.

6. Socio-economic data are also important for determining the installed capacity and annual power generation of SHP. An appropriate attention should be paid to environmental impact of SHP construction specially when a dam should be constructed on a river.

Table 1: Small Hydro Power Development Standard Norms for Surveys

S. No.	Site	Area to be surveyed/extent of surveys	Scale	Contour	Remarks
1.	General layout	The survey should extend from 1 km u/s of diversion structure to 0.5 km d/s of the junction of tailrace channel with the river and should cover all the components of the project	1:2000	2 m	If the terrain is hilly, spot levels should be taken by tachometer, if the area is reasonably plain, block leveling on a suitable grid should be done.
		River cross-section @ 200 m intervals to cover both the banks well above the highest flood marks and include power channel if the channel alignment is close to river course	1:1000	-	On the river X-Section at the axis of the diversion structure, following informations should be indicated. i. Date of survey and water level on that data. ii. Maximum observed HFL. iii. Minimum water level, on the river X-section at the junction of tailrace channel and the river, maximum and minimum water levels in river should indicated.
2.	Diversion Structure	In area covering 50 m u/s and 50 m d/s of the structure and 10 m above highest flood level.	1:200	2 m	
3.	Water Conductor System L-Section X-Section	Contour plan of an area covering 10 m towards the hill side and 10 m towards the valley side At 100 m interval and at locations where topography changes abruptly.	1:1000 1:1000	2 m -	
4.	Penstocks	The area for contour plan	1:200	1 m	

		should include intake, forebay, length of penstock and a width of 20 m on either side of penstock alignment. L-Section	1:200	-	
5.	Power House	Contour plan should cover sufficient area to include different alternative layouts of power house & switchyard, and tailrace channel if length is short.	1:200	2 m	
6.	Tailrace Channel	If the length of the tailrace channel is large, the area to be surveyed should be governed by the norms described in 3).	1:1000	2 m	
7.	Colony (if any)	Contour plan of the required area	1:200	1 m	

Table 2: Geological Investigations

S. No.	Structure	No. of Trial Pits	Location of trial pits	Depth of trial pits	Additional Requirement
1.	Conventional weir/Trench Weir	3	One trial pit at middle and two trial pits, one each on either abatement end	1.5 m 2 m	Geological assessment of stability of rock slope on either abatement.
2.	Water Conductor	3 5	Trial pits at every 500 m. c/c and at critical locations	1.5 m 2 m	Geological assessment of stability of rock slopes along the alignment reach-wise
3.	Forebay	2	One trial pit in forebay area and another trial pit at penstock intake location.	1.5 m 2 m	Geological assessment of rock slope on hill side of forebay.
4.	Penstock	2	Along the alignment of penstock preferably at another block locations.	1.5 m 2 m	Geological assessment of penstock slope.

5.	Power House	1	Power House area	1.5 m	2	Geological assessment of excavation slope
6.	Tailrace	1	Along the alignment	1.5 m	2	Geological assessment of excavation slope.

Table 3

Month	Discharge in Cumecs
January	6.00
February	6.00
March	6.00
April	6.00
May	4.50
June	12.00
July	45.00
August	19.50
September	27.00
October	12.00
November	6.00
December	6.00

Table 4 : Flow-Duration Curve by Rank Ordered Technique

Rank m	Flow in Descending order (Cumecs)	m/n x 100
1.	45.00	8.33
2.	27.00	16.67
3.	19.50	25.00
4.	12.00	33.33
5.	12.00	41.67
6.	6.00	50.00
7.	6.00	58.33
8.	6.00	66.67
9.	6.00	75.00
10.	6.00	83.33
11.	6.00	91.67
12.	4.50	100.00

Table 5: Flow-Duration Curve by Class Interval Technique

Class, I	Class mark x_i	No. of Occurrences n_i	Cumulative Frequency	% of time $\frac{\text{Cum. frequency}}{\text{no. of data}} \times 100$
0-5	2.5	1	12	100
5-10	2.5	6	11	91.60
10-15	12.5	2	5	41.67
15-20	17.5	1	3	25.00
20-25	22.5	0	2	16.67
25-30	27.5	1	2	16.67
30-35	32.5	0	1	8.33
35-40	37.5	0	1	8.33
40-45	42.5	1	1	8.33

References:

1. P.S. Nigam, Handbook on Hydro Electric Engg, Nem Chand & Bros., Roorkee
2. Small Hydro Stations (Publication No. 175), Central Board of Irrigation and Power, New Delhi
3. R.S. Vashney, Hydropower Structures, Nem Chand & Bros., Roorkee

2.11 HYDROLOGICAL CYCLE, HYDROGRAPH, FLOOD DISCHARGE ESTIMATION

2.11.1 Definition and Scope

The word hydrology is derived from the Greek words hydor, which means water, and logos, which means science. Thus in this broad sense hydrology is the science which is concerned with all waters on Earth, its occurrence, distribution and circulation, its physical and chemical properties, its effects on the environment and on life of all forms. However, in customary usage, the word hydrology is rather used in a restricted sense in many respects. For example, it may not cover all studies of ocean waters and it is not concerned with medical uses of water. There are various elaborate definitions of hydrology. But from the view point of practical applications, Wisler and Brater have aptly defined hydrology as the science that deals with processes governing the depletion and replenishment of water resources of the land areas of the earth. It is concerned with the transportation of water through the air, over the ground surface and through the strata of the earth. It is the science that treats of the various phases of the hydrologic cycle. Since, hydrology is a science that underlies the development and control of water resources it has its important influence on Agriculture, Forestry, Geography, Watershed Management, Political Science, Economics and Sociology. It has practical applications in Structural Design, Water Supply, and Irrigation (through use of surface and ground waters), Wastewater Disposal and Treatment, Drainage, Hydropower, Flood Control, Navigation, Erosion and Sediment Control, Salinity Control, Pollution Abatement, Recreational uses of water, Fish and Wild Life Preservation, Insect Control and Coastal Works.

2.11.1.1 Hydrologic Cycle

Water exists on planet earth in its three forms viz. gaseous, liquid and solid forms and is circulated mainly by Solar and Planetary forces. The Sun provides the energy for the evaporation of sea water and earth's gravitational field and coriolis force contributes to the circulation of water. The different paths through which the water in nature circulates are the three parts of the total earth system, namely, Atmosphere, Hydrosphere and Lithosphere. The atmosphere is the gaseous envelope above the hydrosphere. Hydrosphere is the bodies of water that cover the surface of the earth. Lithosphere is the solid rock below the hydrosphere. The activities of water extend through these three parts of the earth system from an average depth of about 1 km in the lithosphere to a height of about 15 km in the atmosphere.

Most of the earth's water sources, such as, rivers, lakes, oceans and underground sources, etc. get their supplies from the rains, while the rain water in itself is the evaporation from these sources. Water is lost to the atmosphere as vapour from the earth, which is then precipitated back in the form of rain, snow, hail, dew, sleet or frost, etc. This evaporation and precipitation continues for ever, and thereby, a balance is maintained between the two. This process is known as Hydrologic Cycle.

The hydrologic cycle can be represented in many different ways in pictorial or diagrammatic forms. It depends on the view point it represents and is simplified in general as it is difficult to represent all aspects of the cycle. Fig. 1 is a descriptive representation of the hydrologic cycle where many of the details are skipped. Though these figures are self-explanatory, a detailed qualitative description of the hydrologic cycle is given below.

The hydrologic cycle has no beginning or end as the water in nature is continuously kept in cyclic motion. However, for the purpose of description the cycle may be visualised to commence with the precipitation from the atmosphere. Precipitation may take place in liquid form as rain and also in solid form as hail, snow, dew, frost etc. While precipitation is taking place, a part of it may evaporate and reach back the atmosphere. Some more precipitation is intercepted by the trees and vegetation and the rest of it only would reach the ground. The intercepted precipitation eventually evaporates into the atmosphere. The precipitation reaching the ground surface is called the throughfall. Considerable portion of the throughfall gets infiltrated into the ground and that in excess of infiltration would be detained temporarily on the ground before it becomes overland flow and subsequently surface runoff. The precipitation falling directly over the streams is called the channel precipitation and it readily becomes runoff without any delay.

The precipitation falling on the water bodies like ponds and lakes may be disposed of either as surface runoff to streams if the water bodies overflow or as evaporation or as infiltration. The evaporation would also be taking place from stream surfaces.

The infiltrated water may be distributed in different ways. First, it supplies moisture to the vegetation and after utilising it for the sustenance of their life, the vegetation sends this moisture back into the atmosphere through the leaves by a process known as transpiration. Secondly, the infiltrated water may percolate deep and become groundwater supply to surface streams known as the groundwater runoff (Fig. 2 and 3), or it may become groundwater supply to oceans. The groundwater runoff is sometimes referred to as the baseflow or the interflow. The total streamflow which is the sum of the surface runoff and the groundwater runoff ultimately joins the oceans wherefrom it again evaporates into the atmosphere thus completing the hydrologic cycle. The entire cycle repeats when the atmospheric moisture

precipitates on to the ground after cloud formation. Thus the hydrologic cycle consists of various complicated processes such as precipitation, interception, evaporation and transpiration, infiltration, percolation, storage and runoff.

2.11.1.2 Importance of Hydrology

The basic knowledge of this science is a must for every civil engineer, particularly the one who is engaged in the design, planning or construction for irrigation and hydropower structures, bridges and highway culverts, or flood control works, etc. Some of the various questions, which this science will be called upon to answer, while designing the above engineering feats, are:

- (i) What maximum flows, after different years, are executed at a spillway or a highway culvert, in a city drainage system ?
- (ii) What minimum reservoir capacity will be sufficient to assure adequate water for irrigation or municipal water supply, during droughts ?
- (iii) How much quantity of water will become available at a reservoir site, and when will it become available ? In other words, what will be the available possible supplies at the reservoir site ?
- (iv) What effects on the river water levels will be produced, after the construction of proposed reservoirs, levees, or any other controlling structures ?

Generally, specialist hydrologists are rarely employed for answering such questions ; and the civil engineers, responsible for the planning, design and construction of hydraulic structures, are themselves required to answer them; thereby making it an imperative upon them to gain a thorough knowledge of Hydrology. Only then, they will be able to design efficiently and economically functioning hydraulic structures.

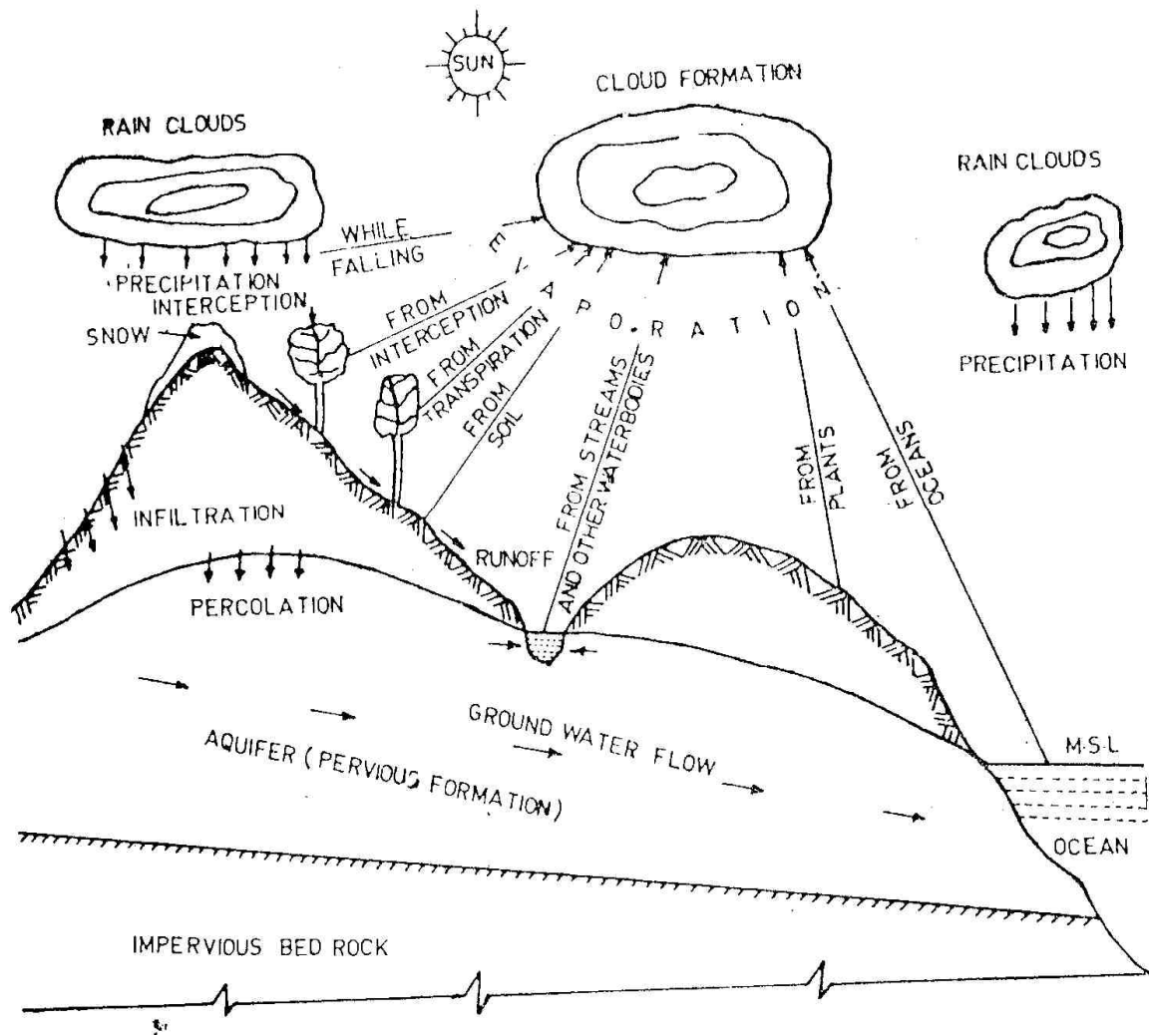


Fig. 2.27: Descriptive representation of hydrologic cycle

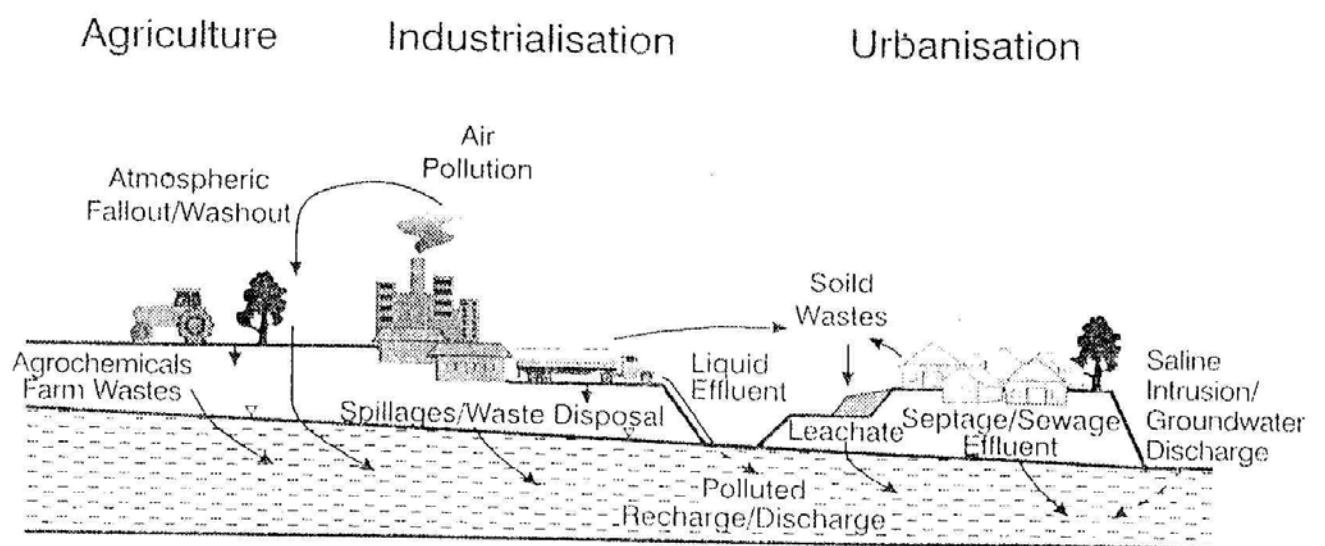


Fig. 2.28: Ground water movement

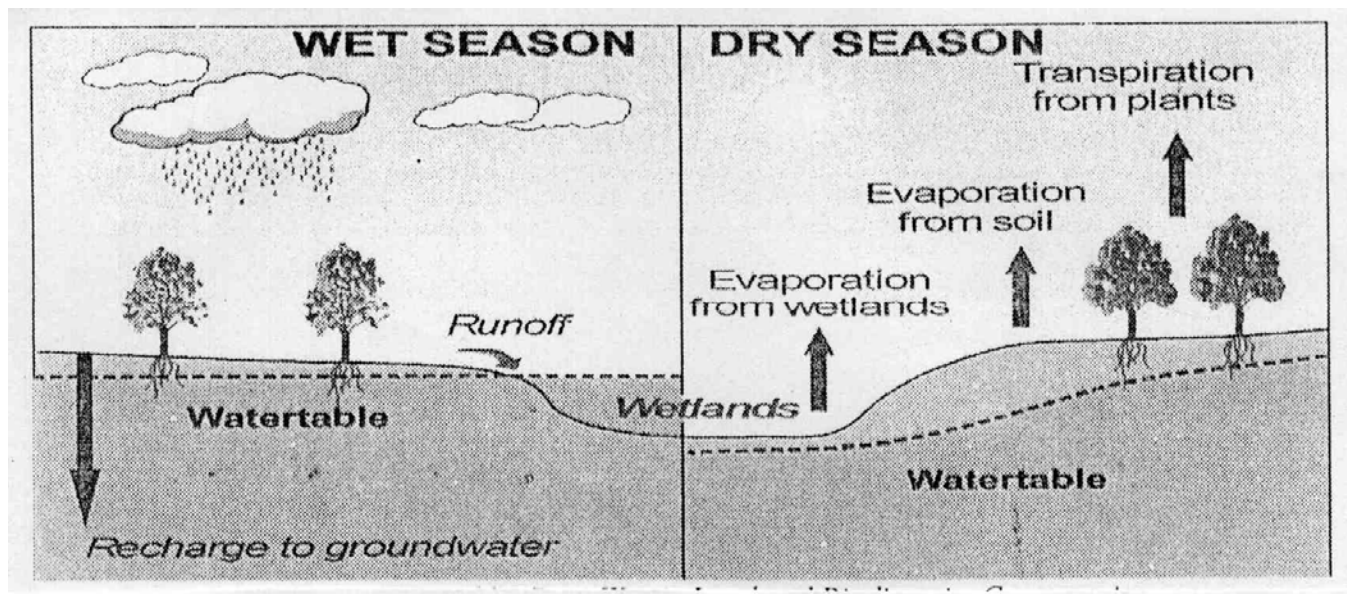


Fig. 2.29: Ground water base flow

2.11.2 Runoff

The portion of precipitation which appears in the surface streams of either perennial or intermittent nature is called the runoff. This is the flow collected from a drainage basin and appearing at an outlet of the basin. In a general sense it is the precipitation excess after meeting the evapotranspiration demands. While the precipitation is sporadic and irregular in nature, the runoff is more uniform compared to precipitation. This contrast between precipitation and runoff is due to the storage effects of the surface layers of the earth.

Runoff is usually expressed as volume per unit time, the common unit being m^3/s or cumec. When runoff from different drainage basins is to be compared, a convenient way of expressing the runoff is, perhaps, cumec/sq. km. Runoff may also be expressed as depth equivalent over a basin, that is, mm/day, mm/month or mm/year. This is a particularly useful unit for comparing runoff rate or runoff volume with precipitation since precipitation is almost invariably expressed in this way. According to the source from which the flow is derived, the total runoff is visualised to consist of surface runoff, subsurface runoff, and groundwater runoff.

Before reaching the ground a small portion of precipitation evaporates and joins back the atmosphere while another small portion is intercepted which also eventually becomes atmospheric moisture through evaporation. This portion is usually small and insignificant in the runoff analysis. The remaining precipitation reaching the ground is called the throughfall. It may fall either on land surface or directly on to the water surfaces of streams, lakes, and reservoirs. The precipitation falling on water surfaces is called channel precipitation and it immediately becomes the streamflow. A very small fraction of the precipitation falling on the land surface may be absorbed in the storage like small ponds, swamps etc., before it becomes evaporation and infiltration. This is called the depression storage. The rest of the precipitation falling on land surface, after satisfying the infiltration demand, is temporarily detained on the ground surface and when sufficient depth is built-up it travels over the ground surface

towards the stream channels either as quasi-laminar sheet flow or in the form of minor rivulets. This is called the overland flow. The overland flow ceases shortly after the rainfall stops. Surface runoff may then be defined as that part of the total runoff which travels over the ground surface to reach a stream channel and then through the channel to reach the basin outlet. It is the combination of the overland flow and the channel precipitation.

Water which infiltrates the soil surface and then moves laterally through the upper soil horizons towards the stream channels above the main groundwater table is known as the interflow. It is also known as subsurface runoff, subsurface storm flow, storm seepage, and secondary base flow. If the lateral hydraulic conductivity of the surface layers is substantially greater than the overall vertical hydraulic conductivity, it is a favourable condition for the generation of interflow. Generally interflow moves more slowly than surface runoff and therefore it may take longer period to reach the stream. In certain formations a part of interflow may enter the stream rapidly.

The infiltrated water which percolates deeply becomes groundwater and when groundwater table rises and intersects the stream channels of the basin it discharges into streams as the groundwater runoff. Since the movement of groundwater is very slow the groundwater runoff to streams may lag behind the occurrence of precipitation by several days, or weeks. The groundwater flow also tends to be very regular and in general it represents the main long-term component of total runoff and is particularly important during dry spells when surface runoff is absent.

For the practical purpose of analysis total runoff in stream channels is generally classified as direct runoff and base flow. The direct runoff or the quick flow is that part of runoff which enters the stream promptly and is equal to the sum of surface runoff and rapid interflow. This clearly represents the major runoff contribution during storm periods and is also the major contribution to most floods. The baseflow is defined as the sustained or fair-leathered runoff and it is composed of groundwater runoff and delayed interflow. Some hydrologists prefer to include the entire interflow as a part of base flow. The distinction between direct runoff and base flow is on the basis of time of arrival of the runoff in the stream rather than on the path followed by the runoff.

The- precipitation excess is that part of total precipitation which contributes directly to the surface runoff. When the precipitation is in the form of rainfall only it is known as rainfall excess. That part of precipitation which contributes to the direct runoff may be called the effective precipitation or effective rainfall if only rainfall is involved.

2.11.3 Hydrograph

The runoff measured at the basin outlet, when plotted against time gives the hydrograph. In other words it is the time distribution of runoff produced by a given precipitation on a basin. As the runoff includes the contributions from surface runoff, interflow and groundwater runoff, the hydrograph can be regarded as an integral expression of the physiographic and climatic characteristics that govern the relations between rainfall and runoff. Thus it forms a basis to relate rainfall and the time distribution of runoff produced by it. Detailed analysis of flood hydrographs is usually important in flood control and flood forecasting, or in establishing design flows for hydraulic structures which must pass flood waters.

The shape of a hydrograph resulting from a single short duration storm occurring over the drainage area follows a general pattern. If the subsequent storm burst does not occur before the direct runoff of the present storm, ceases, a typical single peaked hydrograph as shown in Fig. 1 results. Such a storm is known as an isolated storm. On the other hand if the next rainfall occurs before the direct runoff of the pervious rainfall ceases, there will be a multi-peaked hydrograph. Such a storm may be called a complex storm. A complex hydrograph may be resolved into the corresponding simple hydrographs. However, single peaked hydrographs resulting from isolated storms are generally preferred for hydrograph analysis.

As shown in Fig. 1, a typical single peaked hydrograph produced by an isolated storm consists of a rising limb, a crest segment and a recession limb. The rising limb BC has a well defined point of rise B followed by increasing discharge. The crest segment CE contains the peak discharge within it, and from E it is the recession limb with decreasing discharge. The recession limb is also known as falling limb or the depletion curve. Points C and E are the inflection points on the rising and recession limbs, respectively. The segment AB is called the approach segment which indicates the base flow in the river prior to the storm.

The shape of the rising limb depends mainly on the duration and the intensity distribution of rainfall, and to some extent on the antecedent condition and the shape of the basin. The peak discharge, included in the crest segment, represents the highest concentration of runoff from the basin. It occurs usually at a certain time after the rainfall has ended and this time depends on the aerial distribution of rainfall. The point of inflection on the recession limb is commonly assumed to mark the time at which surface inflow to the channel system or the overland flow ceases. Thereafter the recession curve represents withdrawal of water from storage within the channel system. Therefore, it is more or less independent of variations in rainfall and infiltration. On large basins where the storms produce rainfall only locally the shape of the recession curve may vary from storm to storm. The recession curve is also called a depletion curve since it represents the depletion from the channel-storage.

Though there are number of equations to describe the recession curve, the following is most generally used.

$$Q_t = Q_o K_r^{(t-t_o)} \quad (1)$$

or
$$Q_t = Q_o e^{-a(t-t_o)} \quad (2)$$

where Q_o and Q_t are the flows at time t_o and t and K_r is a recession constant with a value of less than unity, and $a = -\ln K_r$. The value of the recession constant K_r depends on the time unit selected.

The recession curve starting from E represents the depletion from the channel storage. When the direct runoff ceases after some time, it represents the depletion from groundwater storage since the discharge in the stream then is essentially due to base flow. When a time unit of one day is adopted the value of K_r for the direct runoff recession curve will be between 0.05 to 0.20 and for the base flow recession curve it will be between 0.85 to 0.9.

2.11.4 Flood flow estimation using empirical formulae

Many formulae have been devised for purpose of estimating flood flows. They can be safely applied to the areas for which they were specifically derived, but some of them have found a general existence. But these formulae must be used with great prudence and must never be used unless their origin has been investigated. No particular formula will give precise results for all the places. This is because of the fact that the magnitude of the flood of a given frequency depends upon fifteen to twenty factors, and no formula involves all these variables. Hence, a formula involving only two or three variables in place of twenty variables, cannot be expected to give generalised precise results. Some of these important formulae are given below:

(a) The formula involving drainage area only.

(i) **Dicken's Formula:** This formula is generally useful for the catchments of North India.

$$\text{It states that } Q_p = CA^{3/4} \quad (3)$$

where Q_p = High flood or peak discharge in cumecs.

A = Catchment area in sq. kilo metres.

C = Constant depending upon all those fifteen to twenty factors affecting high flood discharge.

The value of C must be ascertained for each catchment depending upon the nature of the catchment and the intensity of rainfall. An average value of C equal to 11.5 is generally used, and it should be increased for hilly catchments, and vice-versa. Secondly, for the same type of catchment, greater is the rainfall, greater will be the value of C and vice-versa.

(ii) **Ryve's formula:** This formula is almost similar to that of Dicken's, the only difference is in the values of the constants. It is applicable to South Indian catchments, and states that

$$Q_p = C_1 A^{2/3} \text{ in cumecs} \quad (4)$$

where Q_p , C_1 , and A have the same meaning as in Dicken's formula.

The average value of C_1 to be used is 6.8, with less value for flat catchments and more for hilly catchments. Different values of C_1 must be ascertained for different catchments, as given below:

Location of Catchment	Values of C_1 in Ryve's formula
Area within 80 km from the coast	6.8
Area within 80-2400 km from the coast	8.8
Limited areas near hills	10.1
Actual observed values are	Upto – 40

(iii) **Inglis' formula:** This is applicable to fan-shaped catchments in old Bombay state. It states that

$$Q_p = \frac{123 A}{\sqrt{A + 10 \cdot 4}} \text{ in cumecs} \approx 123\sqrt{A} \quad (5)$$

where A = The area of the catchment in sq. kilometers.

- (iv) **Nawab Jung Bahadur formula:** This has been derived for Hyderabad Deccan catchments. It states that

$$Q_p = C.A'^{[0.92 - (1/14) \log A]} \text{ in cumecs} \quad (6)$$

$C = 48$ to 60 , maximum value 86
 $A' = \text{Area in square miles} = 0.39 A$

Where A = Area in sq. km.

This formula is widely used in India.

- (v) **W.P. Creager's formula:** This formula was evolved by Creager from the study of flood peaks in U.S.A. It states that

$$Q_p = C.A'(0.894A'^{-0.048}) \text{ in cumecs} \quad (7)$$

where $C = 40$ to 130 ; lower values for ordinary floods, and higher values for intense and acute floods.

$A' = \text{catchment area in sq. miles} = 0.39 A$

where A is the catchment area in sq. km.

- (vi) **Jarvis formula:** It states that

$$Q_p = C\sqrt{A} \text{ in cumecs} \quad (8)$$

where C varies between 177 as minimum and 177 as maximum. Limiting or 100 percent chance floods are given by the value of C of 177 .

- (vii) **Modified Myer's formula:** It states that

$$Q_p = 177 p\sqrt{A} \text{ in cumecs} \quad (9)$$

where p has a value of unity for stream that has the greatest flood flow of the area. For any other stream, p is the fraction that the flood flow of that stream is, of the maximum given above. For different streams, values of p vary from 0.002 to 1.0 ; usually taken as 1 .

- (b) **Formulas Involving Drainage Area and its Shape**

The previous formulae were based only upon the more important variable, i.e., the area of the drainage system. But here are presented certain formulae making use of the area as well as the shape of the basin.

- (i) **Dredge or Burge formula:** It is based on Indian records and states that

$$Q_p = 19 \cdot 6 \frac{A}{L^{2/3}} \text{ in cumecs} \quad (10)$$

where A and Q_p have the same meaning, and L is the length of the drainage basin in kilometres.

If B is the average width of the basin in km; then

$$A = B \cdot L$$

The above formula can then be reduced to,

$$Q_p = \frac{19 \cdot 6 (B \cdot L)}{L^{2/3}} = 19.6 B \cdot L^{1/3}$$

- (c) Formulae Involving Rainfall and Drainage Area Variables:

- (i) **Pettis formula:** It was originated for Northern United States, Ohio to Connecticut, by Pettis, and it states that

$$Q_p = C (P \cdot B^{5/4}) \quad \text{cumecs} \quad (11)$$

where P = Probable 100 year maximum 1 day rainfall in cm.

B = Average width of the basin in kilometers

C = Constant and is equal to 1.5 for humid areas and 0.2 for desert areas.

This formula is generally applicable to areas ranging from 1,600 to 16,000 square kms, with no storage effect and fairly uniform width. If the area is wider at the lower end, the formula gives too small results, and if it is wider at its upper ends, the results obtained are too large. A correction of 10 to 13 percent may be required for width variations.

- (d) Formulae Involving Total Runoff and Drainage Area:

- (i) **Boston Society of Civil Engineers Formula:** The committee on floods of Boston Society of Civil Engineers made a study of floods, and based on the new England flood of November 1927, it stated that

$$q_p = 0.0056 \cdot \frac{D}{t} \quad (12)$$

where q_p = peak flow in cumecs/square km

D = Total depth of flood runoff on the basin in cm.

t = Total flood period in hours or the base of the flood hydrograph.

This formula was evolved by assuming the flood hydrograph as a triangle.

This formula was found to give reasonable satisfactory results when checked for numerous rivers. It was also found that the base of the hydrograph, i.e., t remains almost constant irrespective of the size of the flood.

Where no flood hydrographs are available, the committee suggested

$$q_p = \frac{C_F D}{\sqrt{A}} \quad (13)$$

$$\text{or } Q_p \frac{C_F D A}{\sqrt{A}} = C_F D \sqrt{A} \quad (14)$$

where C_F = Coefficient of the stream or flood characteristics generally varies from 0.7 to 3.5, but upto 7 in mountains and less than 0.7 for very flat streams.

A = drainage area in sq.kms.

Q_p = Peak flow in cumecs

For new England, values of D generally varies from 7.5 cm to 15 cm for occasional floods to rare floods, and is not over 20 cm even for maximum floods.

(e) Formulae Involving Rainfall Intensity and Drainage Area

(i) Rational method: This is the oldest and best known formula for determining peak flow from a given catchment, and has been extensively used for the storm-sewer designs.

$$Q_p = \frac{1}{36} (K p_c A) \quad (15)$$

where K = The percentage of rainfall that becomes surface runoff, called runoff coefficient.

2.11.5 Mass curve (ripr diagram)

A mass curve of inflows at a reservoir (refer Fig. 1) is a time plot of cumulative inflows obtained from an historical recorded inflows. For example, if $I_1, I_2, \dots, I_t, \dots, I_n$ is a historical record with time, the ordinates of the mass curve are given by

$$M_t = \sum_{n=1}^t I_n, \text{ where } t = 1, 2, \dots, N. \quad (16)$$

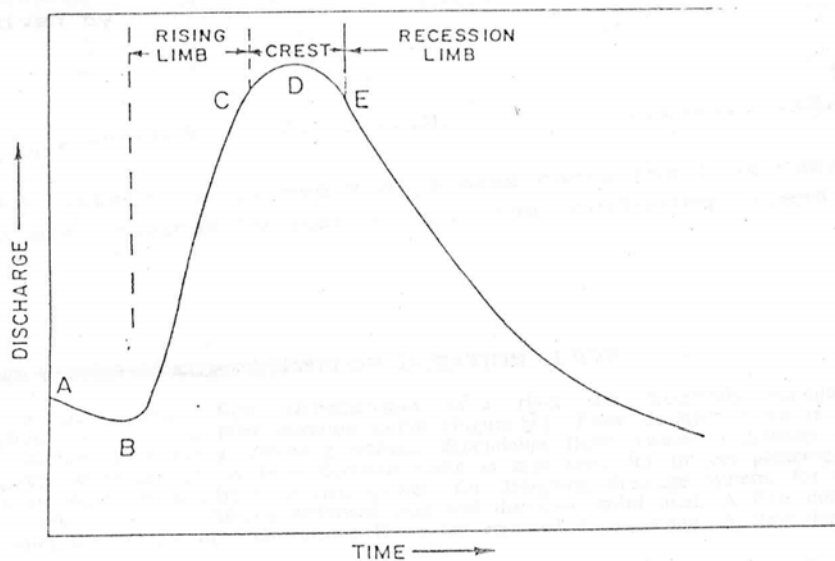


Fig. 1 Typical single peaked hydrograph

2.12 BANKING, MORATORIUM AND PPA

2.12.1 Banking

Developers can avail of the facility of banking of energy within fixed period spans of 2 months, which would be specified in the standard wheeling and banking agreement. The energy banked into the grid by the IPP shall be mentioned at "the average pooled purchase prepaid by UPCL" during the month of banking-in (into the UPCL system). The points of linking-in would be the interconnection point at which the developer would feed in the energy into UPCL system. The amounts so credited to the developer for the banked-in energy would be set off against the monetised valued of the banked out energy. The monetisation of the banked out energy shall be reckoned on the basis of the average pooled purchase price of electricity by the UPCL during the months of banking-out (of UPCL system). However, in addition, the loss incurred by UPCL on account of over-drawal during peak hours compared to input the system during the peak hours will be compensated by charging the IPP the average differential between the rate for HT consumers in the State for peak and non-peak hours for the net overdrawal against peak power banked. The banked out energy shall be deemed to have been delivered at the interconnection point. The developer would be required to pay the difference between monetised value of the banked-in and the banked-out energy and the peak period differential adjustment.

2.12.2 Moratorium

The moratorium period is the period during which borrowers is not obligated to pay any installment of loans or repay only interest on loan and the maximum moratorium period available in small hydropower Sector is upto three years. Term loan is to be repaid in quarterly/half yearly/yearly instalments, within a maximum period of 12 years (including moratorium period). The moratorium period will be defined well in advance. Moratorium is a legally authorized period of delay in the performance of a legal obligation or the payment of a debt. The purpose of the moratorium period is to ensure that adequate time is allotted to the

borrower to complete the construction activities and the plant goes to operation so the he may be able to repay his debt from the electricity generation.

2.12.3 Power Purchase Agreement

2.12.3.1 Some Relevant highlights of National Electricity Policy are as follows:

- i) Generation to be delicensed and captive generation to be freely permitted. Hydro projects would, however, need approval of the state governments and clearance from the Central Electricity Authority.
- ii) Transmission Utility at the Central as well as State level, to be a Government company-with responsibility for planned and coordinated development of transmission network. Provision for private transmission licensees.
- iii) The State Electricity Regulatory Commission is a mandatory requirement as per Indian Electricity Act 2003.
- iv) Trading as distinct activity is being recognized with the safeguard of the Regulatory Commission being authorized to fix ceilings on trading margins, if necessary.

2.12.3.2 Guidelines for Fixation of Purchase Price for Power Produced From Small Hydro Non-Conventional Energy

- i) The State Electricity Board will announce a base purchase price every year for the electrical energy purchased by it from non-conventional energy based power projects. These rates shall be valid from 1 st April to 31 st March of-the following year.

The base electrical energy purchase price valid for 1994-95 shall be a minimum of Rs. 2.25/ kWh.

The base prices shall be applicable to all non-conventional energy based power projects based on solar, wind, small hydro, biomass, etc. for which Power Purchase Agreements are signed during a year.

- ii) A promoter/developer shall be entitled to receive the base price set out in PPA for all electrical energy delivered from his project to the State grid for the duration of the Power Purchase Agreement. The rate shall be equal to the base price in the year of signing of PPA, escalated at a rate of 5% per year for a period of 10 years, from the date of signing of the Power Purchase Agreement. From the end of the 10th year, and for the remaining duration of the Power Purchase Agreement, the new purchase price shall be equal to the purchase price at the end of the 10th year, or the High Tension (HT) tariff prevalent in the State at that time, whichever is higher.
- iii) A monthly invoice shall be submitted by the promoter/developer to the State Electricity Board, at its designated offices, for the net electricity supplied by him to the Board. The Board shall make payment of amounts due, calculated at the purchase price for that particular year, within a period of 30 days.

The Board shall also provide facilities of an escrow amount or an irrevocable, transferable, divisible and confirmed standby letter of credit issued by State Bank of India, or another nationalized bank, acceptable to the promoter/developer. The

amount of the letter of credit shall be equal to the expected total of two years payment by the Board.

To ensure prompt realization of the dues, and in order to provide a security cover, the Board shall issue 'Electricity Credit Notes' to the promoter/developer equivalent to the amount of electricity received by the Board, whenever it is unable to pay in cash within the stipulated period. The Electricity Credit Notes shall be transferable to one or more High Tension consumers of the Board, who will be allowed to adjust the amount for which the Credit Notes have been issued, from their electricity bills due to the Board. The validity of Credit Notes shall be six months.

- iv) The duration of the Power Purchase Agreement shall be a minimum of 20 years, which could be extended by another 10 years, through mutual agreement.

2.12.3.3 Highlight of a typical power purchase agreement area given below

This power purchase agreement between PTC India Limited (formerly known as power trading corporation of India limited), a public limited company incorporated under the Companies Act, 1956, having its registered office at 2nd Floor, NBCC Tower, 15 Bhikaji Cama Place, New Delhi - 110066 (hereinafter referred to as "PTC", which expression shall, unless repugnant to the context or meaning thereof, be deemed to include its successors and permitted assigns); and

Swasti Power Engineering Limited, a limited liability company incorporated under the Companies Act, 1956, having its registered office at 120 0, Pocket - 4, Mayur Vihar I, Delhi -110091 (hereinafter referred to as the "Company", which expression shall, unless repugnant to the context or meaning thereof be deemed to include its successors and permitted assigns); and

Each of the above also individually referred to as the "**Party**", and collectively referred to as "**Parties**".

Whereas:

- (A) PTC has been established with an objective, *inter-alia*, to carry out in India and abroad, the business of purchase-of all forms of electrical power from independent power producers, captive power plants and other generating companies, state electricity boards, state government statutory bodies, licensees, power utilities, and sale of all forms of electrical power to the state electricity boards, power utilities, bulk consumers of power and other organizations buying power, whether in the private or public sector.
- (B) The Central Electricity Regulatory Commission (hereinafter referred to as CERC) constituted under the Electricity Act, 2003 has granted a licence to PTC to undertake inter State Trading in Electricity
- (C) The Company, a generating company as defined in the Electricity Act, 2003 is implementing the 22.5 MW (3 X 7.5 MW) capacity Bhilangana Hydro Electric Project (the "Project") in the District of Tehri Garhwal, Uttaranchal state along with a Tie Line for wheeling of power and energy through the state grid system and to deliver the power and energy from the above Units to the Delivery Point at the substation of the Power Grid Corporation of India Limited.

- (D) The Company has requested PTC to purchase the Delivered Power and Delivered Energy from the Project at Delivery Point.
- (E) PTC and the Company have entered into a memorandum of understanding on 23rd December 2003 for PTC to purchase, from the Company, such Delivered Power and Delivered Energy from the Project for a period of thirty five (35) years from the Commercial Operation Date of the Project, for onward sale on a long-term basis.
- (F) Subsequent to such memorandum of understanding the Company and PTC have agreed that the sale and purchase of power from the above project be based on single part fixed Tariff subject to certain terms and conditions for periodical limited adjustments and further PTC and the Purchaser have also agreed or will agree on the above scheme for sale and purchase of power based on single part fixed Tariff provided however such a scheme is duly approved by the Appropriate Commission(s).
- (G) Subject to the grant of the requisite approval by the Appropriate Commissions the Company and PTC desire to reduce the agreement reached between them to writing.

NOW THEREFORE, IN CONSIDERATION OF THE PREMISES AND MUTUAL AGREEMENTS, COVENANTS AND CONDITIONS SET FORTH HEREIN, IT IS HEREBY AGREED BY AND BETWEEN THE PARTIES AS FOLLOWS:

2.12.3.4 Principal Obligations of the Parties

The Company Obligations:

Notwithstanding anything to the contrary specified in this Agreement, the Company agrees and undertakes to:

- i) always be in compliance with Law and obtain and maintain in full force and effect all Consents and insurance coverage pursuant to this Agreement and Law, and if required by PTC, provide PTC with evidence, in a form satisfactory to PTC, that all such Consents have been duly obtained;
- ii) design, construct, complete, test, and commission the Project using only material and equipment that are new and of international/Indian utility-grade quality, and always in accordance with Prudent Utility Practices, in such a manner as to ensure that the useful life of the Project, with proper maintenance and operations, shall be at least equal to the Term of Agreement;
- iii) own the Project throughout the Term of Agreement, free and clear of encumbrances, except those permitted by Article 16.7.2.
- iv) ensure reliable availability of the Contracted Performance Parameters by use and application of Prudent Utility Practices, consistent with the technical limits and meet the Despatch Instructions throughout the Operation Period;

- v) ensure that the initial promoters retain the controlling shares in the Company till the fifth anniversary of the COD;
- vi) coordinate and cooperate with the Project State Transmission Utility, including with regards to any acquisition of land for construction and installation with regards to the Interconnection Facilities and to facilitate delivery of the power and energy to PTC at the Delivery Point; and
- vii) make available to PTC the Delivered Power and Delivered Energy at the Delivery Point throughout the Term of Agreement.

PTCs Obligations

PTC agrees and undertakes to:

- i) offtake all Delivered Power and Delivered Energy at the Delivery Point and pay Monthly Bills and Supplementary Bills, in accordance with this Agreement;
- ii) co-operate with the Company to facilitate the Performance Tests and Commissioning of the Units and the Project;
- iii) maintain trading license, as may be required under Law, for purchase and sale of Delivered Power and Delivered Energy; and.
- iv) arrange for due evacuation of Delivered Power and Delivered Energy from the Delivery Point

Right to Electrical Output

- i) The Company undertakes to, sell all the power and energy generated from the Project, upto the Contracted Maximum Capacity, to PTC at the Delivery Point, and PTC undertakes to purchase the Delivered Power and Delivered Energy at the Delivery Point and pay the Tariff in accordance with this Agreement for the Adjusted Delivered Power and Adjusted Delivered Energy supplied to PTC from the Project
- ii) PTC shall have the right to sell the Delivered Power and Delivered Energy to a party other than the Purchaser. This shall not relieve PTC's obligation to offtake Delivered Power and Delivered Energy from the Project and to make tariff payments to the Company.
- iii) The Company shall not grant or sell to any third party or allow any third party to obtain any entitlement to the Delivered Power and the Delivered Energy generated by the Project without the prior written consent of PTC, provided that such consent shall not be required upon the occurrence and during the subsistence of a PTC Event of Default under Article 15.2 or an Extended Force Majeure (where the Company is not the Affected Party or where PTC is unable to take delivery of the Delivered Power and Delivered Energy for any reason other than those attributable to the Company, in which case the procedure set out under Article 11.4 shall be followed).

- iv) Subject to Law, the Company shall not, during the Term of Agreement, use any electricity generated by the Project, except for the purpose of meeting the Project's auxiliary load.
- v) Notwithstanding Article 4.3.3, the Company may expand the capacity of the Project and enter into arrangements for the sale of power generated from such expansion to a third party, provided that:
 - (a) the obligations of the Company to deliver the Contracted Performance Parameters under this Agreement shall remain unaffected;
 - (b) PTC shall have the right of first refusal over the additional power generated by such expansion; and
 - (c) in the event that certain facilities of the Project are utilised by the expanded unit(s), suitable tariff adjustments shall be agreed to between PTC and the Company.

PTC's Observation Visits

PTC or its authorized representatives shall have the right, upon reasonable prior written notice to the Company (except that no such notice shall be required in an emergency), to observe the progress of the construction of the Project, the Commissioning of the Units or Project, as the case may be, or operation of the Project. The Company shall co-operate with all reasonable requests of PTC and assist in arranging any such observation visits to the Project and providing such information regarding the Project as may be reasonably requested by PTC. All such authorized representatives undertaking such observation visits on behalf of PTC shall comply with reasonable safety and other applicable procedures notified to them by the Company. The Company shall provide suitable accommodation for such authorized representatives.

Payment of Taxes

Each Party shall pay all Taxes applicable to it, and comply with all rules and regulations as regards such Taxes and not do or omit to do or cause or suffer to be done anything which could reasonably be expected to adversely affect or prejudice the interest and rights of the other Party in any manner whatsoever.

2.13 SERC – STATE ELECTRICITY REGULATORY COMMISSION

2.13.1 Central and State Electricity Regulatory Commission are set up in accordance with Indian Electricity Act, 2003. Relevant extracts from the act are given below:

Part X

Regulatory Commissions

Constitution, powers and functions of central commission

Constitution of Central Commission	76.(1)	There shall be a Commission to be known as the Central Electricity Regulatory Commission to exercise the powers conferred on, and discharge the functions assigned to, it under this Act.
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Functions of Central Commission	79.(1) The Central Commission shall discharge the following functions, namely:- (a) to regulate the tariff of generating companies owned or controlled by the Central Government; (b) to regulate the tariff of generating companies other than those owned or controlled by the Central Government specified in clause (a), if such generating companies enter into or otherwise have a composite scheme for generation and sale of electricity in more than one State; (c) to regulate the inter-State transmission of electricity ; (d) to determine tariff for inter-State transmission of electricity; (e) to issue licenses to persons to function as transmission licensee and electricity trader with respect to their inter-State operations. (f) to adjudicate upon disputes involving generating companies or transmission licensee in regard to matters connected with clauses (a) to (d) above and to refer any dispute for arbitration; (g) to levy fees for the purposes of this Act; (h) to specify Grid Code having regard to Grid Standards; (i) to specify and enforce the standards with respect to quality, continuity and reliability of service by licensees. (j) to fix the trading margin in the inter-State trading of electricity, if considered, necessary; (k) to discharge such other functions as may be assigned under this Act. (2) The Central Commission shall advise the Central Government on all or any of the following matters, namely - (a) Advise the Central Government on all or any of the following matters, namely:- (i) formulation of National electricity Policy and tariff policy; (ii) promotion of competition, efficiency and economy in activities of the electricity industry; (iii) promotion of investment in electricity industry; (iv) any other matter referred to the Central Commission by that Government. (3) The Central Commission shall ensure transparency while exercising its powers and discharging its functions. (4) In discharge of its functions, the Central Commission shall be guided by the National Electricity Policy, National Electricity Plan and tariff policy published under section 3.
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2.13.2 Main Functions of SERC are as follows:-

- i) Determine tariff for generation, supply transmission and wheeling of electricity: wholesale / bulk / rental/ within the State.
- ii) Regulate electricity purchase and procurement process of distribution licensees including the price for distribution and supply within the State.
- iii) Adjudicate upon disputes between licensees and generating companies for above.

- iv) Specify and enforce standards for quality, continuity and reliability of services by licensees.

2.13.3 Setting Standards

For transmission & Distribution Licensees

- By setting codes for operational performances; accounting and financial standard and commercial standard
- By license conditions
- By directions in tariff orders
- By miscellaneous orders

For Generation Company

- Tariff orders/miscellaneous orders

2.13.4 Grid code (grid standard) for transmission license

- i) Optimum scheduling and despatch of electricity in accordance with the contracts.
- ii) Disciplined grid operations;
- iii) Keeping accounts of the quantity of electricity transmitted through the State grid;
- iv) Supervision and control over the transmission system.

2.13.5 Distribution Code (For Distribution licensee)

The Distribution Code shall be designed so as to permit the development, maintenance and operation of an efficient, coordinated and economical Distribution System

2.13.6 Distribution system planning and security standards

For planning and operation of Distribution System so as to ensure availability of adequate generating capacity, the system is capable of providing Consumers with a safe, reliable and efficient Supply of electricity.

2.13.7 Overall performance standards (For Distribution licensee)

For conducting Distribution and Retail Supply Business in the manner which it reasonably considers to be best calculated to achieve the Overall Performance Standards in connection with providing of electricity Supply services and the promotion of the efficient use of electricity by Consumers.

2.13.8 Obligation to connect consumers

For new connections on the application of the owner or occupier of any premises within the Area of Supply, give connection of the Licensee's Distribution System for the purposes of providing a Supply of electricity to those premises, including the laying of any required Distribution mains

2.13.9 Obligation to Supply and Power Supply Planning Standards

For taking all reasonable steps to ensure that all Consumers connected to the Licensee's Distribution System receive a safe, economical and reliable supply of electricity.

2.13.8 Consumer services

- a) Code of practice on payment of bills
- b) Complaint handling system
- c) Consumer rights statement

Consumer Rights Statement explaining to Consumers their rights as Consumers of the Licensee in its capacity as operator of its Distribution and Retail Supply Business

2.14 COST ESTIMATION

2.14.1 General

Cost of the scheme is worked out in sufficient details so as to arrive at realistic cost estimate. The cost of civil works is worked out for total proposed installation and type of turbine and generator. The estimates of quantities for civil works is prepared working out costs is as below:

- a. Rates for various components of civil structures are adopted on the basis prevailing schedule of rates for year fixed by local authorities and price obtained from manufacturers for the items, which are not included in the schedule. The rates of civil works are increased by the premium fixed by the authority upto date of preparation so as to arrive at present realistic cost. Cost escalation during construction period @ 10% on total cost of civil works is also included to take care of any cost inflation during construction.
- b. Provisions is also made for
 - i. Establishment charges at the rate of 10% percent of the cost of works.
 - ii. Audit and accounts charges at the rate of 1 percent of the cost of works.
 - iii. Losses on stock at the rate of 0.25 percent of the cost of civil works.
- c. Cost of electromechanical units including generator and control panels etc. is based on budgetary price quoted by several manufacturers in the country and experience. Cost of other equipments such as switchyard equipment, crane, ventilation system equipment etc. are based on local enquiry with equipment manufacturers.
- d. Duties, taxes, freight and insurance charges are included in the cost of electro-mechanical equipment. The estimates include inspection, erection and commissioning charges, losses on stock and maintenance during construction.

2.14.2 ABSTRACT OF COST

Abstract of item wise cost of civil and electromechanical works is worked out and as shown in table 1.

Table 1
Abstract of Project Cost

S.No.	Particular	Cost (Rs. in Lacs)
I.	Works	
1.	A-Preliminary	
2.	B-Land	
3.	C-Works	
4.	K-Building	
5.	M-Plantation	
6.	O-Miscellaneous	
7.	P-Maintenance	
8.	O-Special T&P	
9.	R-Communication (Approach road)	
10.	S-Power Plant	
11.	X-Environment and ecology	
12.	Transmission lines	
13.	Establishment 10% of I-Works excluding cost of land	
14.	Ordinary T&P 1% of I-Works	
15.	Losses on Stock 0.25% of C-Works	
16.	Suspense	
17.	Receipt and Recoveries	
18.	Indirect Charges	
	1% of I-Works for audits and accounts	

CHAPTER 3

MAIN PARTS OF HYDRO POWER STATION

3.1 INTRODUCTION

Hydro Electric development is a well established technology. Power plants with unit size of upto 5 MW are designed as a small hydro plants.

Type on Classification of Hydro projects is detailed in chapter 2.1.

Large hydro schemes are generally multi purpose i.e. combined benefit of irrigation flood control etc. small hydro power schemes are generally for economic power generation only. Tehri Dam Power Project is typical large multi purpose schemes for power generation and irrigation (fig. 3.1). Small hydro is shown in fig. 3.2.

3.1.1 Components of A Hydroelectric Scheme

Most of the hydro schemes in hilly areas in India are the high head and medium head and have the same basic and common components of a hydroelectric head. The major components of a hydro electric scheme are listed here under as (1) to (8).

- (1) Diversion and Intake structure
- (2) Water Conductor system
- (3) Desilting chamber
- (4) Forebay, Balancing Reservoir and Spilling arrangements
- (5) Penstock
- (6) Surge Tank (If necessary)
- (7) Power House Comprising of turbine, generator, inlet valve and other auxiliary systems like cooling water, drainage and dewatering systems, auxiliary power system and equipment, emergency and standby power system and equipment, lighting system and equipment, instrumentation protection and control system and equipment, ventilation system and equipment, station grounding, fire fighting equipment and system.
- (8) Tail Race Channel

The hydroelectric stations on irrigation canals and dams are generally low head schemes consequently have fewer components. Small hydro schemes on cooling water channel of thermal power stations are typically low head schemes.

3.1.2 Intake Structure

An intake structure is an arrangement by which water is diverted for the required use. The intake is an arrangement which allows water to be taken from its source and then discharged into the conveyance system from where it is led to the desired use (e.g. hydro electric power generation). Arrangements for routing high flood discharge are also made.

Based on operating heads intakes may be classified as: (a) Low head intake (b) Medium head intake and (c) high head intake.

3.1.3 Water Conductor System

3.1.3.1 Feeder Channel

This is provided from Intake! to desilting tank, and carry sediment ridden water. The velocity in the section should be enough, so that sediments present in water may not get deposited at channel bed.

3.1.3.2 Head Race Channel

This is provided from desilting tank to forebay tank. It carries silt free water. The channels may be of following types.

- Open channel (R.C.C., cut & cover & steel pipes are provided in reaches where the slopes are geologically unstable).
- R.C.C. cut & cover / concrete Hume pipe
- P.V.C./HDPE/Fibre Glass
- Steel pipe
- Tunnel
- Open channel could be trapezoidal with thin concrete lining -or rectangular with masonry or concrete walls.
- For access, provision needs to be made only for a bridle path to economies costs as also to avoid unnecessary hill slope cutting.
- Loss of water due to seepage - Data on same may be obtained for representative schemes so that its significance can be assessed.

3.1.4 Desilting and Sediment Controlling Actions

Sediment control by excluders or ejectors is accomplished by using following devices.

Settling basin is one of the most effective devices for removing sediment particles from the flowing water. The reduction in the velocity of flow in the settling basin is caused by expansion of the channel cross section over the length of the basin. Such reduction in the velocity also reduces the bed shear stress and the turbulence. Reduction in the velocity, shear stress and the turbulence, if adequate, stops the bed material from moving and also causes part of the suspended material to deposit. Once the minimum size of sediment to be removed has been decided, the design of the settling basin involves determination of the depth and length of the basin and choice of the method of removal of the deposited material.

3.1.5 Forebay Tank/Balancing Reservoir and Spilling Arrangements

The purpose of forebay tank/balancing reservoir is as follows:

- * Balancing storage Provide storage of 1,2 to 4 hours during off peak hours to supply the same during peak hours and thus meet variable demand justifying economics.
- * Forebay tank provides immediate water demand for starting the units (2-3 minutes capacity) and enough submergence of penstock intake to prevent vortex formation and air entry.
- * Suitable side spillway to provide safety to the system equal to design discharge.

3.1.6 Penstock

Various types of material are nowadays available for manufacturing the pipes which could be used as penstocks for hydropower development in the country. The merits and demerits of these pipes vary widely. For making selection of the type of pipe that should be used for a specific site, several factors such as basic cost, transportation and erection and availability of material and skill should be considered thoroughly and a comparative analysis shall lead to the designer to make some decision.

Design of Penstock : (1) Criterion for Hydraulic Design of Penstock IS : 11625-1986
(2) Criterion for structural design of Penstocks IS : 11639(PartI)-1986

The most common types of pipes which could be used as penstocks are :

1. Steel pipe
2. P.V.C.
3. Reinforced Concrete Pipe and Prestressed Concrete pipe

3.1.7 Surge Tank

Surge tanks are required to be provided on turbine penstock installations for speed regulation on the following important basis.

- i) Surge tanks are provided where the resulting reduction in water hammer pressure will provided a more economical turbine penstock installation.

- ii) A surge tank also be provided for the condition where computed percent of speed rise based on rejection of the entire rated load for a unit operating independently can not be reduced to about 35 percent by other practical methods. This is required for hydro unit meant for isolated operation. The speed rise parameter may be increase to about 45 percent for unit designed for system frequency regulation.

3.1.8 Tailrace Channel

Each unit has its own tailrace. Rectangular section with bed slope as per terrain is provided for the tailrace channel.

3.1.9 Power House

3.1.9.1 Layout

The following two types of hydropower plants are most common in India:

- (1) Low head power plants built into irrigation systems of canals and dams in the plains.
- (2) Comparatively high/medium head power plants in the mountain valleys on streams-rivers-tributaries (Fig.3.2) shows a small hydro power station.

3.1.9.2 Power Plant Auxiliary Equipment & Appurtenant Facilities

Space is to be provided in a powerhouse for the following auxiliary equipment and appurtenant faculties:

- a) Turbine governor and shut off valve
- b) Generator
- c) Unit and auxiliary power transformers
- d) Control cubicle and relaying equipment
- e) Neutral grounding cubicle and surge protection
- f) Station battery
- g) Cooling water system
- h) Drainage and dewatering system
- i) Ventilation
- j) Fire extinguishers
- k) Compressed air system
- l) Powerhouse crane/cranes

3.1.10 Design Calculation for civil work of typical high headAngong SHP are appended in Annexure-.1. these are prepared by Sh. M.K. Singhal S.S.O. AHEC, IIT Roorkee.

TEHRI DAM



Fig. 3.1



Fig. 3.2

3.2 HYDRAULIC TURBINES AND GOVERNORS

3.2.1 Classification and Types of Turbines

The hydraulic turbine is a mechanical device that converts the potential energy contained in an elevated body of water (a stream or reservoir) into rotational mechanical energy. Impulse or velocity wheel known as water mill is of great antiquity. Thousands of these are existing in the Himalayan region used for grinding grain. An Improved variety upto about 5 kW capacity is also used to generate electricity by belt coupling to increase speed and use standard generator. A typical water mill installation is shown in figure 3.2.1.

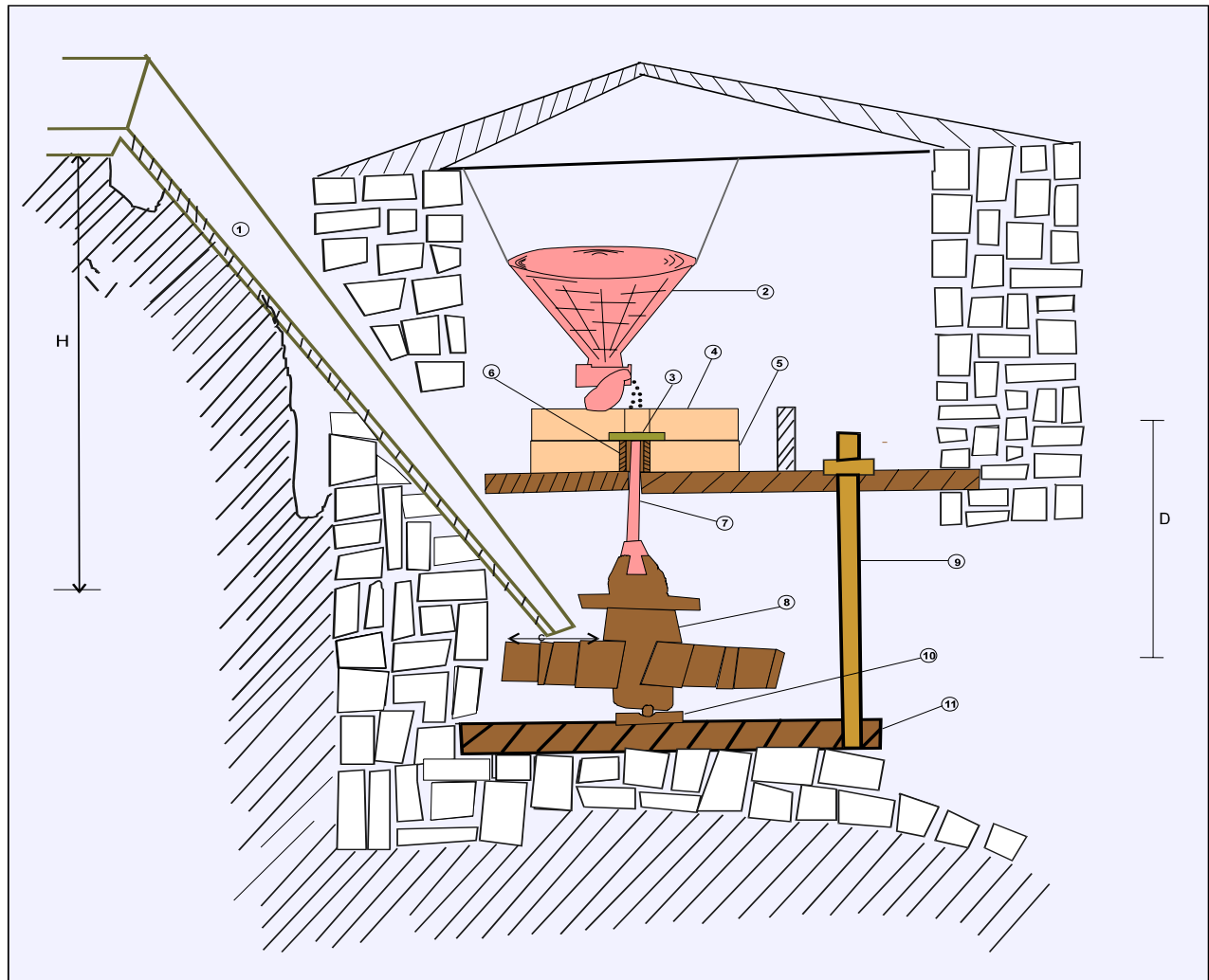


Fig. 3.3

- | | | | | |
|----------------------------|--------------------|---------------------------|-------------------------|-------------------------|
| 1. Flume | 2. Hopper | 3. Rynd/Cam | 4. Upper Grinding Stone | 5. Lower Grinding Stone |
| 6. Upper Bearing/Bush | 7. Shaft | 8. Runner with Hub | | |
| 9. Lifting Mechanism Lever | 10. Bottom Bearing | 11. Lifting Mechanism Bar | | |

Modern turbines are very efficient, long lasting, can be started quickly and can go from speed-no-load to full load in 4 to 10 seconds and can drop load instantly without damage.

Classification of turbines according to size is given in table 3.2.1.

Table- 3.2.1 (Classification of SHP)

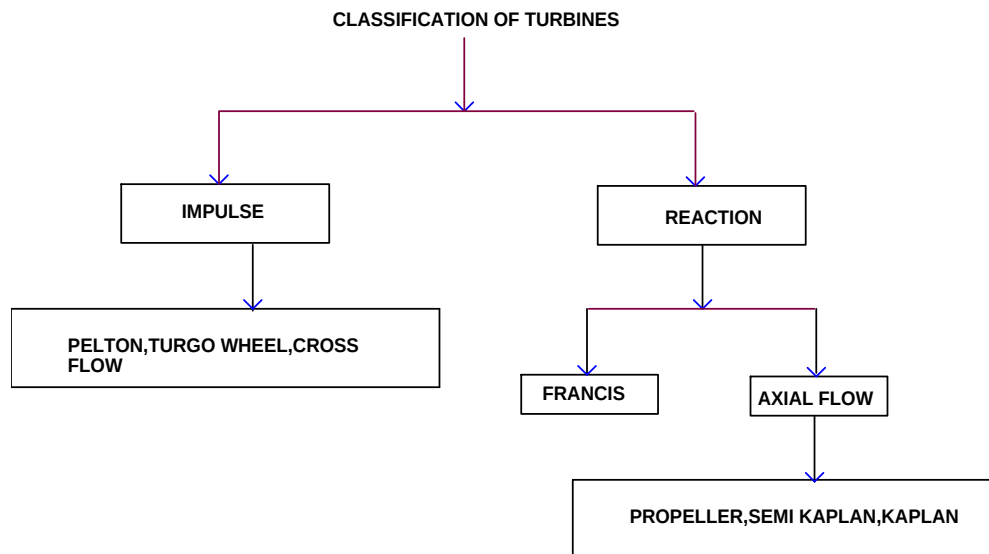
Class	Station Capacity
Micro	Up to 100 kW
Mini	101 kW to 2000 kW
Small	2001 kW to 25000 kW (unit size 5000 kW)
Large	Above unit size of 5000 kW

Turbines can be either reaction or impulse types. The turbines type indicates the manner in which the water causes the turbine runner to rotate. Reaction turbine operates with their runners fully flooded and develops torque because of the reaction of water pressure against runner blades. Impulse turbines operate with their runner in air and convert the water's pressure energy into kinetic energy of a jet that impinges onto the runner buckets to develop torque.

Reaction turbines are classified as Francis (mixed flow) or axial flow. Axial flow turbines are available with both fixed blades (Propeller) and variable pitch blades (Kaplan). Both axial flow (Propeller & Kaplan) and Francis turbines may be mounted either horizontally or vertically. Additionally, Propeller turbines may be slant mounted.

Classification of turbine according to type is given in table 3.2.2 and cross section of turbine of various types is shown in fig. 3.2.1. and typical installation shown in fig. 3.2.2.

Table – 3.2.2 (Classification of Turbines)



The net head available to the turbine dictates the selection of type of turbine suitable for use at a particular site. The rate of flow determines the capacity of the turbine. The term specific speed is generally used in classifying types of turbines and characteristics within type as shown in figure 3.2.3. Exact definition of specific speed is given later Impulse turbines have application in high head hydropower installations. Application of impulse turbine in low head range is limited.

Application range of the three types of turbine is overlapping as shown in figure 2.2. Description & Application of important turbine types is as follows:

3.2.2 Specific Speed

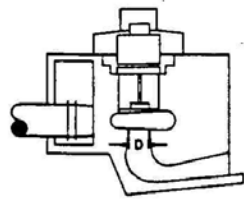
The term specific speed is often used in classifying types of turbines and characteristics of turbines within types. This term is specified as follows:

Specific Speed (Ns) – The speed in revolutions per minute at which the given turbine would rotate, if reduced homologically in size, so that it would develop one metric horse power at full gate opening under one meter head. It is given by (metric horsepower units)

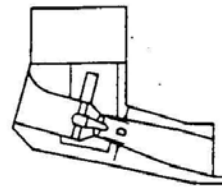
$$N_s = \frac{N_r \sqrt{P_r}}{H_r^{(5/4)}}$$

Where N_r = revolutions per Minute
 P_r = power in metric horse power at full gate opening
 H_r = rated head in m.

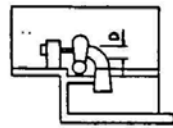
As shown in Figure 3.2.3, the specific speed value defines the approximate head range application for each turbine type and size. Low head units tend to have a high specific speed, and high-head units to have a low specific speed.



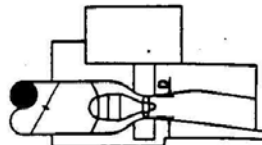
VERTICAL FRANCIS



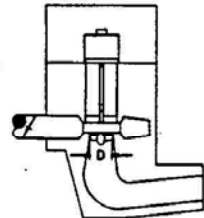
RIGHT ANGLE TUBE



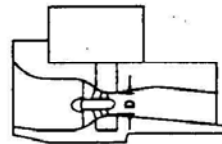
HORIZONTAL FRANCIS



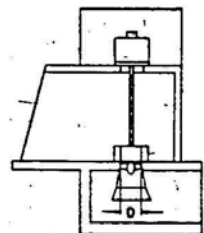
BULB



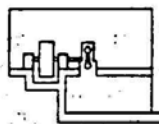
VERTICAL PROPELLER



RIM



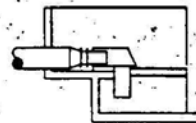
OPEN FLUME FRANCIS OR PROPELLER



HORIZONTAL PELTON



TUBE



CROSSFLOW (OSSBERGER)

Fig. 3.4

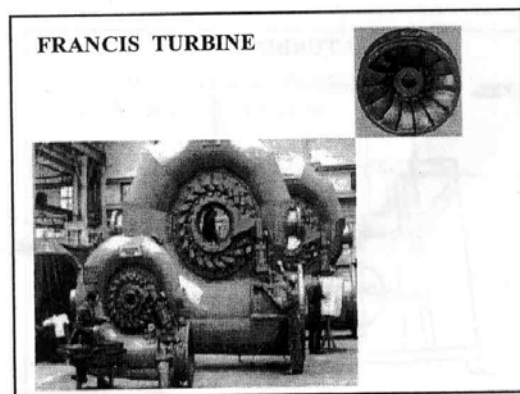
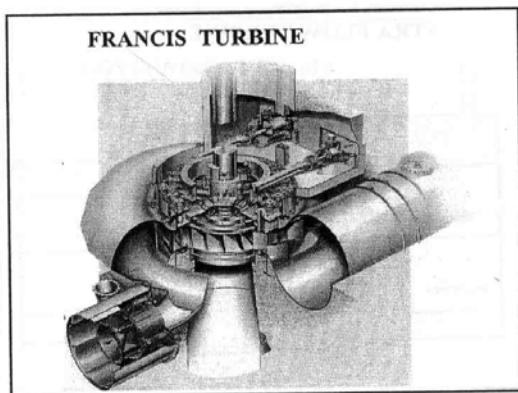
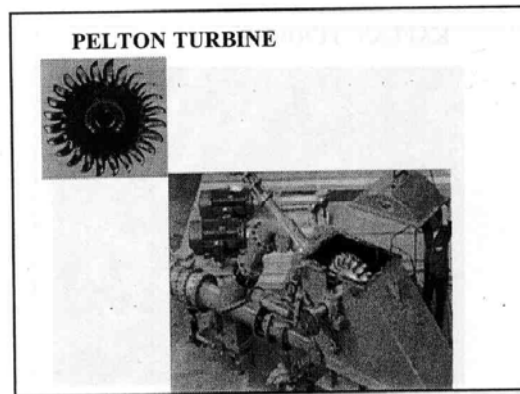
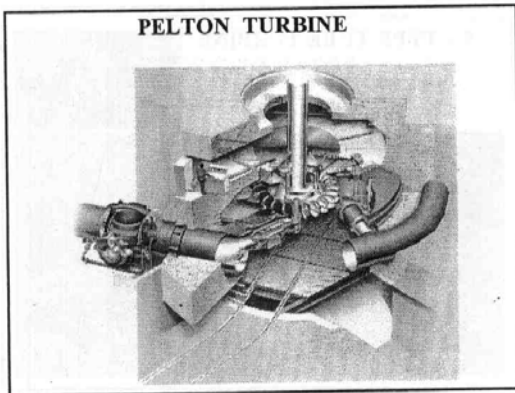
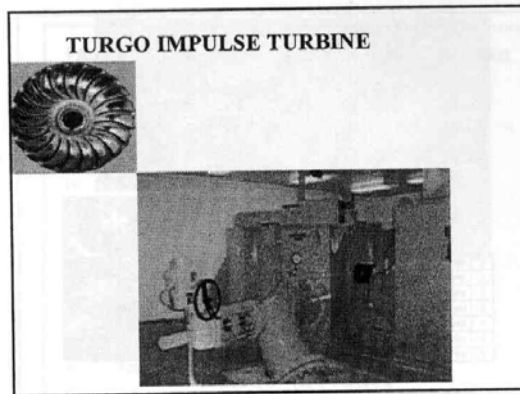
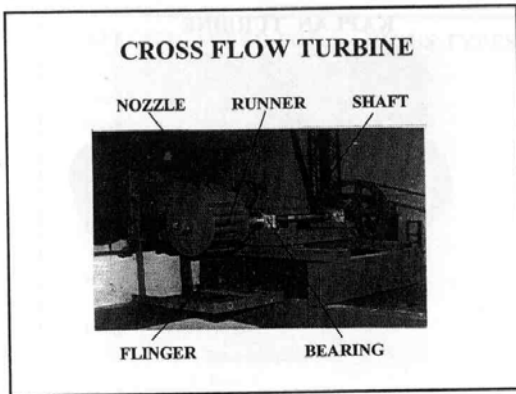
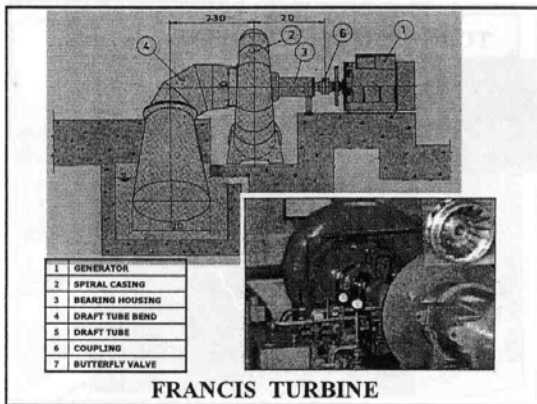
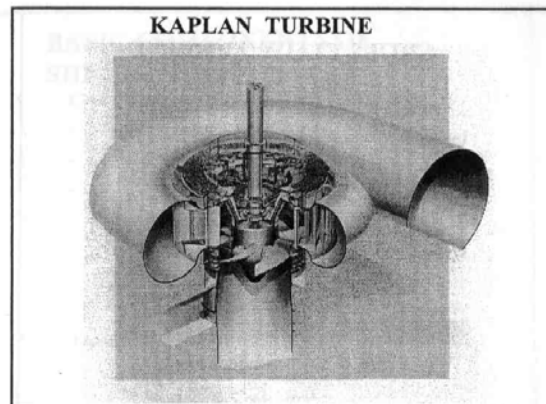


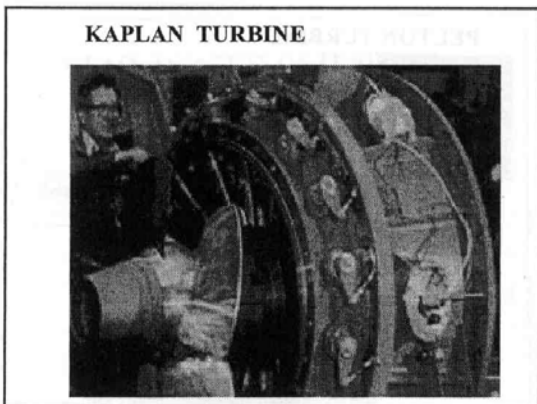
Fig. 3.5



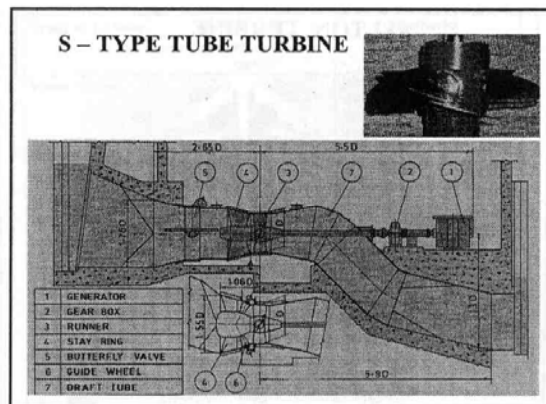
FRANCIS TURBINE



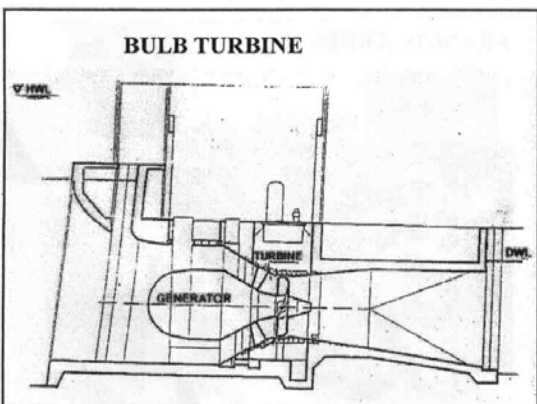
KAPLAN TURBINE



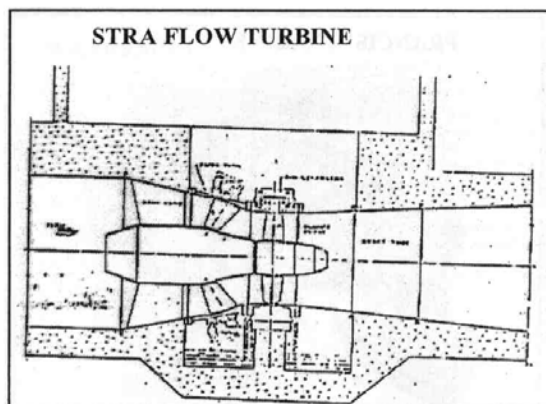
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S - TYPE TUBE TURBINE



BULB TURBINE



STRA FLOW TURBINE

Fig. 3.6

Reaction turbines are classified as Francis (mixed flow) or Propeller (axial flow). Propeller turbines are available with both fixed blades and variable pitch blades (Kaplan).

Impulse turbines have application for small hydropower installations in low head range.

Specific speed of various types of turbines is given in table 3.2.2.

Table 3.2.2

Types of Runner	N_s
Pelton	12 – 30
Turgo	20 – 70
Cross Flow	20 - 80
Francis	80 – 400
Propeller and Kaplan	340 - 1000

3.2.3 Francis Turbines

A Francis turbine is one having a runner with fixed buckets (vanes), usually nine or more, to which the water enters the turbine in a radial direction, with respect to the shaft, and is discharged in an axial direction. Principal components consist of the runner, a water supply case to convey the water to the runner, wicket gates to control the quantity of water and distribute it equally to the runner and a draft tube to convey the water away from the turbines.

It exists in large numbers throughout the world. It is applied at head ranges generally from about 15 to 750 meters and in power ranges from about 0.25 to 800 MW per unit. here are also numerous small units at very low heads, for example, 1.5 meters, and output, for example, 2 kW, but these are not typical of the current practice.

A Francis turbine may be operated over a range of flows approximately 40 to 105% of rated discharge. Below 40% rated discharge, there can be an area of operation where vibration and/or power surges occur. The upper limit generally corresponds to the generator rating. The approximate head range for operation is from 60 to 125% of design head. In general, peak efficiencies of Francis turbines, within the capacity range of 25 MW, will be approximately 88 to 90%. For higher capacities units efficiency is generally higher (93%). Relative efficiency of turbine types is shown in figure 2.3 and 2.4. The peak efficiency point of a Francis turbine is established at 90% of the rated capacity of the turbine. In turn, the peak efficiency at 60% of rated head will drop to near 75%.

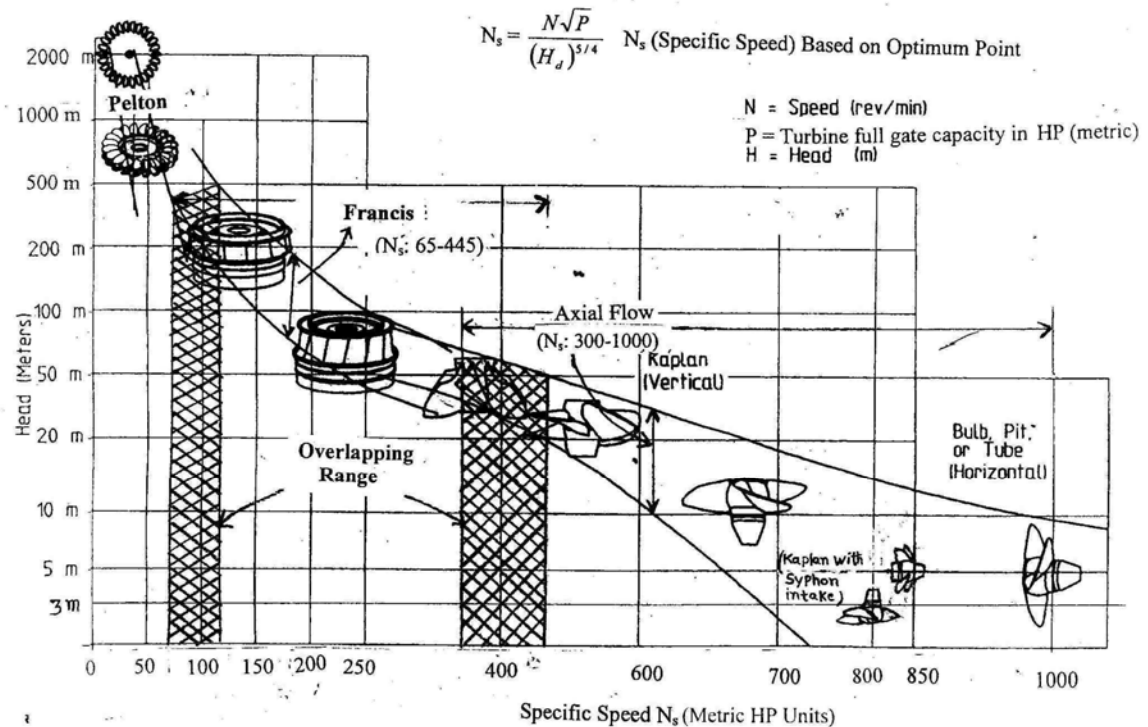


Fig. 3.7 N_s Versus Head. This figure shows the various turbine used a guideline, as there is overlap between the various turbine types as a function of specific speed (N_s) and head. This figure should be with respect to their operating ranges

The conventional Francis turbine is provided with a wicket gate assembly to permit placing the unit on line at synchronous speed, to regulate load and speed, and to shutdown the unit. The mechanisms of large units are actuated by hydraulic servomotors. Small units may be actuated by electric motor gate operations. It permits operation of the turbine over the full range of flows. In special cases, where the flow rate is constant, Francis turbines without wicket gate mechanisms may be used. These units operate in case of generating units in Micro Hydel range (upto 100 kW) with Electronic Load Controllers or Shunt Load Governors. Start up and shut down of turbines without a wicket gate is normally accomplished using the shut off valve at the turbine inlet. Synchronising is done by manual load control to adjust speed.

Francis turbines may be mounted with vertical or horizontal shafts. Vertical mounting allows a smaller plan area and permits a deeper setting of the turbine with respect to tailwater elevation locating the generator below tailwater. Generator costs for vertical units are higher than for horizontal units because of the need for a larger thrust bearing. However, the savings on construction costs for medium and large units generally offset this equipment cost increase. Horizontal units are often more economical for small higher speed applications where standard horizontal generators are available.

The water supply case is generally fabricated from steel plate. However open flume and concrete cases may be used for heads below 15 meters.

Francis turbines are generally provided with a 90-degree elbow draft tube, which has a venturi design to minimize head loss. Conical draft tubes are also available, however the head loss will be higher and excavation may be more costly.

3.2.4 Axial Flow Turbines

Axial flow turbines are those in which flow through the runner is aligned with the axis of rotation. Axial flow hydraulic turbines have been used for net heads up to 75 meters with power output up to 200 MW. However, they are generally used in head applications below 35 meters. S-turbines are used below 30 meters head and 8 MW capacity. Bulb and pit units can be used to about 25 meters head and 100 MW capacity. Specific mechanical designs, civil construction, and economic factors must be given full consideration when selecting among these three axial flow turbine arrangements.

A propeller turbine is one having a runner with four, five or six blades in which the water passes through the runner in an axial direction with respect to the shaft. The pitch of the blades may be fixed or movable. Principal components consist of a water supply case, wicket gates, a runner and a draft tube.

The efficiency curve of a typical fixed blade Propeller turbine forms a sharp peak, more abrupt than a Francis turbine curve. For variable pitch blade units the peak efficiency occurs at different outputs depending on the blade setting. An envelope of the efficiency curves cover the range of blade pitch settings forms the variable pitch efficiency curve. This efficiency curve is broad and flat. Fixed blade units are less costly than variable pitch blade turbines; however, the power operating ranges are more limited.

Turbine manufacturers have developed runner designs for a head range of 3 to 40 meters. Four blade designs may be used upto 12 meters of head, five blade designs to 20 meters and six blade designs to 35 meters. In general, peak efficiencies are approximately the same as for Francis turbines.

Propeller turbines may be operated at power outputs with flow from 40-105% of the rated flow. Discharge rates above 105% may be obtained; however, the higher rates are generally above the turbine and generator manufacturers' guarantees. Many units are in satisfactorily operation is from 60 to 140% of design head. Efficiency loss at higher heads drops 2 to 5% points below peak efficiency at the design head and as much as 15% points at lower heads.

The conventional propeller or Kaplan (variable pitch blade) turbines are mounted with a vertical shaft. Horizontal and slant settings will be discussed separately. The vertical units are equipped with a wicket gate assembly to permit placing the unit on line at synchronous speed, to regulate speed and load, and to shutdown the unit. The wicket gate mechanism units are actuated by hydraulic servomotors. Small units may be actuated by electric motor gate operators. Variable pitch units are equipped with a cam mechanism to coordinate the pitch of the blade with gate position and head. Digital control envisages Control of wicket gates and blade angle by independent servomotors co-ordinated by digital control. The special condition of constant flow, as previously discussed for Francis turbines, can be applied to propeller turbines. For this case,

elimination of the wicket gate assembly may be acceptable. Variable pitch propeller turbines without wicket gates are discussed in a subsequent section.

The water supply case is generally concrete. Either an open flume or a closed conduit type of construction may be used. Open flume construction may be economical when heads are below 13 meters. At higher heads the turbine shaft length becomes excessive. Also open flume construction is disadvantageous with regard to maintenance costs. The wicket gate assembly and guide bearing are water lubricated causing additional maintenance particularly when silt or debris is in the water. At capacities above 1500 kW, wicket gate and guide bearing loading are such that an open flume may not be a satisfactory choice. For closed conduits, spiral cases of steel or concrete may be used. The concrete case is generally less costly. The cross-section of a concrete case, taken in a direction radial to the shaft is usually rectangular.

The draft tube designs discussed for Francis turbines apply also to propeller turbines.

3.2.5 Tubular Turbines

Tubular or tube turbines are horizontal or slant mounted units with propeller runners. The generators are located outside of the water passageway. Tube turbines are available equipped with fixed or variable pitch runners and with or without wicket gate assemblies.

Performance characteristics of a tube turbine are similar to the performance characteristics discussed for propeller turbines. The efficiency of a tube turbine will be one to two % higher than for a vertical propeller turbine of the same size since the water passageway has less change in direction.

The performance range of the tube turbine with variable pitch blade and without wicket gates is greater than for a fixed blade propeller turbine but less than for a Kaplan turbine. The water flow through the turbine is controlled by changing the pitch of the runner blades.

When it is not required to regulate turbine discharge and power output, a fixed blade runner may be used. This results in a lower cost of both the turbine and governor system. To estimate the performance of the fixed blade runner, use the maximum rated power and discharge for the appropriate net head on the variable pitch blade performance curves.

Several items of auxiliary equipments are often necessary for the operation of tube turbines. All tube turbines without wicket gates should be equipped with a shut off valve automatically operated to provide shut-off and start-up functions.

Tube turbines can be connected either directly to the generator or through to a speed increaser. The speed increaser would allow the use of a higher speed generator, typically 750 or 1000 r/min, instead of a generator operating at turbine speed. The choice to utilize a speed increaser is an economic decision. Speed increasers lower the overall plant efficiency by about 1% for a single gear increaser and about 2% for double gear increaser. (The manufacturer can supply exact data regarding the efficiency of speed increasers). This loss of efficiency and the cost of the speed increaser must be compared to the reduction in cost for the smaller generator. It

is recommended that speed increaser option should not be used for unit sizes above 5 MW capacity.

The required civil features are different for horizontal units than for vertical units. Horizontally mounted tube turbines require more floor area than vertically mounted units. The area required may be lessened by slant mounting, however, additional turbine costs are incurred as a large axial thrust bearing is required. Excavation and powerhouse height for a horizontal unit is less than that required for a vertical unit. Standard Tube turbines of Bharat Heavy Electricals based on runner diameter is shown in Figure 3.2.6.

3.2.6 Bulb Turbines

Bulb Turbines are horizontal, which have propeller runners directly connected to the generator. The generator is enclosed in a water-tight enclosure (bulb) located in the turbine water passageway. The bulb turbine is available with fixed or variable pitch blades and with or without a wicket gate mechanism. Performance characteristic are similar to the vertical and Tube type turbines previously discussed. The bulb turbine will have an improved efficiency of approximately 2% over a vertical unit and 1% over a tube unit because of the straight water passageway.

Due to the compact design, powerhouse floor space and height for Bulb turbine installations are minimized. Maintenance time due to accessibility, however, may be greater than for either the vertical or the tube type turbines.

3.2.7 Pelton Turbines

An impulse turbine is one having one or more free jets discharging into an aerated space and impinging on the buckets of a runner. Efficiencies are often 90% and above. In general, an impulse turbine will not be competitive in cost with a reaction turbine in overlapping range (Fig. 3.2.5 section 3.2.2). However, certain hydraulic conditions or surge protection requirements may warrant investigation into the suitability of an impulse turbine in the overlapping head.

Single nozzle impulse turbine have a very flat efficiency curve and may be operated down to loads of 20% of rated capacity with good efficiency. For multi-nozzle units, the range is even broader because the number of operating jets can be varied.

Control of the turbine is maintained by hydraulically operated needle nozzles in each jet. In addition, a jet deflector is provided for emergency shutdown. The deflector diverts the water jet from the buckets to the wall of the pit liner. This features provides surge protection for the penstock without the need for a pressure valve because load can be rapidly removed from the generator without changing the flow rate.

Control of the turbine may also be accomplished by the deflector alone. On these units the needle nozzle is manually operated and the deflector diverts a portion of the jet for lower loads. This method is less efficient and normally used for speed regulation of the turbine under constant load.

Runners on the modern impulse turbine are a one-piece casting. Runners with individually attached buckets have proved to be less dependable and, on occasion, have broken away from the wheel causing severe damage to powerhouse. Integral cast runners are difficult to cast, costly and require long delivery times. However, maintenance costs for an impulse turbine are less than for a reaction turbine as they are free of cavitation problems. Excessive silt or sand in the water however, will cause more wear on the runner of an impulse turbine than on the runner of most reaction turbines.

Draft tubes are not required for impulse turbines. The runner must be located above maximum tailwater to permit operation at atmospheric pressure. This requirement requires an additional head loss for an impulse turbine not required by a reaction turbine.

Impulse turbines may be mounted horizontally or vertically. The additional floor space required for the horizontal setting can be compensated for by lower generator costs on single nozzle units in the lower capacity sizes. Vertical units require less floor space and are often used for large capacity multi-nozzle units.

Vertical shaft multi-jet turbines are generally selected for large flow installations, whereas horizontal shaft turbines are suitable for those applications that have less water available.

Abrasive material entrained in the water will erode the buckets of a multi-jet turbine more rapidly than in the case of a single jet per runner.

For the same rated head and flow conditions, increasing the number of jets results in a smaller runner and a higher operating speed. Therefore, whether vertical or horizontal, multi-jet turbines tend to be less costly for comparable outputs because the cost of the runner represents up to 20% of the cost of the entire turbine.

A deflector is normally used to cut into the jet when rapid power reductions are required such as a complete loss of connected-load. The deflector is mounted close to the runner on the nozzle assembly and typically is provided with its own servomotor.

3.2.8 Turgo Impulse Turbines

Another type of impulse turbine is the Turgo impulse. This turbine is higher in specific speed than the typical impulse turbine. Eric Crewdson originally patented this turbine in 1920. the difference between a Pelton unit and a Turgo is that, on a Turgo unit, the jet enters one side of the runner and exits the other side. The Turgo unit operates at a higher specific speed, which means for the same runner diameter as a Pelton runner, the rotational speed can be higher. The application head range for a Turgo unit is 15 meters to 300 meters. Turgo units have been used for application up to 7,500 kW.

3.2.9 Cross Flow Turbines

A cross flow turbine is an impulse type turbine with partial air admission.

Performance characteristics of this turbine are similar to an impulse turbine, and consist of a flat efficiency curve over a wide range of flow and head conditions. The wide range is accomplished by use of a guide vane at the entrance, which directs the flow to a limited portion of the runner depending on the flow. This operation is similar to operation of multi-jet impulse turbine.

Peak efficiency of the cross flow turbine is less than that of other turbine types previously discussed. Guaranteed maximum efficiency seldom exceeds 80%. Efficiency of indigenous available turbines is about 60-65%.

The largest size runner of cross flow is about 1.2 meter in diameter. This limits unit capacity but multi-unit installations can be used. Allowable heads range from 2 meter to 180 meter.

Cross flow turbines are sometimes equipped with a conical draft tube creating a pressure below atmosphere in the turbine chamber. Therefore the difference between the turbine centerline elevation and the tail water is not lost to Cross-flow turbines as is the case for an impulse turbine. Air is admitted into the chamber through an adjustable air inlet valve used to control the pressure.

Cross flow turbines are free from cavitation, but are susceptible to wear when excessive silt or sand particles are in the water. Runners are self-cleaning and, in general, maintenance is less complex than for the other types of turbines

Floor space requirements are more than for the other turbine types, but a less complex structure is required and a savings in cost might be realized.

3.2.10 Vertical Semi-Kaplan Turbine With Syphon Intake

Vertical semi-Kaplan turbine with Syphon intake with adjustable runner blade and fixed guide vane are being very frequently used. Moveable runner blade is controlled by a hydraulic servomotor. The runner blades are adjusted to accommodate the variation in flow of water through the turbine and consequent control of load on the machine. This is achieved by movement of piston of runner servomotor. This also eliminates provision of intake/draft tube gates. By adopting proper control of opening of runner blades the load on the machine will be adjusted such that the level of water in the upstream of the fall will remain undisturbed. In this case also a gearbox is used between the turbine and generator for using standard generator and in this case also the efficiency comes down by 1 to 2% due to gearbox. In this case the investment cost is also less as the cost of machine as well as the cost of civil works in construction of power station is less. As the name suggests, the Vertical Turbine with Syphon Intake operation on the

Syphon Principle i.e. the intake flume chamber valve is closed and made water tight and vacuum is created by a pump which enables water to enter flume chamber and energise the runner. When the machine reaches synchronous speed this is synchronised with the grid like any conventional turbine. Shut down is brought about by following the reverse procedure i.e. by breaking vacuum. Since turbine operates on a Syphon Principle, it is not necessary to have Intake and Draft gates thereby reducing the cost. The drawing showing Step – I, II & III fully explain how the machine operation is started by creating Syphon Intake.

The Syphon Intake semi Kaplan Vertical Turbine is claimed to run at even 30% minimum load without the problem of cavitation. Its efficiency at this minimum load goes down to 76% only.

This type of turbine is suitable for variable head also.

3.2.11 Turbine Control and Hydro Governor

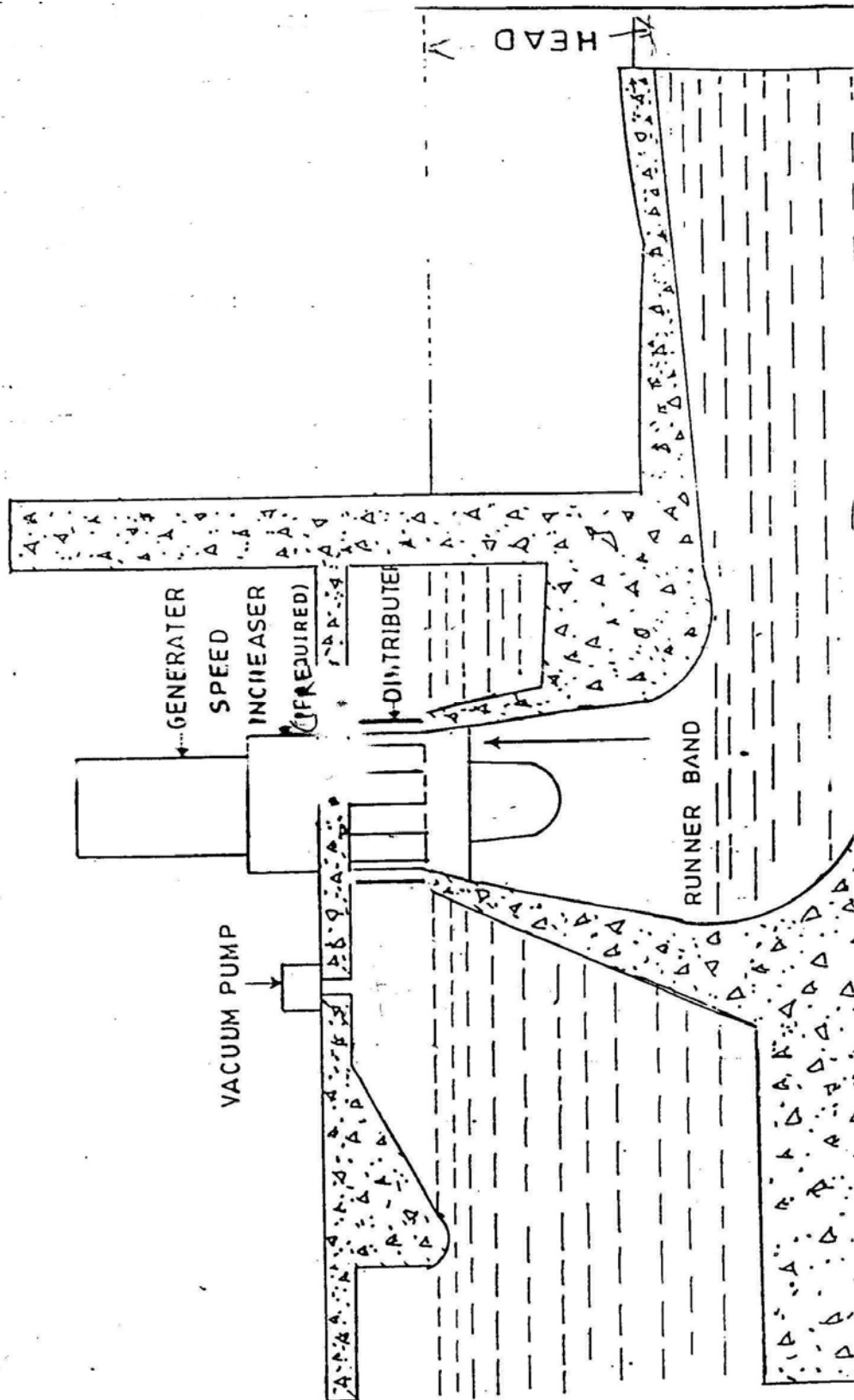
3.2.11.1 Control

This is the speed control of turbine in which the governor adjusts the flow of water through the turbine to balance the input power with the load. In case of small plants in the range of micro hydel (100 kW unit size), load control is also used, where excess load is diverted to dummy load to maintain constant speed. With an isolated system; the governor controls the frequency. In interconnected system, the governor may be used to regulate the unit load and may contribute to the system frequency control. Figure 3.2.10 shows the different types of control applicable to turbines.

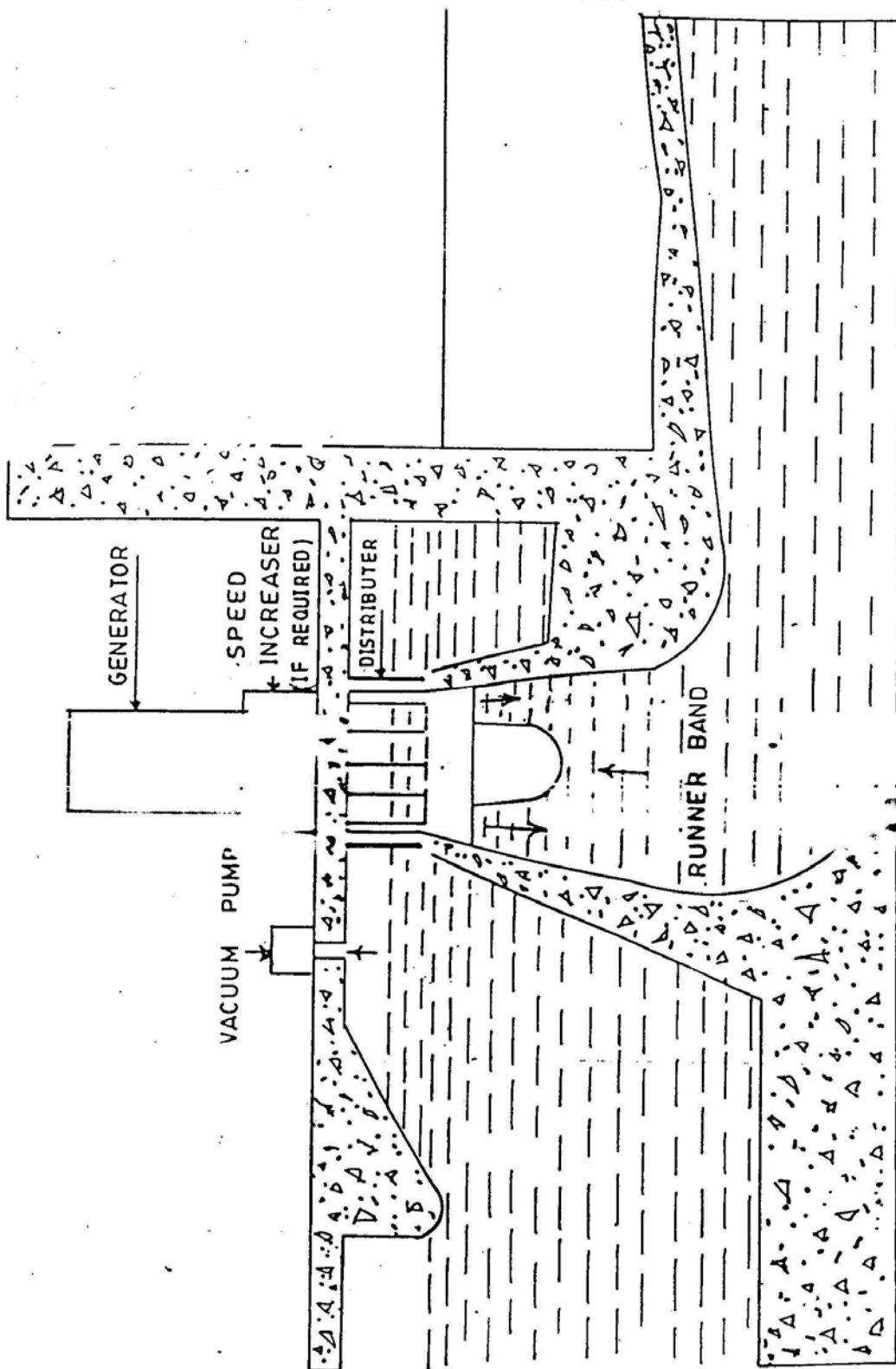
3.2.11.2 Considerations for Selecting Governor and Control System

Governor and control systems for small hydro units especially in developing countries have to be selected keeping in view the following:

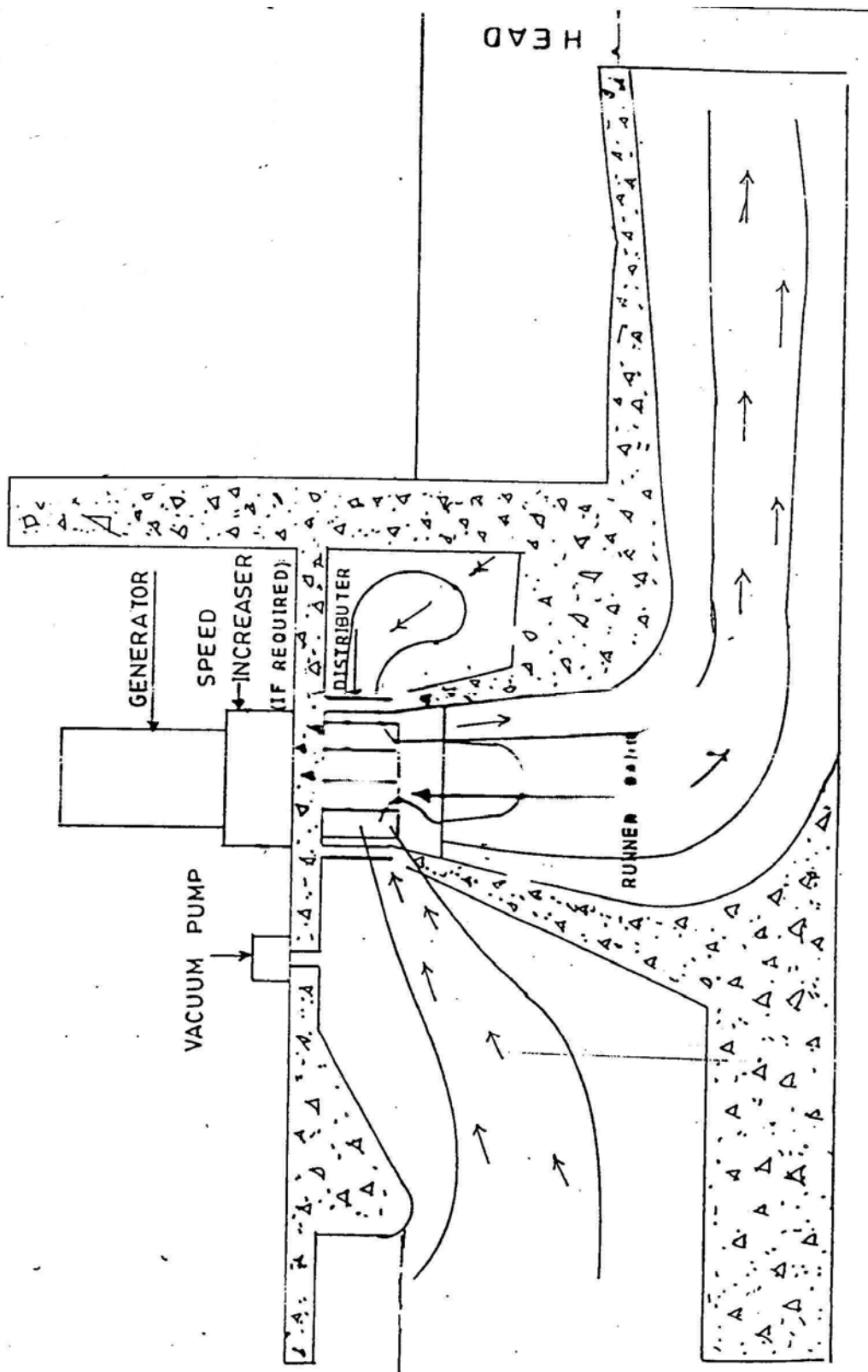
- (a) Traditional mechanical flow control governor with mechanical hydraulic devices is complex demanding maintenance and high first cost. Further performance requirements of stability and sensitivity i.e. dead band, dead time and dashpot time especially for interconnected units may not be met by mechanical governors.
- (b) Electronic and digital flow control governors can take up plant control functions.



Step - I



Step - II



Step - III

- (c) Cost of speed control and automation with currently installed analog flow governors, unit control and protection systems is high. These systems require attended operation and are mostly based on large capacity hydro units. This is making most of the units very costly and uneconomical to operate.
- (d) The manpower as available for SHP operation is unskilled and further adequate supervision is not feasible.
- (e) Load factors for stand alone micro hydels are usually low affecting economic viability.
- (f) Flow control turbine governors are expensive and not recommended for small hydro units in micro hydel range. Electronic load control governing system with water cooled hot water tanks as ballast loads for unit size upto 100 kW be used. This will make a saving of about 40% on capital cost as given in Table-6.1. The generator flywheel is not required. If the thyristor control (ELC) is used then the alternator needs to be oversized upto 20% on kVA to cope with the higher circulating current induced. Accordingly, in case of small units upto 100-150 kW size elimination of flow control governors of use by shunt load governor (electronic load controllers) will make these units economically viable and properly designed will eliminate continuous attendance requirement.

Comparison of a typical 100 kW, 130 m head, 120 litres/sec. Run of the river system using either ELC or Flow control governing system

Table : 6.1

ITEM	Cost ELC System	Cost, flow Control system	Percentage difference
Intake Weir	100,000	100,000	0
Settling tank system	75,000	75,000	0
Canal	400,000	400,000	0
Forebay	100,000	120,000	- 20%
Penstock & anchors	850,000	1,150,000	- 22%
Power House	100,000	100,000	0
Turbine & Drive	1,000,000	1,450,000	-30%
Alternator	350,000*	300,000	+15%
Governor, protection & instrumentation	180,000	700,000	-76%
Construction, transport, installation	450,000	500,000	- 10%
Commissioning	50,000	60,000	- 20%
Sub total	3,655,000	4,955,000	
Engineering Costs (25%)	913,750	1,238,750	
TOTALS	4,568,750	6,193,750	- 36%
Total Cost/ kW	45,688	61,938	

* Designed for full runaway overspeed condition

- (g) Data storage function can be added to the digital governors.
- (h) The dummy loads in the Shunt Load Governors (ELC) can be useful load system or can be used for supplying domestic energy needs.
- (i) Analog electronic governors and plant controllers are also used for small hydro auto synchronizing and for remote control and monitoring of system. Experience in the successful operation of these system in India is so far not very good.
- (j) Digital generation controllers were evolved to take care of speed control, unit control and automation, unit protection and even generation scheduling and have been successfully in operation for over ten years.
- (k) PLC based system are costly but are stated to be reliable and have been in operation in India and abroad.
- (l) Dedicated PC based systems for complete generation control can be easily adopted for data acquisition and storage at low cost and can also be adopted to SCADA system.

3.2.12 Modern Practice Regarding Governor and Plant Control

Control of a hydro Plant generating unit was typically performed from a central control board containing iron vane meters, hardwired control switches, and a large No. of auxiliary relays to perform the unit start/stop operations. All the necessary sensors and controls required to operate the unit or units were hardwired to the control panels allowing control of power station and centralised control room. Modern digital integrated control and protection system including Programmable Logic Controller (PLC's), distributed Computer control system or personal Computer control system not only provide Supervisory Control And Data Acquisition (SCADA) but also flexibility in control, alarming, sequencing, remote communication in a cost affective fashion and has been specifically recommended for SHP's in India, under UNDP-GEF Project.

Control function of Small Hydro Plants are standardised in following U.S. Standards.

- a. IEEE Guide for Control of Small Hydroelectric Plants, "ANSI/IEEE Standard 1020, American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE), 1990.
- b. "IEEE Guide for Control of Hydroelectric Powerplants," ANSI/IEEE Standard 1010, ANSI/IEEE, 1991.

Specific Hardware or Software to be utilised for implementation is not however addressed in this American standard.

Architecture and Communication are two potential problem area for Computer systems

In 1990, the International Organisation for Standardisation (ISO) developed a model for open architecture and protocol, known as SI (Open System interconnection) – ISO mode. The designs consistent into OSI – ISO models will allow upgrades or expansion of the Computer sub section by manufacturers other than sellers and is recommended.

Programmable Logic Controller (PLC) type plant controllers combined with PC based SCADA system are used as Governors and for Plant control and data acquisition. This makes the system less costly and reliability is stated to be good and can be used for small hydro generation control. It is considered that dedicated digital control systems which is digital P.C. based can perform all functions of governing, unit control and protection as well as for data storage and can be more economical, dependable and are being manufactured in U.S.A., Europe, India and other countries. These dedicated systems with back up manual control facility of turbine control in emergency by dedicated semi automatic digital controllers can be low cost option and was also recommended for UNDP-GEF projects in India.

A comparison of various turbine governor and plant control option alongwith cost comparisons and recommendations of European; U.S. and National Consultants for UNDP-GEF Projects is at Table 3.3.1.

3.2.13 Modern Typical Digital Shunt Load Governor for Microhydels

3.2.13.1 General

A typical Digital Shunt Load Governors (ELC) was developed in India. These controllers are reported to be working successfully in India and abroad for last seven years. These Generation Controllers (load shunt governors) are Digitally controlled electronic governors for controlling Micro Hydel power plants (upto 200 kW) by controlling the output load only.

Standard controllable loads (like water heaters) are provided alongwith the governor system and the load on the machine is maintained using these load in such a way so that user gets stable voltage and frequency. No major input control is required resulting in considerable saving in cost of equipment and civil works. Dummy load can be replaced by useful loads. Load controller can be designed to manage the useful load system for surplus energy. It is fool proof and suitable especially for unattended operation in remote Rural Area of developing countries by unskilled operators.

3.2.13.2 Advantage of Shunt Load Governors

The generator always generates the maximum power possible. The generation not immediately required is used up in secondary loads that are controlled by TRIACS. The secondary loads can be for useful purposes and the overall system efficiency can be extremely high. Other advantages are as follows :

- i. Since the control is by digital means with speed as reference the response of the governor to changes in frequency can be faster and more accurate as compared to the mechanical governing or by electronic governing based on current / voltage as reference.
- ii. Governing by control of water is complicated by the effects of water hammer. Water hammer results from having to accelerate and decelerate the moving water in the power plant and penstock in order to vary the flow through the turbine. Faster governing (for stability) can increase water hammer pressures. Water hammer induced pressure fluctuations create governing difficulties if not corrected for. Water hammer problems are reduced in large hydro-power plants by keeping the length of the pipeline as short as possible or by reducing the speed of operation of the governor (possible only if the loads change slowly enough) or by installing surge tanks to absorb the impact of flow changes. If the governing is done by load control, no quick changes are necessary.
- iii. No moving parts: Mechanical governing requires relatively fast and accurate mechanical movement. These devices necessary to control water add to the turbine expense.
- iv. Less expensive types of turbines having no provision for flow control of water can be used. Industrial Centrifugal pumps for example, can be applied as low cost turbines by operating them backwards but pumps do not have any inherent method for controlling water and must use load controller.
- v. Little or no custom engineering is required, because the governing motion is not affected by site dependent characteristics such as length and size of the penstock. Provision of adjustable dead band and dash pot time in the field ensures stability of operation.

Table-3.3.1

S. No	Turbine Gov. And Controller type	Unit size kW	Mode of operation	Suitability					Cost including Governor,Control, Protection SCADA Data Aq., Storage And Retrivel (See note 1)		Recommendations			
				Turbine Gov.	Unit Control	Unit Port.	Data Storage & Retrivel	SCADA	Capital	O M &	Mead & Hunt U.S.A.	MHPG (Europe)	National	
1	Mech Flow Control Gov.	50-200	Iso.		At high extra cost					Very high	High without SCADA	Not recommended		
			Grid											
		200-500 & above	Iso.											
			Grid											
2	Load control governor	50-200	Iso.		Suitable	At extra cost	Low	Low	Not considered	Recommended				
			Grid					Not recommended						
		200-500	Iso.	See note-3				Do not available		See note -3				
			Grid							Not recommended				
		Above 500	Iso.					Not feasible		Not recommended				
			Grid											

3	Analogue, Electronic & Controller Gov. Plant	50-200	Iso.	Suitable	At high extra cost	Very high cost		Not recomme nded	Not recom mende d	Not recomm ended
			Grid			High	Moder ate		Recom mende d(for grid linked only)	
		Above 200	Iso.							
			Grid							
4.	Digital Gov. & Plant Controller	50-200	Iso.	Suitable (See note 2)		Moderate cost		Not considere d	Not recommended	
			Grid							
		Above 200	Iso.						Recommended	
			Grid							
5.	PLC Based Gov. & Plant Cotroller	50-200	Iso.	Suitable	At extra cost	Very high	Low	Recommen ded	Not recommended	
			Grid							
		Above 200	Iso.							
			Grid							

Notes :

- 1 Cost normalised with main and back up SCADA system.
- 2 Dedicated digital controller with P.C. based SCADA back up.
- 3 Recommended in conjunction with partial water flow control

3.2.13.3 Governor Functions

Shunt load Governors can be designed to perform following jobs in a hydro-electric installation.

- (a) Stable speed control for all inflows
- (b) Management of useful for surplus energy
- (c) Prevent overloading of an hydro-electric plant in case of reduction in stream inflow. Shedding load at peak demand periods or during low water.
- (d) Control and protection functions as described in a subsequent paragraph.

3.3 Hydro Generator

3.3.1 Synchronous Generator

All large hydro turbine driven generators are synchronous alternating current generators. The electric generator converts the mechanical energy of the turbine into electrical energy. The two major components of the generator are the rotor and the stator. The rotor is the rotating assembly to which the mechanical torque of the turbine shaft is applied. By magnetizing or “exciting” the rotor, a voltage is induced in the stationary component, the stator. The principal control mechanism of the generator is the exciter-regulator which sets and stabilizes the output voltage. The speed of the generator is determined by the turbine selection. High speed generators are provided by using speed increaser for small hydro generators for economic reasons. In general, for a fixed value of power, a decrease in speed will increase the physical size and cost of the generator. Hydraulic turbine driven generators for hydro plants are salient pole (projecting) synchronous alternating current machines. The salient pole generators are relatively slow speed machines in the range 80-1000 rpm with large number of rotor poles. Bhakra generators have 36 poles. The generator vertically shaft and directly coupled to the hydraulic turbine.

Most of the Small hydro generators (upto 5000 kW unit size) are also salient pole synchronous generators. These are generally horizontal shaft. For economic reasons the generator may be coupled to turbine through speed increaser (gear boxes) to have high-speed generators. Induction generators upto a maximum about 2000 kW unit size have been used. In some cases where system conditions permit.

3.3.2 Induction Generator

Induction generator are essentially same as induction motors. When rotated at super synchronous speeds the machine works in generation mode feeding kW into grid. The power output is determined by the slip-torque characteristics of the machine. The speed of the torque generator set thus does not need to be controlled by a governor nor is there a need for a voltage regulator. However, the machine draws kVAR from the system for its excitation. Consequently net power factor of the unit is very low. Further the generation operation is fully dependant on alive grid. Hence, if supply from grid is interrupted by tripping anywhere, the generation from the unit will cease. Also the unit will tend to go to runaway speed, for which special protection will have to be particularly provided.

3.3.3 Capacity & Rating

kW Rating: The kilowatt rating of the generator should be compatible with the kW rating of the turbine. The most common turbine types are Francis, fixed blade propeller, and adjustable blade propeller (Kaplan). Each turbine type has different operating characteristics and impose a different set of generator design criteria to correctly match the generator to the turbine. For any turbine type, however, the generator should have sufficient continuous capacity to handle the maximum kW available from the turbine at 100-percent gate without the generator exceeding its rated nameplate temperature rise. In determining generator capacity, any possible future changes to the project, such as raising the forebay (draw down) level and increasing turbine output capability, should be considered.

In a variable head power plant the turbine output may vary depending upon available head. In general the generator is rated for turbine output at rated head. In peaking power plant higher generator kW rating could be specified to take care of possible higher turbine output. Economic analysis is required for this purpose as the cost will increase and generator capacity remains unutilized when heads are low.

kVA Rating and power factor: kVA and power factor is fixed by consideration of interconnected transmission system and location of the power plant with respect to load centre. These requirements include a consideration of the anticipated load, the electrical location of the plant relative to the power system load centers, the transmission lines, substations, and distribution facilities involved.

Where a generator is connected to the load through transformer bank, the determination of the voltage is generally based on economic factor. Generator cost for unit of a fixed KVA rating and speed vary with the voltage, and these change in cost must be balanced against corresponding cost of generator leads, instrument transformer, surge

Protective equipment involved. The possibilities of load connected directly to the generator may influence the selection of the generator voltage. The generator frequency is determined by the frequency of the system to which it will be connected.

$$\text{Generator MVA} = \frac{(\text{Turbine output in MW}) \times (\text{Generator efficiency})}{\text{Generator power factor}}$$

3.3.4 Rated Voltage of Generators

Following are recommended rated voltages for generators of different rated outputs from economic reasons.

Up to 750 kW	415 V
751 – 2500 kW	3.3 kV
2501 – 5000 kW	6.6 kV
more than 5000 kW	11 kV

3.3.5 Speed and Weight

The speed of a generator is established by the turbine speed. The turbine speed for maximum efficiency corresponding to an even number of generator poles should be determined by the hydraulic turbines. Generator dimensions and weights vary inversely with the speed. Shipping weights are generally 10 to 15 % more than net weights. The weight of the assembled rotor on the shaft is generally a little less than one-half the total weight of the generator when WR^2 is normal. The powerhouse crane must have sufficient capacity to handle the assembled rotor on the shaft.

3.3.6 Categories of Generator Assembly

Four categories of generator assembly, which depend on the MW rating and size of the generator as per American practice are:

Category 1: Factory assembled generators that are shipped to the site completely assembled. Category 1 generators are usually less than 5 MW, but the classification also depends on the rpm selected, unit speed/weight, and the method of transportation to the site.

Category 2: Factory assembled generators that are shipped to the field as two integral component parts, rotor and stator, or three component parts, the rotor and two stator halves. Those are usually between 5 and 15 MW.

Category 3: Generators are that require field assembly of the stator, but can have the rotor shipped to the site as an integral component part. Category 3 generators are usually between 15 and 50 MW.

Category 4: Generators that require complete assembly of the stator and rotor at the site. There are usually greater than 50 MW.

3.3.6 Construction of Large Hydro Generators

3.3.6.1 Types Of Generators

Vertical shaft generators are generally used. There are three types of vertical shaft hydro generators distinguished by design speed and the bearing arrangements.

Umbrella type generators: This design is shown in fig. 3.3.1. These generators have combined bottom thrust and guide bearings and confined to low operating speeds (upto 200 rpm) and is the least expensive generator design.

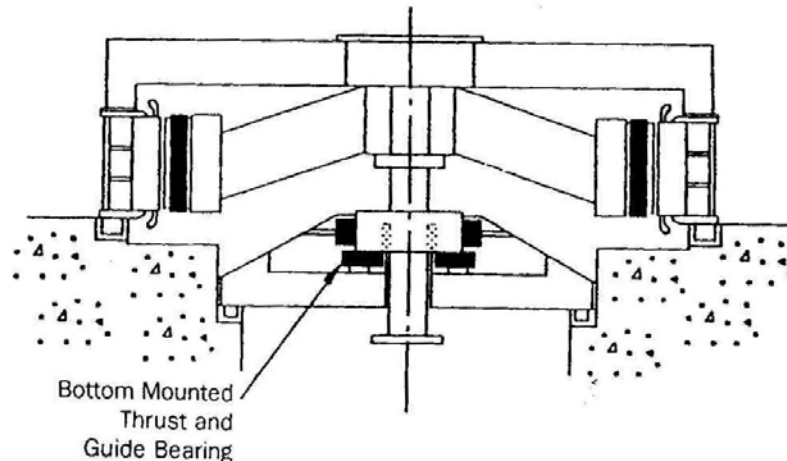


Fig. 3.8 The Umbrella Type Generator. The umbrella type generator, designed for low operating speeds, does not require a top guide bearing

Semi Umbrella: This is shown in fig. 3.3.2. This is use for medium speed 150-300 rpm generators. In semi umbrella type generators a top guide bearing is added. Umbrella/Semi Umbrella design is being increasingly used for vertical generator. 165 MW Dehar power generators are semi umbrella type design and have speed of 300 rpm.

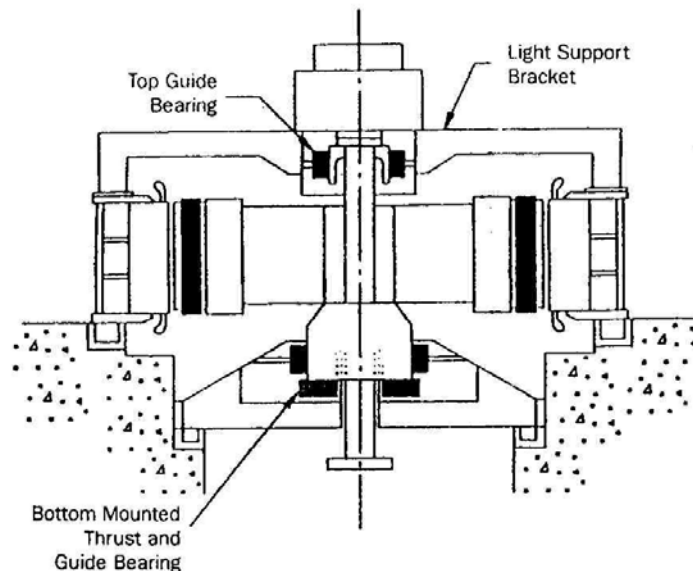


Fig. 3.9 The Semi-Umbrella type generator has a combined bottom thrust and guide bearing and a top guide bearing

Conventional Standard Type Generators: This is shown in fig. 3.3.3. This type of generator can be used upto 1000 rpm generators. Prior to introduction of umbrella and semi umbrella designs conventional design comprised of top-mounted thrust and guide bearing supported on heavy brackets, capable of supporting total weight of generator. A bottom guide bearing combined with turbine shaft is usually provided. This conventional design is used for high speeds (upto 1000 rpm) generators.

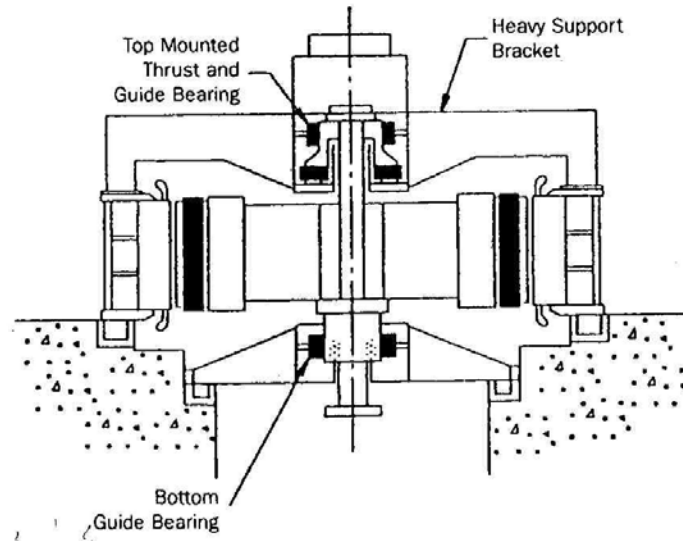


Fig. 3.10 The Standard Type Generator. The standard type generator has a top-mounted thrust and guide bearing, which supports the entire weight of the machine during operation

3.3.7 Construction of Small Hydro Generators

Some medium size low flow turbine and most of the small hydro units upto 5 MW and tube turbine generators are horizontal shaft. A typical small hydro turbine driven generator is shown in fig. 3.3.4 to 6. Direct driven bulb turbine generators are also horizontal shaft generators located in the bulb.

3.3.8 Generator Component

A hydroelectric generator consists of several major component. Fig. 3.3.7 shows various componenet parts for a typical umbrella type generator.

Stator: The generator stator consists of stator foundation supports members, a stator frame, stator core, and the stator windings. The foundation members are embedded in the powerhouse concrete and provide support for the stator frame structural members. The generator stator frame structural members provide support for the stator core and other machine components. The generator stator frame or yoke is generally fabricated from rolled-steel plate and consists of a rigidly welded structure of ample stiffness to withstand, without distortion, the stresses imposed by short circuits or by braking operations.

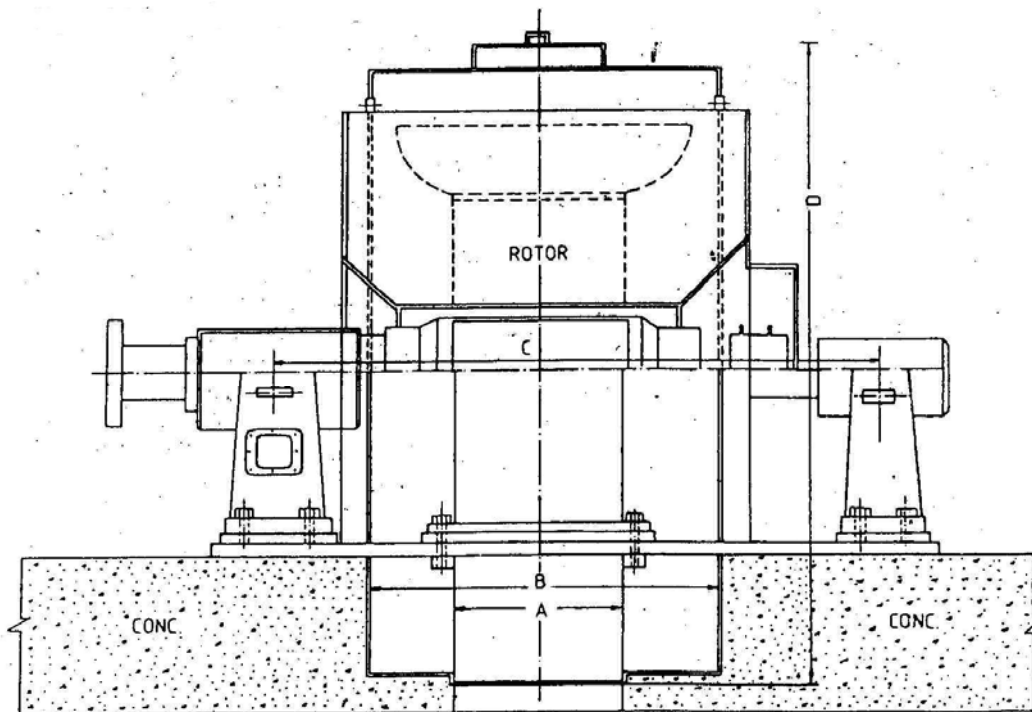


Fig. 3.11 Synchronous generator with static excitation – dimensions of assembly

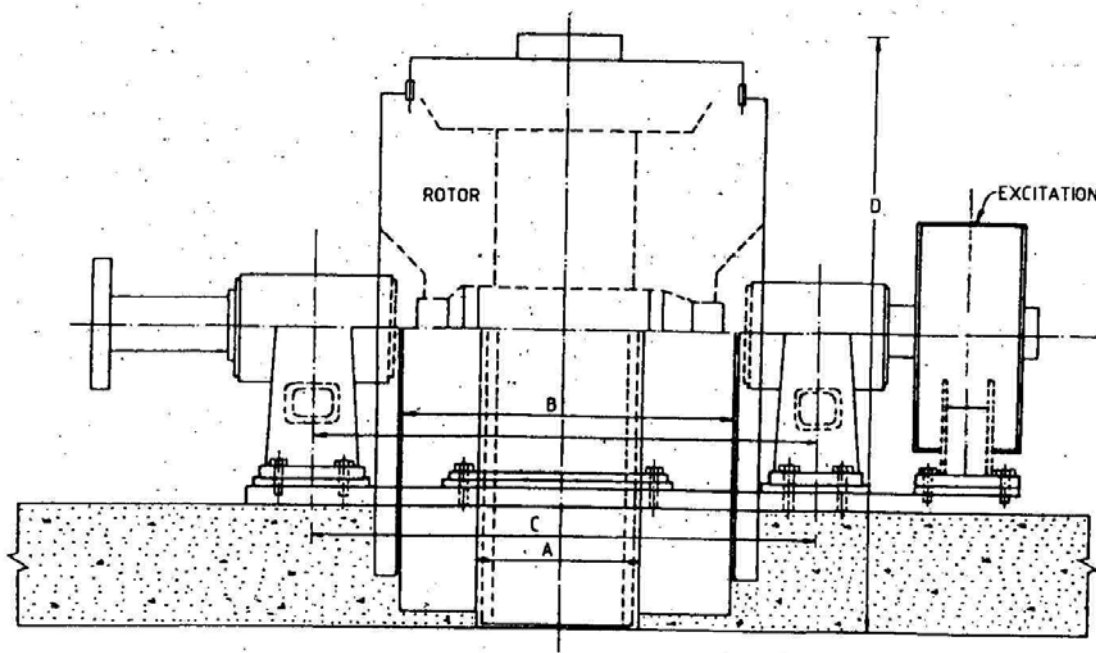


Fig. 3.12 Synchronous generator with Brushless excitation – dimension & arrangement

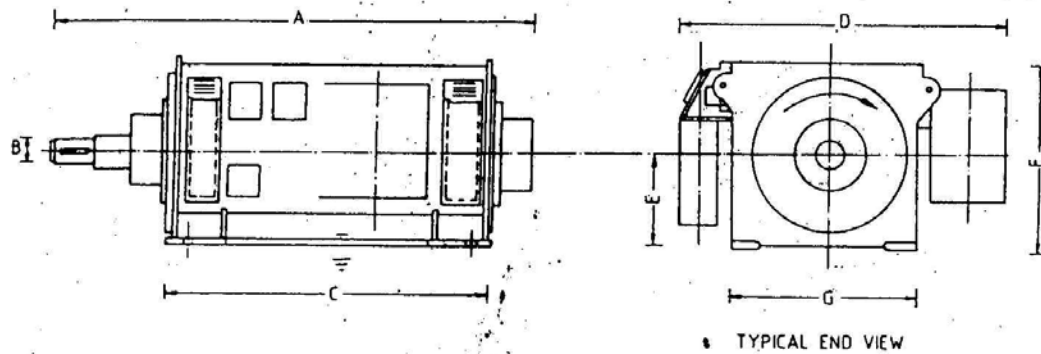


Fig. 3.13 Induction generator – dimension & arrangement

The stator core consists of thin silicon steel laminations each of which is coated on both sides with air insulating material to avoid eddy losses. The lamination are keyed on dovetailed to the stator frame and are held rigidly in place by clamping flanges. The laminations are stacked on top of one another. The stator core is secured to the stator frame structural members to embedded sole plates to avoid mechanical vibrations during generator operation.

The stator winding are inserted into the stator core slots and terminated on collector rings, commonly called the ring bus, located at the top of the stator core. The collector rings are used to connect parallel circuits of a given phase together and to act as the neutral element of the winding. The windings may consist of multi-turn coils or single turn bar windings depending upon the size of the generator. The generator stator frame or yoke is generally fabricated from rolled steel plate and consists of a rigidly structure of ample stiffness to withstand, without distortion, the stresses imposed by short circuits or by braking operations.

The stator or armature winding is ordinarily wye-connected, with both ends of each brought to terminals outside the stator frame. The terminals are generally brought out of the stator in such a manner that, looking down on the generator, or at the end opposite the driven for horizontal units, the electromotive forces reach their maximum at the terminals in the order of the direction of rotation. The armature coils are completely insulated with class. For class H insulation before being placed in the stator core slots, and are interchangeable to facilitate replacement in case of failure. Large coils have multiple strands of copper conductor which are transposed to reduce eddy-current losses. The end connections of the coils are rigidly supported and braced to prevent vibration and distortion under short-circuit stresses as shown in fig. The armature windings are designed to withstand the maximum 3-phase, short circuit current of the generator, but not the maximum line-to-ground short circuit current. This must be given consideration in determining the method of grounding the machine neutral. Depending on the physical size of the generator, resistance –temperature detector coils are provided in the armature winding for temperature indication as per BIS.

Rotor: The rotor hub is attached directly to the generator shaft. The purpose of the rotor hub is to mount and fasten the rotor spider. Rotor spider consists of several mechanical arms that

radiate outward from the rotor hub. A continuous rotor rim is connected to the outside end of each rotor spider arm. In physically large generators, this rim consists of individual steel sheets, stacked and bolted together to provide a continuous outside rotor perimeter to which the rotor poles are fastened.

In smaller generators, the rotor rim is made of a solid forged steel ring. In small, low-speed machines, the rotor poles are bolted directly to the rim. In larger machines with high or medium speeds, the rotor poles are connected using a dovetail or T – head connection.

The field windings are wrapped around the outside of each rotor pole and connected to each other to form alternate north/south poles around the periphery of the rotor. Modern machines usually use flat, rectangular copper strips with brazed dovetail or jigsaw joints at each corner.

The damper windings consist of copper bars that extend the length of the rotor pole face. The damper windings are used to “dampen” or restrict generator oscillation during steady-state operation. The damper copper bars on each rotor pole are connected to each other. On most hydroelectric generators, the damper windings also are connected from pole to pole.

Shaft: The assembled rotor is designed to withstand the stresses imposed by the maximum runaway speed of the unit. A brake ring is provided on the lower side of the rotor, the wearing surface of which is removable and renewable. Fans for circulating air through the stator are attached to the rotor.

The collector or slip rings for the field current are generally helically grooved and are accessibly located above the stator cover plates. Bronze collector rings are provided on some generators and iron or steel collector rings provided on others. The field leads from the exciter are provided with extra capacity and are of sufficient length to reverse the connections to the collector rings.

The generator shaft is bolted directly to the turbine shaft and conveys the mechanical power from the turbine to the generator rotor. The generator is designed with the shaft as short as possible, in order to reduce vibrations and minimize cost.

Brakes: Hydro generators are provided with a mechanical friction braking system. This system helps stop the generator’s rotation after the unit is tripped off-line. Mechanical friction brakes usually are applied when the unit rotation has slowed to less than 25-30 % of the operating speed. Stopping the unit at this point avoids wear on the thrust bearing.

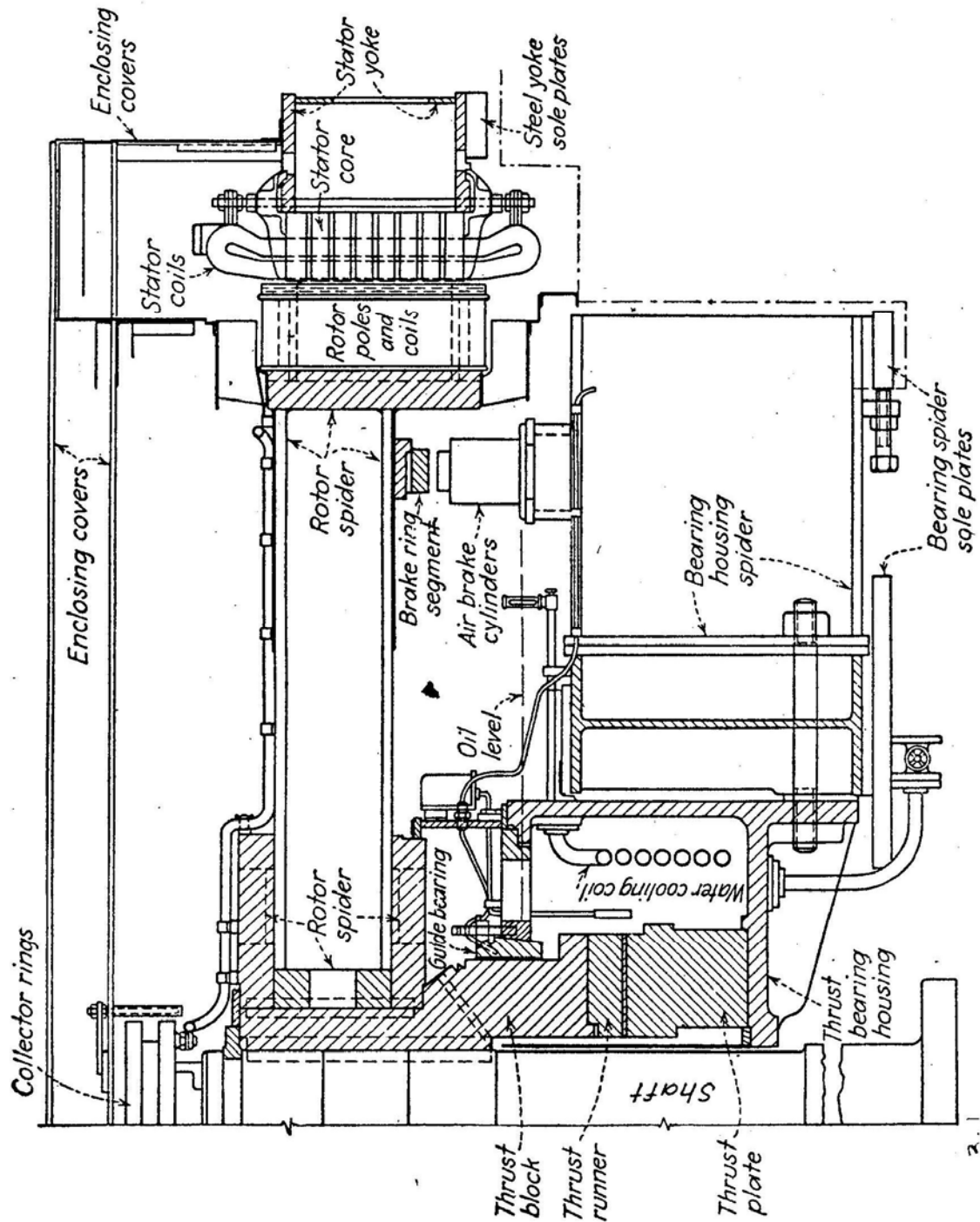


Fig. 3.14 Typical Vertical Water-Wheel Generator With Thrust and Guide Bearings Below The Rotor

Bearings

Thrust Bearing: The thrust bearing in the generator is the most important bearing element in the generator turbine assembly as it carries not only the weight of rotating generator parts but also the weight of turbine shaft and turbine runner, in addition to hydraulic thrust on the runner.

Hydro generators have thrust bearing located either at the top (standard conventional type) or bottom (semi-umbrella or umbrella type) of the generator to support the rotating weight of the machine (see Para 3.3.6.2). Common types of thrust bearing design are:

- Bearings Kingsbury in US and Michell bearing in Europe
- Spring loaded mattress type bearings

The basic principle of operation of all bearing types requires a film of oil between the rotating bearing plate and the babbited stationary shoes. Modern thrust bearings have a high-pressure oil lift system, which injects oil into each shoe pad of the bearing during starting and stopping of the unit. This helps establish a hydrodynamic oil film between the rotating (thrust collar) and stationary (bearing shoes or pads) members of the thrust bearing.

The presence of the hydrodynamic oil film minimizes bearing wear and failure. Consequently, during a unit start the high-pressure oil system is turned on before the unit starts to rotate. It is usually shut off after the unit speed exceeds 75 to 90 % of rated speed because, at the higher rotational speeds, the hydrodynamic oil film is self-sustaining. On unit shutdown, the high-pressure oil system is turned on when the unit speed decreases to the 75 to 90 % range and maintained until the unit is at stand-still. The maximum wear on the bearings pads occurs at slow speeds, when, due to hydrodynamic effects, the oil film no longer is maintained over the entire bearing surface.

Bearing Temperature Indication and Alarm

Bearing temperature indication and alarm can be obtained in several ways. One of the most positive methods is to be the embedding in the bearing metal of resistance temperature detectors or thermometer bulbs to give temperature indication and alarm bulbs to give high-temperature alarm. Several embedded detectors, evenly spaced, should be used in thrust bearings to give a positive indication of temperature.

The thrust bearing and guide bearings should be insulated to prevent electric current, either inherently in the unit or from an external source, from passing through the bearings.

Coolers

Closed circuit air-cooling water-to-air coolers normally are provided for all modern hydro generators rated greater than 5 MVA. The coolers are situated around the outside periphery of the stator core. Generators equipped with water-to-air coolers can be designed with smaller physical dimensions, reducing the cost of the generator.

The generator cooling water normally is supplied from the penstock via a pressure reducing station or pumped from the tailrace. In either case, automatic self-cleaning filters must be provided in the cooling water supply lines to avoid frequent fouling or plugging of the water-to-air coolers.

3.3.9 Excitation System

A D. C. current has to be supplied to the field winding of a synchronous machine. The field winding are on rotor. A special arrangement is necessary to connect the D. C. source to the field.

All hydro generators are separately excited. From the D. C. source through slip rings or collector rings and brushes. Slip rings are metal rings completely encircling the shaft of the machine (see figure 3.3.7) but insulated from the shaft. A brush rids on each slip ring. The positive end D. C. voltage source is connoted to one brush and negative end connected to another bus. Excitation systems supply and regulate the amount of D. C. current required by generator field windings and include all power regulating control and protective element as sown in fig. 3.3.8. There are three basic types of excitation systems as shown in table 3.3.1 which also shows the source of excitation Power.

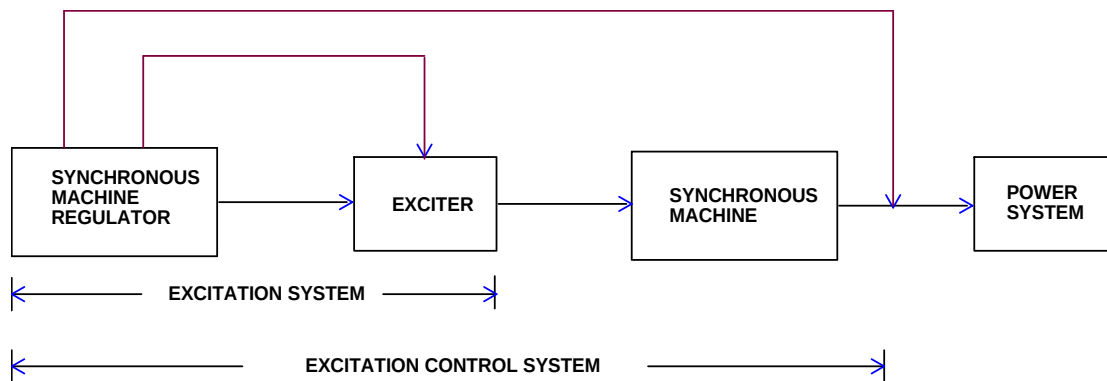


Fig. 3.15

Some time back, synchronous AC generators were provided with shaft mounted separate DC generator for excitation and often also with pilot exciters (fig. 3.3.9) with the development of thyristor and static power equipment such conventionally excited generators are no longer being used. The two types of excitation systems being used now are:

- i) Static excitation system
- ii) Brushers excitation system

Table 3.3.1

Sl. No.	Type of Exciter	Exciter Power Source	Figure
1.	D. C. generator commutator exciter	Normally generator shaft mounted or Motor generator set	Figure 3.3.9
2.	Alternator rotating non controlled rectifier (brush less)	Generator shaft	Figure 3.3.10
3.	Static Excitation System	Synchronous machine voltage and current	Figure 3.3.11

Excitation System Type

Modern static excitation have completely replaced older shaft mounted rotating exciters with DC field current controlled by motor operated field rheostat. Brushless excitation system and static excitation systems are being used in modern systems.

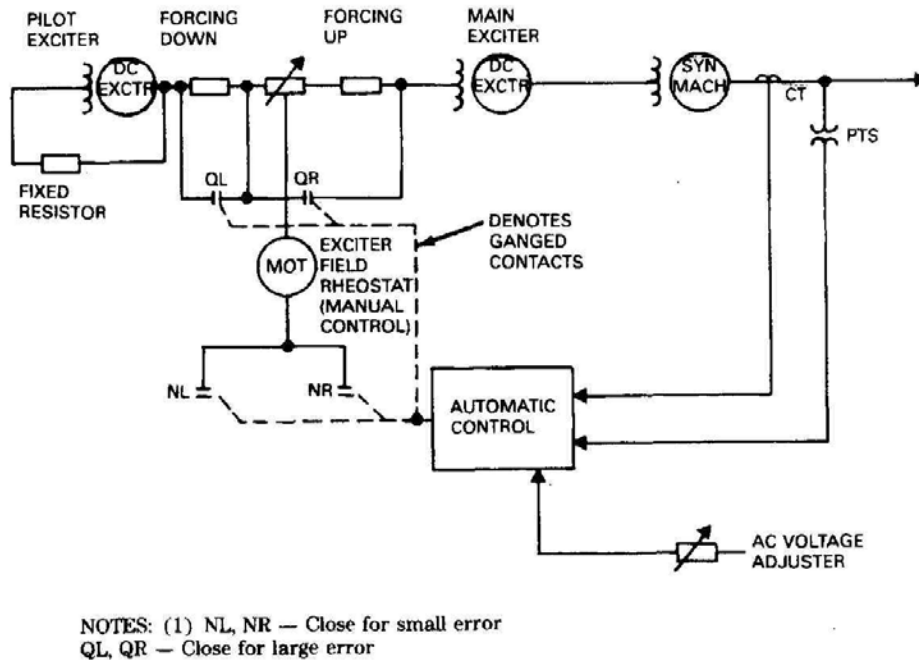


Fig. 3.16 DC Generator – Commutator Exciter Excited with Noncontinuously Acting Rheostatic Regulator (self excited due to residual magnetism of d. c. generators)

Brushless Exciter: An alternator-rectifier exciter employing rotating rectifiers with a direct connection to the synchronous machine field thus eliminating the need for field brushes, is typically shown in Fig 3.3.10. Brushless system may be used small hydro generators upto about

10 MVA where large DC current Capacity is not required. Connection diagram of Brushless excitation systems for 2 x 1.5 MW, 3.3 kV, 750 RPM, 50 Hz, 0.8 PF, 8 poles alternators is shown in fig. 3.3.11.

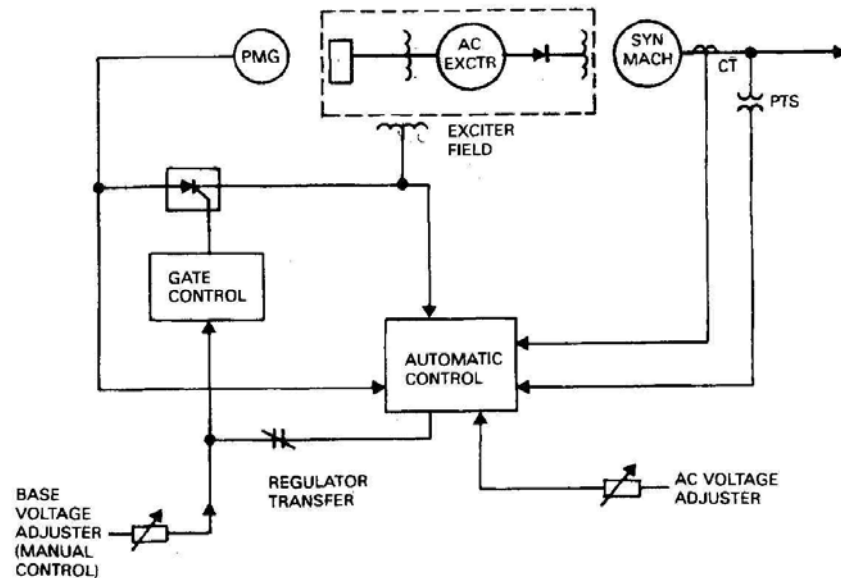


Fig. 3.17 Brushless Excitation System

Static Excitation System: The static excitation system does not have any moving parts, but does require heavy current slip rings and brush gear to transfer D. C. current to the generator field winding.

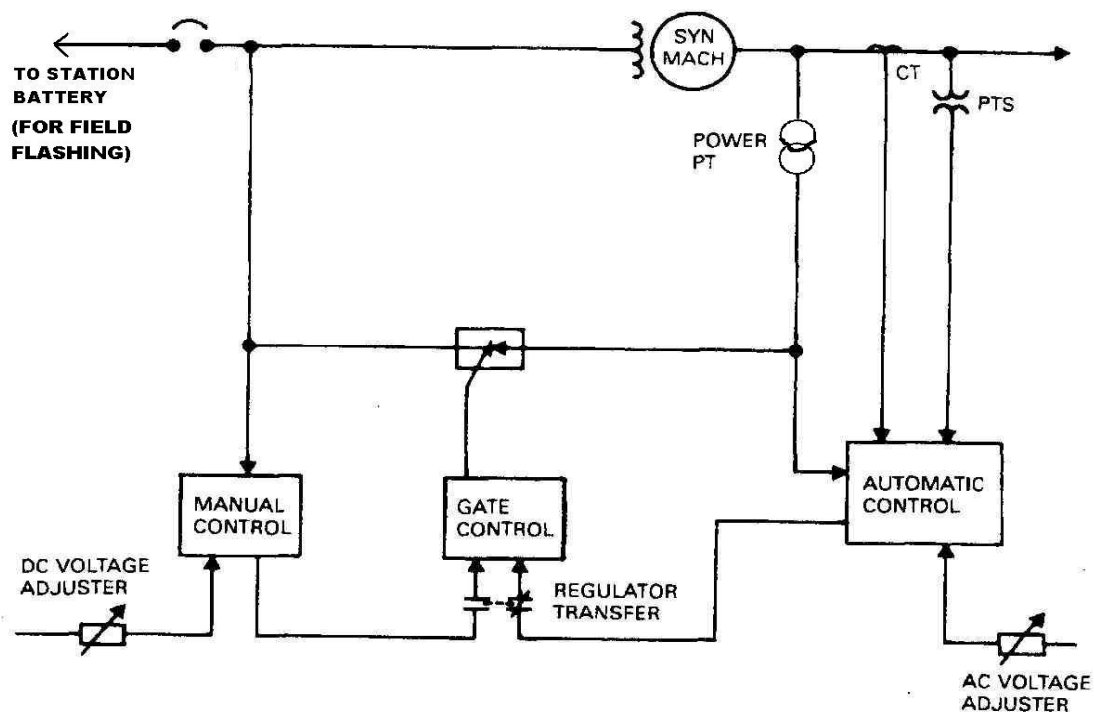


Fig. 3.18 – Static Excitation System

The static excitation system is the most commonly used excitation system for hydro generators. A single line diagram is shown in fig. 3.3.12 and excitation system block diagram for a 9 MW, 11 kV, 0.9 PF, 125 RPM generators is enclosed at fig. 3.3.13. The controls logic is digital.

Rated Field Current

The direct current in the field winding of the synchronous machine when operating rated voltage, current, power factor and speed.

The voltage required across the terminals of the field winding of the synchronous machine under rated continuous load conditions of the synchronous machine with its field winding at (1) 75°C for field windings designed to operate at rating with a temperature rise of 60°C or less; or (2) 100°C for field windings designed to operate at rating with a temperature rise greater than 60°C .

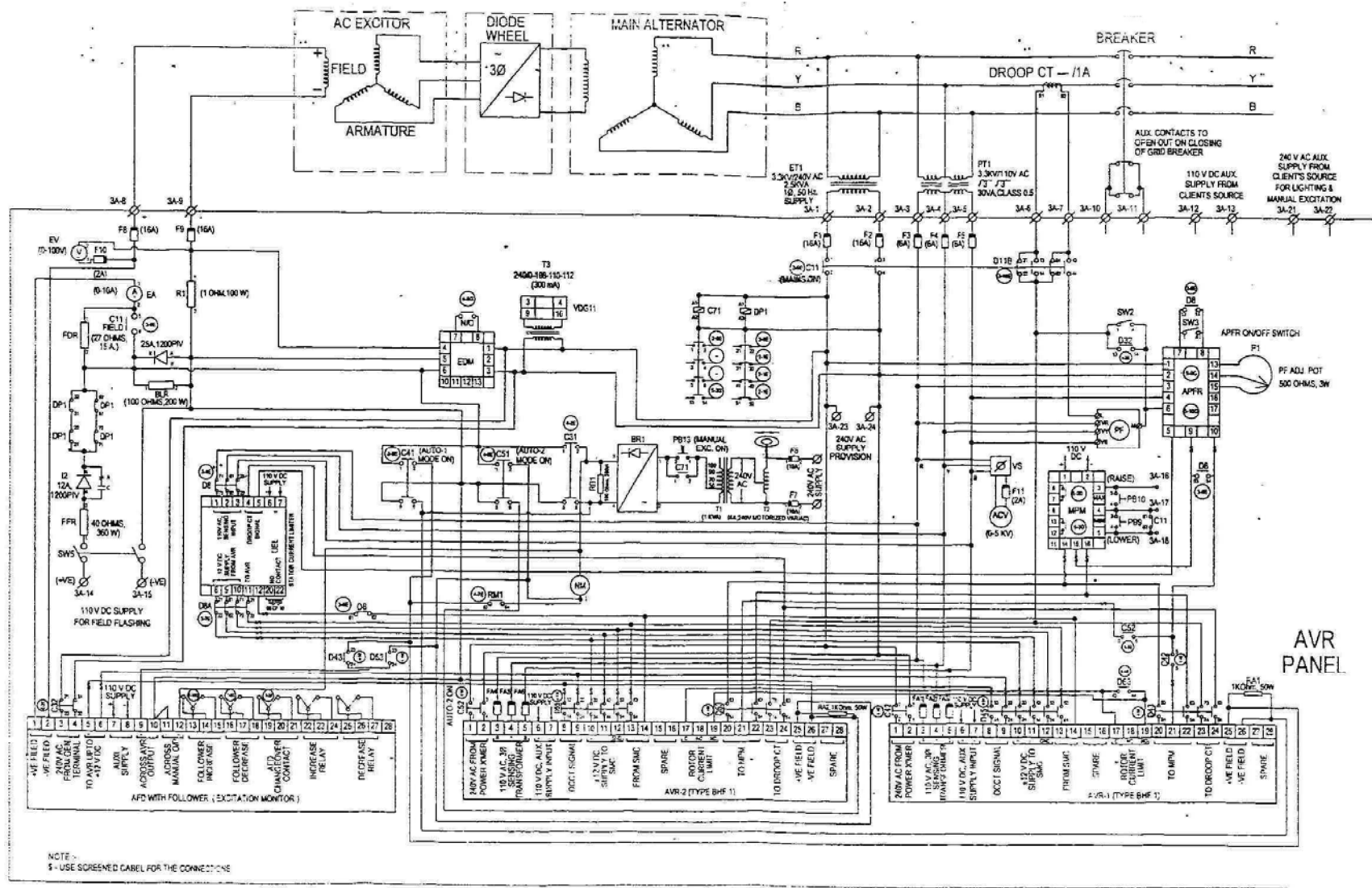


Fig. 3.19 - Brushless Excitation System for 1.5 MW, 3.3 kV, 750 RPM, 50 Hz, 0.8 PF, 8 poles Generators (Pacha Project) (Grid Connected)

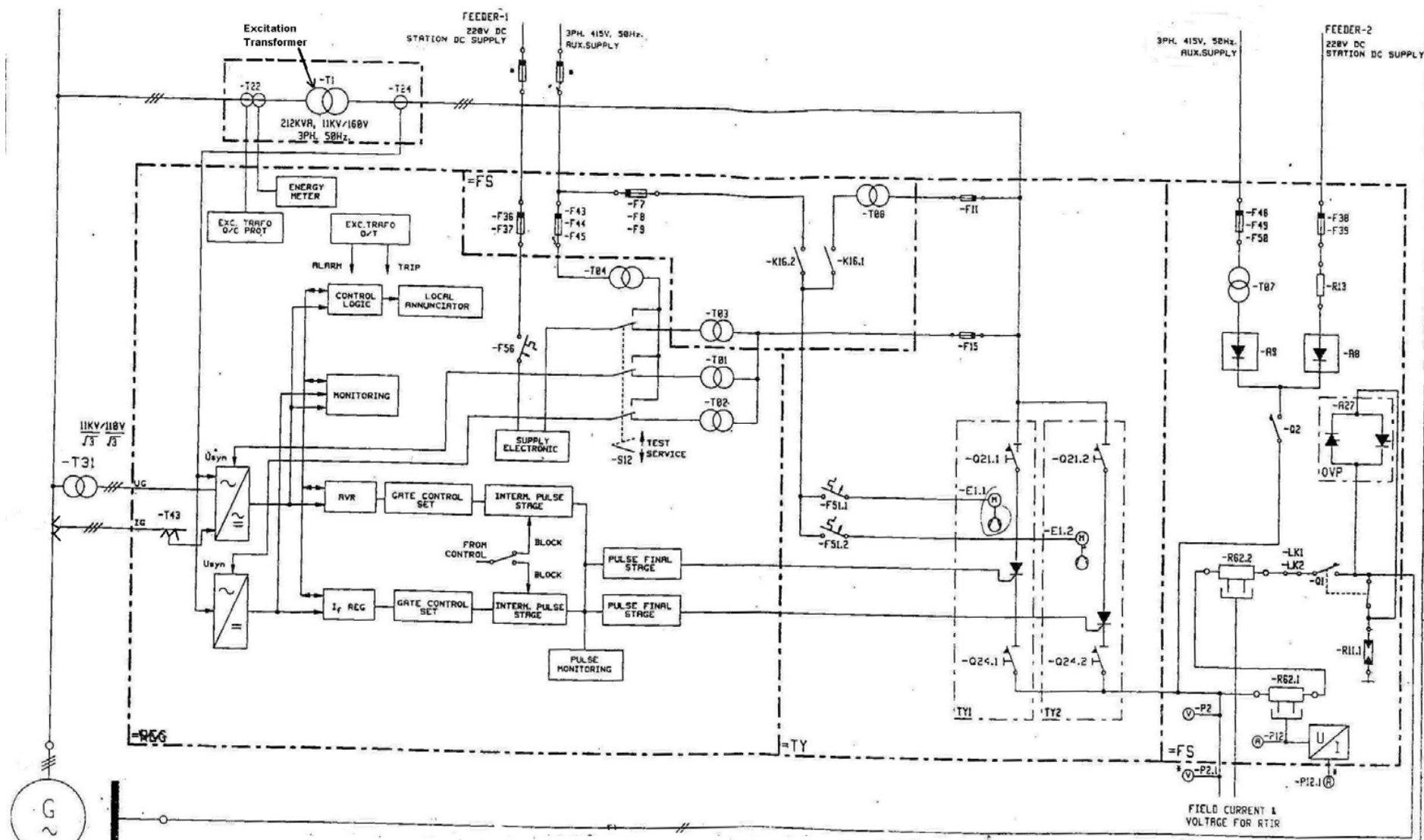


Fig. 3.20- Static Excitation System - Block Diagram for 9 MW, 11 kV, 0.9 PF, 125 RPM Generators

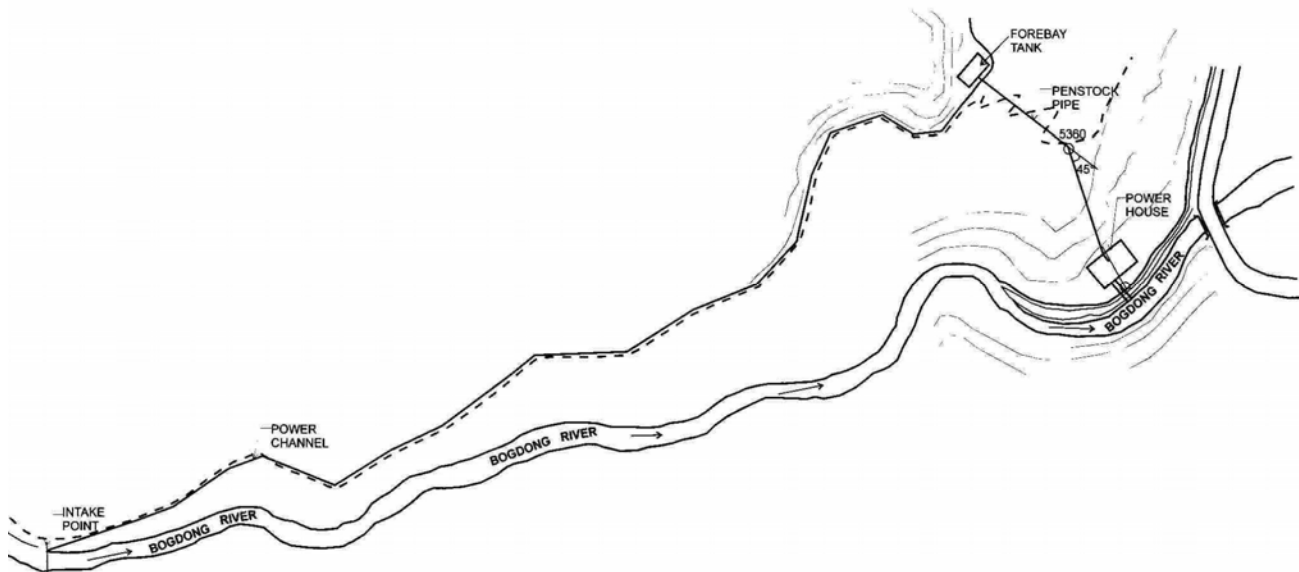
DESIGN CALCULATIONS OF MAJOR CIVIL WORKS

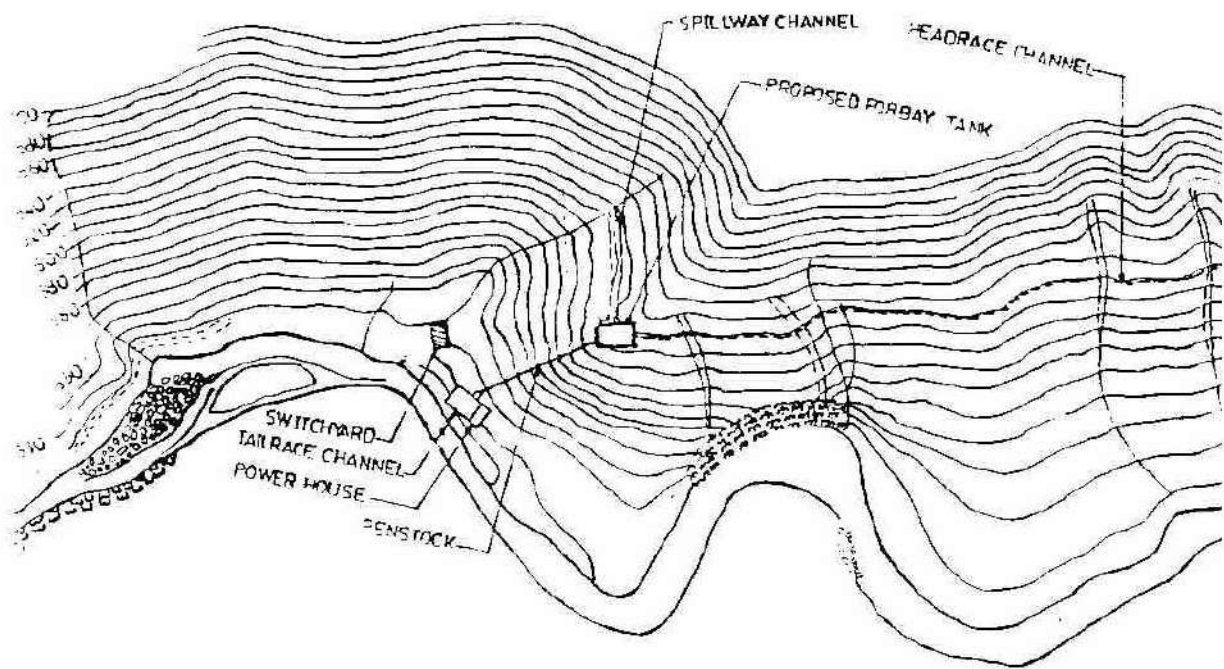
By

M. K. Singhal Senior Scientific Officer, AHEC

The Angong Small Hydro Project comprises of the following Civil Works.

- Diversion Weir and Intake
- Intake Channel
- Desilting Tank
- Head Race Channel
- Forebay Tank, Spillway and Spilling Channel
- Penstock
- Power House Building
- Tailrace Channel





1. DESIGN DATA

F.S.L. at Forbay	=	607.54 m
Water level in tail race channel	=	511.21 m
Gross head	=	607.54 – 511.21 m
	=	96.33 m
Head loss	=	4.33 m
Net head	=	96.33 – 4.33
	=	92.0 m
50% dependable discharge	=	8.38 cumecs
75% dependable discharge	=	6.96 cumecs
90% dependable discharge	=	5.65 cumecs
100% dependable discharge	=	5.10 cumecs

2.0 POWER POTENTIAL AVAILABLE

Taking efficiency of turbine and generator as 0.88 & 0.94 respectively. The power potential (P) available at site.

(i) At 50 % dependable discharge

$$\begin{aligned} P &= 9.81 \times 92.0 \times 8.38 \times 0.88 \times 0.94 \\ &= 6256.21 \text{ kW} \end{aligned}$$

(ii) At 75 % dependable discharge

$$\begin{aligned} P &= 9.81 \times 0.88 \times 92.0 \times 0.94 \times 6.96 \\ &= 5196.08 \text{ kW} \end{aligned}$$

(iii) At 90 % dependable discharge

$$\begin{aligned} P &= 9.81 \times 5.65 \times 92.0 \times 0.88 \times 0.94 \\ &= 4225.55 \text{ kW} \end{aligned}$$

Discharge required for 4500 kW generation

$$= \frac{4500}{9.81 \times 0.88 \times 92.0 \times 0.94} = 6.0 \text{ cumecs}$$

Rated Discharge = 6.0 cumecs

It is proposed to provide 3 machines of 1500 kW each for the generation.

3.0 FIXING OF DISCHARGING CAPACITY FOR VARIOUS CIVIL STRUCTURES

(i) Design discharge for forebay,

Penstock, Spillway and Tailrace Channel

$$(5\% \text{ over rating capacity}) = 6.0 \times 1.05 = 6.30 \text{ cumecs}$$

(ii) Design discharge for head race

channel (5% for seepage loss)

$$= 6.30 \times 100 / 95 = 6.63 \text{ cumecs}$$

(iii) Design discharge of intake channel

upto desilting tank

$$(\text{Add } 15\% \text{ discharge for silt flushing}) = 6.63 \times 100 / 85 = 7.80 \text{ cumecs}$$

(iv) Design discharge for Trench Weir

$$= 7.80 \times 100 / 95 = 8.21 \text{ cumecs}$$

(Add 5% of item iii)

4.0 CALCULATION OF HFL AT WEIR SITE

High flood discharge = 447.0 cumecs

Natural cross section of river upto 622.50m (at 60 m U/s of proposed diversion site)

$$\text{Area} = 60.34 \text{ m}^2$$

Wetted perimeter	=	37.8 m
Taking value of N	=	0.035
River bed slope	=	1 in 27
Discharge comes out	=	453.0 m
Therefore, H.F.L. at diversion site	=	$622.50 - 60 \times 1/27$
	=	620.27 m
Bed level at diversion site	=	617.70 m
H.F.L.	=	620.27 m

4.0 CALCULATION FOR SCOUR DEPTH

$$\text{Scour depth (Ds)} = 1.35 \times \left(\frac{q^2}{f} \right)^{1/3}$$

$$\begin{aligned} \text{Discharge per unit width} &= 447/40 \text{ m}^3/\text{sec.} \\ &= 11.175 \text{ m}^3/\text{s/m} \end{aligned}$$

(Silt factor varies from 1.0 for sandy rivers to 20.0 for rivers having big boulder movement)

$$\begin{aligned} \text{Take } f &= 8.0 \\ \text{Ds} &= 1.35 \times (11.175^2 / 8)^{1/3} \\ &= 3.37 \text{ m} \\ \text{U/s cut off wall depth} &= 1.25 \times \text{Scour depth} \\ &= 1.25 \times 3.37 = 4.21 \text{ m} \\ \text{U/s cut off wall level} &= \text{HFL} - \text{U/s cut off wall depth} \\ &= 620.27 - 4.21 = 616.06 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{The U/s cut off wall has been provided upto the level of } 616.06 \text{ m.} \\ \text{HFL } 25 \text{ m D/s} &= 620.27 - 25/27 \\ &= 619.344 \text{ m} \\ \text{The D/s cut off wall depth} &= 1.5 (\text{Scour depth}) \\ &= 1.5 \times 3.37 = 5.055 \text{ m} \\ \text{The D/s cut off level} &= 619.344 - 5.055 \\ &= 614.289 \text{ m} \\ \text{The D/s cut off wall has been provided upto the level of} &= 614.289 \text{ m} \end{aligned}$$

5.0 DESIGN OF TRENCH WEIR AND INTAKE

High flood discharge of Nala is $447.0 \text{ m}^3/\text{sec.}$ (refer Chapter II)

$$\begin{aligned} \text{Lacey's water way} &= 4.75 \times \sqrt{Q} \\ &= 4.75 \times \sqrt{447.0} \end{aligned}$$

	=	100.426 m
40% of Lacey's	=	40.17 m
Provide length of weir	=	40.0 m
Section of trench of weir	=	Trapezoidal
Design discharge	=	8.21 cumecs

$$B = \frac{Q}{E_1 E_2 C d L \sqrt{2gE}}$$

$$C = \text{Coefficient of discharge of broad crested weir}$$

$$= 1.543$$

$$E = \left(\frac{8.21}{1.543 \times 40} \right)^{2/3} = 0.260$$

$$B = \left(\frac{8.21}{0.5 \times 0.5 \times 0.46 \times 40 \sqrt{2 \times 9.81 \times 0.60}} \right)$$

$$= 0.789 \text{ m}$$

Provide a width of 2.0 m from practical consideration

Check-Width

Width of trash rack for 0.40 m/s velocity of water. Allowable width through trash rack

$$= \left(\frac{Q}{V \times L} \right)$$

$$= \left(\frac{8.21}{0.40 \times 40} \right)$$

$$= 0.513 \text{ m}$$

Width required for 50% clogging = $2 \times 0.513 = 1.02 \text{ m}$

1.02 m is less than 2.0 meter provided and hence safe

5.1 Check Discharge Capacity Of Trench Weir

Discharge	=	8.21 m ³ /s
Length L	=	40 m
Width of trench	=	2.0 m

Let d	=	water depth along section of channel
Area	=	2.0 x d
Velocity head at the end of trench	=	$h\sigma$
$h\sigma$	=	$\frac{n}{n+1} \frac{A}{2T}$
Where n	=	Constant depending upon the bottom profile of the channel
	=	0.50
$h\sigma$	=	$\frac{0.5}{0.5+1} \frac{2.0d}{2 \times 2.0}$
	=	0.166 d
Q	=	$A \sqrt{gh\sigma}$
8.21	=	$2.0 d \sqrt{2g \times 0.166d}$
d	=	1.76 m
How ever provide total water depth	=	1.0 m at the start increasing to 2.60 m towards the intake end

6.0 INTAKE CHANNEL/ FEEDER CHANNEL

Length of channel	=	90 m
Q	=	7.80 m ³ /s
S	=	1 in 25 0
n	=	0.018

Rectangular reinforced cement concrete section has been provided.

Area	A	=	Bd
Wetted perimeter	P	=	B + 2d
	R	=	A/P
	Q	=	$\frac{R^{2/3} S^{1/2}}{n}$
Provide	B	=	2.490 m
	D	=	1.24 m
Free board		=	0.45 m
Flow velocity		=	2.55 m/s

Area A	=	3.08 m ²
Wetted perimeter P	=	4.97m
Hydraulic Radius	=	0.62 m
Design discharge	=	7.89 m ³ /s

7.0 DESIGN CALCULATION OF DESILTING TANK

The recommend particle size to be removed for power projects having gross head of 96.33 m and above is 0.25 mm.

Design discharge	=	7.80 m ³ /s
Flow Velocity (V _f)	=	0.22 m/s
Particle size to be removed	=	0.25 mm & above
Settling velocity (V _s)	=	2.75 cm/sec
Width proposed (W)	=	12.0 m
Depth required $\frac{Q}{W \times V_f}$	=	$\frac{7.80}{12.0 \times 0.22}$
	=	2.95 m 3.0 m
Depth provided	=	3.0 m
Moderate settling velocity	=	$V_s - \frac{0.132}{\sqrt{D}} \times V_s$
	=	$2.75 - \frac{0.132}{\sqrt{3.0}} \times 2.75$
	=	2.75 – 0.2095
	=	2.54 cm/s
	=	0.0254 m/s
Settling length $\frac{V_f}{V_s} \times \text{Depth}$	=	$\frac{V_f}{V_s} \times \text{Depth}$
	=	$\frac{0.22}{0.0254} \times 3.0$
	=	25.98 m
Provided length	=	26.0 m
Depth	=	3.0 m
Width	=	12.0 m
Provide U/s transition length	=	$3 \times \left(\frac{120 - 2.490}{2} \right)$
	=	14.26 m

$$\begin{aligned}
 & \approx 14.50 \text{ m} \\
 \text{Provide D/s transition length} &= 2 \times \left(\frac{12.0 - 1.60}{2} \right) \\
 &= 10.40 \text{ m say } 10.50 \text{ m} \\
 \text{Provide free board} &= 0.40 \text{ m}
 \end{aligned}$$

8.0 HEAD RACE CHANNEL

$$\text{Length of channel} = 4500 \text{ m}$$

Trapezoidal Channel

$$\begin{aligned}
 Q &= 6.63 \text{ m}^3/\text{s} \\
 S &= 1 \text{ in } 500 \\
 \text{Side Slope} &= 1:1 \\
 n &= 0.018
 \end{aligned}$$

Trapezoidal stone masonry section has been provided

$$\begin{aligned}
 \text{Hydraulic Radius } R &= \frac{A}{P} \\
 \text{Discharge } Q &= \frac{R^{2/3} S^{1/2}}{n} \\
 \text{Provide bottom width } B &= 1.60 \text{ m} \\
 \\
 \text{Provide Top width} &= 4.06 \text{ m} \\
 \text{Water depth} &= 1.23 \text{ m} \\
 \text{Free board} &= 450 \text{ mm} \\
 \text{Area } A &= 3.48 \text{ m}^2 \\
 \text{Wetted perimeter} &= 5.07 \text{ m} \\
 \text{Hydraulic Radius} &= 0.68 \text{ m} \\
 \text{Velocity} &= 1.93 \text{ m/s} \\
 \text{Discharge capacity} &= 6.72 \text{ m}^3/\text{s} \\
 Q &= 6.63 \text{ m}^3/\text{s} \\
 S &= 1 \text{ in } 500 \\
 n &= 0.018
 \end{aligned}$$

8.1 Rectangular RCC

$$\begin{aligned}
 \text{Area } A &= B \times d \\
 \text{Wetted perimeter } (P) &= B + 2d \\
 R &= \frac{A}{P} \\
 Q &= \frac{AR^{2/3} S^{1/2}}{n}
 \end{aligned}$$

Provide	B	=	2.66m
Water depth	D	=	1.33m
Free board		=	0.45 m
Flow velocity	V	=	1.89m/s
Area	A	=	3.53 m
Wetted perimeter		=	5.32
Discharge Capacity		=	6.69 m ³ /s

9.0 DESIGN CALCULATION OF FOREBAY TANK

Design discharge		=	6.30 m ³ /s
Storage required		=	2 minute
Capacity of tank		=	6.30 x 2 x 60
		=	756.0 m ³
Taking water depth		=	3.0 m
Area A		=	$\frac{756}{3.0}$
		=	252.0 m ²
Area		=	L x B
Taking length		=	23.0 m
		=	$\frac{224.80}{23}$
Width B		=	10.95 m
Provide Length		=	23.0 m
Provide width		=	11.0 m
Provide Depth		=	3.0 m

10.0 DESIGN CALCULATION OF SPILLWAY

Discharge capacity	Q	=	6.30 m ³ /s
	Q	=	CLH ^{3/2}
	C	=	2.0
	H	=	Head over the crest of spillway
	=	=	0.40 m (Assume)
	L	=	Length of spillway
		=	$\frac{6.30}{2.0 \times (0.40)^{3/2}}$
		=	12.45 m
		=	Say 12.50 m

10.1 Design Of Spillway Channel

Length of channel	=	60.0 m
Q	=	6.30 m ³ /s
S	=	1 in 250
n	=	0.018
Rectangular stone masonry section has been provided		
Area	A =	B x d
Wetted perimeter	(P) =	B + 2 d
	R =	A/P
	Q =	$\frac{AR^{2/3}S^{1/2}}{n}$
Provide	B =	2.40 m
Water depth	D =	1.10 m
Free board	=	0.30 m
Flow velocity	V =	2.42 m/s
Area	A =	2.64 m ²
Wetted perimeter	=	4.60 m
Discharge Capacity	=	6.40 m ³ /s

11.0 PENSTOCK

Economical Diameter Of Penstock

$$D = \frac{C_1 C_2 Q^{0.43}}{(92.0)^{0.14}}$$

$$= \frac{1.20 \times 1.0 \times (2.10)^{0.43}}{(92.0)^{0.14}}$$

Where

D _e	=	Economical diameter in m
Q ₀	=	Design discharge of the penstock in m ³ /s
H ₀	=	Design head in m
C ₁	=	Coefficient taking into consideration the energy cost in the area, 1.2 to area where energy cost is low.
C ₂	=	Coefficient taking into account the material of penstock, 1 for steel penstock
D	=	0.876 m
	=	0.880 m
	=	880 m
V	=	$\frac{Q}{\frac{\pi}{4} \times D^2}$

$$= \frac{2.10}{\frac{\pi}{4} \times (0.880)^2}$$

$$= 3.454 \text{ m/s}$$

11.1 Calculation For Thickness Of Penstock

Gross Head	=	96.33 m
Stress in steel	=	1050 kg/cm ²
Diameter of Main penstock	=	88.0 cm
Pressure rise due to water hammer	=	50% (Assured)
Total Head	=	96.33 + 48.165
	=	144.495 m
	=	14.44 kg/ cm ² Thickness of steel liner
Penstock	=	$\frac{P \times D}{2 \times \sigma}$
	=	$\frac{14.44 \times 88}{2 \times 1050}$
	=	0.605 cm
	=	6.05 mm

Add 1.5 mm corrosion & 1.5 mm corrosion allowances

	=	6.05 mm
Thickness of penstock	=	6.05 mm + 1.50 + 1.50
	=	9.05 mm 10.0 mm
Penstock Inner Dia	=	880 mm
Outer Dia	=	900 mm
Thickness from handling criteria		
t	=	$\frac{D + 50}{400}$
D	=	Diameter in cm
t	=	$\frac{88.0 + 50}{400}$
	=	0.345 or 3.45 mm (O.K.)

11.2 Loss in Penstock

The friction factor depends upon Reynolds number of flow and relative roughness of pipe.

$$\text{Reynolds number (Re)} = \frac{VD}{\gamma}$$

Where

$$\begin{aligned} \gamma &= \text{Kinematic viscosity of water} \\ \text{Re} &= \frac{3.454}{1 \times 10^{-6}} \\ &= 3.45 \times 10^6 \text{ Relative Roughness} \\ &= k/D \\ &= \frac{0.045}{0.880 \times 1000} \\ &= 0.000051 \end{aligned}$$

$$\text{Friction factor (f) from Moody's diagram} = 0.011$$

$$\begin{aligned} 1. \quad \text{Length of Penstock} &= 162.0 \text{ m} \\ 2. \quad \text{No. of Anchor block} &= 7.0 \\ 3. \quad \text{Friction Loss in penstock} &= \frac{0.011 \times 162.0 \times 3.454^2}{2 \times 9.81 \times 0.88} \\ &= 1.13 \text{ m} \\ 4. \quad \text{Trash Rack Loss} &= K_t \frac{V^2}{2g} \quad k_t = 0.35 \\ &= \frac{0.35 \times 3.454^2}{2 \times 9.81} \\ &= 0.212 \text{ m} \\ 5. \quad \text{Intake entrance loss} &= \frac{0.25 \times V^2}{2g} \\ &= \frac{0.25 \times 3.454^2}{2 \times 9.81} \\ &= 0.1520 \text{ m} \end{aligned}$$

$$\begin{aligned}
6. \quad \text{Exit Loss} &= K_E \frac{V^2}{2g} \quad K_E = 1.0 \\
&= \frac{1.0 \times (3.454)^2}{2 \times 9.81} = 0.608 \\
7. \quad \text{Bend Losses (7 bends)} &= n K_b \frac{V^2}{2g} \\
&= \frac{7 \times 0.20 \times 3.454^2}{2 \times 9.81} \\
8. \quad \text{Valve losses} \\
a) \quad \text{Near forebay for gate valve (hvg)} &= \frac{0.5 \times V^2}{2g} = \frac{0.5 \times 3.454^2}{22.98} \\
&= 0.3 \text{ m} \\
b) \quad \text{Inside power house (hvb)} &= \frac{0.5 \times V^2}{2g} = \frac{0.5 \times 3.454^2}{2 \times 9.81} \\
&= 0.3 \text{ m} \\
9. \quad \text{For butterfly valve (hvg)} &= 0.60 \frac{V^2}{2g} \\
&= 0.60 \frac{3.454^2}{2 \times 9.81} \\
&= 0.390 \text{ m} \\
10. \quad \text{Transmission losses} &= 0.65 \frac{V^2}{2g} \\
&= 0.60 \frac{3.454^2}{2 \times 9.81} \\
&= 0.390 \text{ m} \\
\text{Total loss} &= 1.13 + 0.212 + 0.152 + 0.608 + 0.85 \\
&\quad + 0.30 + 0.30 + 0.360 + 0.390 \\
&= 4.302 \text{ m} = 4.33 \text{ m}
\end{aligned}$$

POWER HOUSE BUILDING

The layout of the powerhouse building has been worked out on the basis of IS code Horizontal Francis turbine of size 31.0 m x 13.50 m x 9.50 m . is proposed.

TAIL RACE CHANNEL

Each unit will have its own Tailrace. Tailrace channel is designed as rectangular section to cater design discharge 6.30 m³/s. Rectangular section with bed slope as per the terrain is proposed for tailrace channel. The tailrace channel length is about 20 m.

Bed Slope	=	1 in 380 m
n	=	0.018
Water Depth	=	1.158 m
Bed Width	=	2.65 m
Area	=	3.06 m ²
Perimeter	=	4.96 m
Hydraulic Radius	=	0.619
Velocity	=	2.07 m/

CHAPTER – 4

EARTHING AND GROUNDING

4.1 EARTHING AND GROUNDING

4.1.1 Introduction

Grounding systems means connecting the electrical equipment in powerhouse and step up sub station to general mass of earth. In an electrical installation, a grounding system is of very great importance for it has to perform the following functions:

- (a) To provide safety to persons in or near the station by reducing step and touch voltages occurring under normal or fault conditions to values, which are considered safe.
- (b) To limit the potential difference across communication or control lines leaving the station during power system faults.
- (c) To provide means of circuit relaying for clearing ground faults.
- (d) To protect the equipment from high voltage surges resulting from lightning.
- (e) To positively discharge and de-energise the feeders or equipment before proceeding with maintenance on them.

4.1.2 Ground Mats

Ground mats are laid in alternating-current outdoor substation installation, and under the power plant building. Ground gradient problems which exist in a substation yard, will not be present to that extent within a power plant building, due to its floors with its closely spaced reinforced steel presenting almost an equipotential area. In the later case, it is more important to obtain a relatively low value of over-all resistance of the grounding system. The grounding system comprises an earthing mat consisting of mild steel flats buried horizontally at a depth of about half a meter below the surface of the ground and ground rods at suitable points. Under the normal conditions, the ground rods contribute little towards lowering the ground resistance. However, these are helpful in lowering mesh potentials and maintaining low values of resistance under all weather conditions.

In Small Power starting and sub station earthing as per REC standards (Fig. 4.1 a & b) is used.

Several variable factors are involved in the design of earthing mat conductor. Therefore, earthing mat for each substation and powerhouse has to be designed individually usually. The earthing mat has to be designed for the site conditions to have a low overall resistance and a current carrying capacity consistent with the fault current magnitude. The main parameters listed below influence the designed of earthing mat. Earth mat may be designed in accordance with IS: 3043-1987.

- (a) Magnitude of fault current;
- (b) Soil resistivity;
- (c) Resistivity of surface material;
- (d) Material of earthing mat conductor and

Fault current magnitude is determined by system studies.

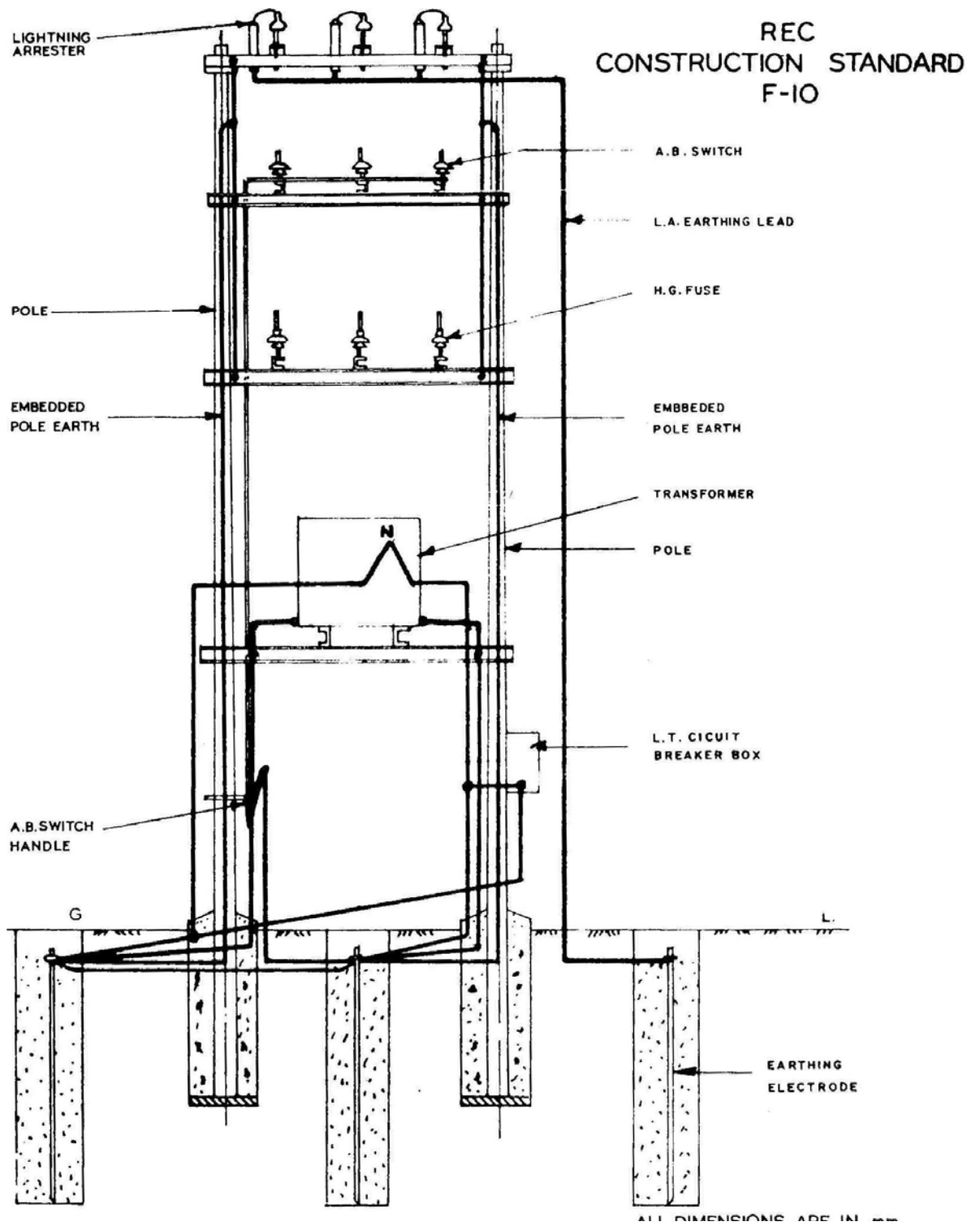
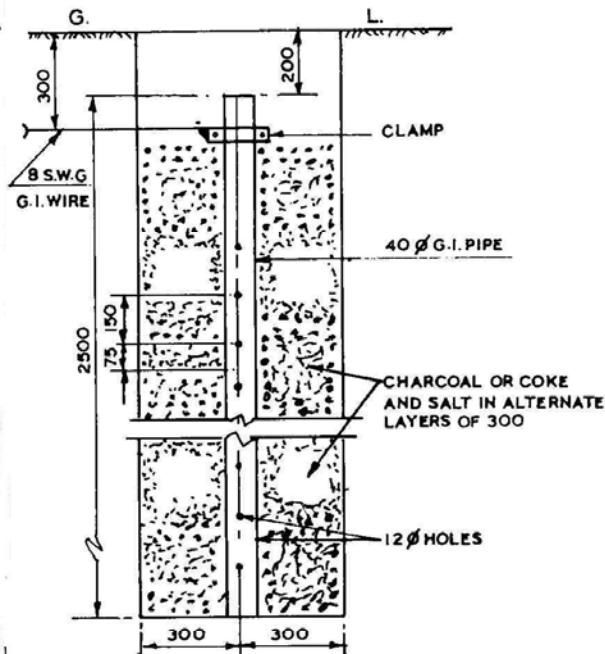
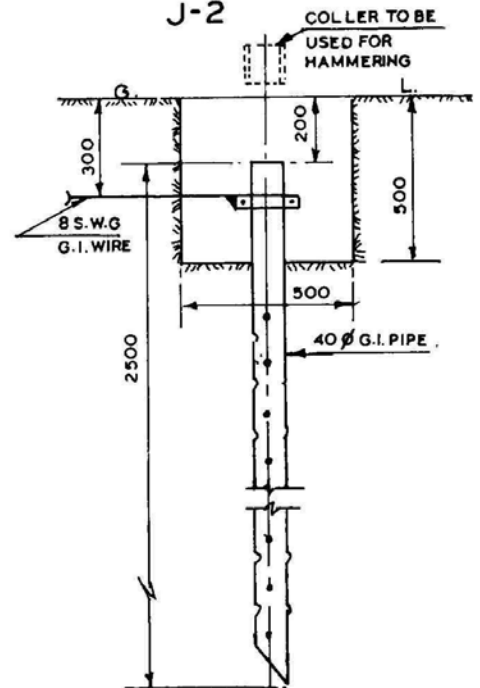


Fig. 4.1 (a) – Substation Earthing (Pole Mounting)

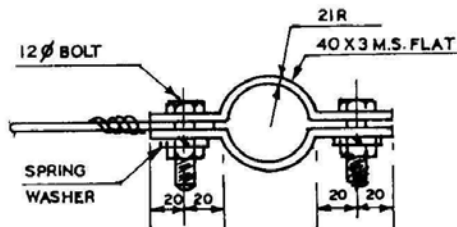
REC
CONSTRUCTION STANDARD
J-2



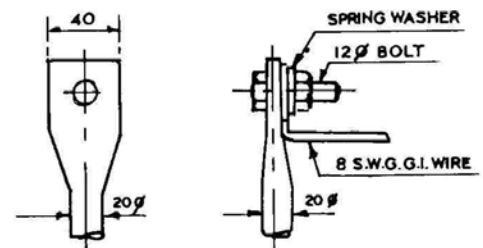
EARTHING FOR HARD, STIFF
OR MEDIUM CLAY



EARTHING FOR ORDINARY SOIL
WHERE PIPE COULD BE HAMMERED IN



TYPICAL DETAIL OF CLAMP
FOR PIPE EARTH



TYPICAL DETAIL OF CONNECTION
FOR ROD EARTH

ALL DIMENSIONS ARE IN mm.

NOTES:-

1. ALTERNATIVELY 20 ϕ G.I. ROD MAY BE USED INSTEAD OF PIPE.
2. WATER TO BE POURED INTO SUMP TO KEEP THE SOIL SURROUNDING THE EARTH PIPE/ROD MOIST.
3. FOR COIL EARTHING REFER CONSTRUCTION STANDARD. J-1.

Fig. 4.1 (b) – Rod Earthing

4.1.3 Soil Resisting Measurement

4.1.3.1 Soil Resistivity Measurements

4.1.3.2 Period of Tests: Estimates based on soil classification permits only a crude approximation of the resistivity. Therefore for obtaining an accurate data on the soil resistivity, field tests at the site are very essential. Further in order to know the effects of temperature and moisture content, the tests may be performed in the hottest month of June before rains; then sometime in the month of September and again in the coldest months of December/January.

4.1.3.3 Test Locations: The area at the station site should be covered adequately by conducting resistivity measurements at several positions as shown in Fig. 4.2; and with different probe spacings to get an indication of any important variations of resistivity with location or depth.

4.1.3.4 Extent of Probe-Spacings: It can be shown that the portion of the earth, which has an influence on the station ground resistance, extend down to a depth roughly equal to the station equivalent radius “r” (the radius of a circle, having the same area as the station grounding net-work). This means that to establish the nature of the soil at a given site for grounding design; the resistivity tests should be performed, as far as practicable, with probe spacings upto the station equivalent radius.

4.1.3.5 Formulae for equal probe spacing: Resistivity measurements should be done by the conventional 4-probe method described by Dr. F. Wenner of the U.S. Bureau of Standards. This consists of driving two current probes and two intermediate potential probes into the earth at equal distance apart and in a straight line, to a depth, as shown in Figure 4.3. An earth tester circulates a current I between the outer two probes. Due to this current, a potential difference is established between the two potential electrodes equal to I x R where R is the resistance of the earth between the potential electrodes. The ratio IR/I i.e., the resistance of the portion of the earth between two inner electrodes is indicated directly on the earth tester. Using this value of the resistance, the resistivity of the soil is found out from the equation.

$$\rho = \frac{4\pi SR}{1 + \frac{1+2S}{\sqrt{S^2 + 4Z^2}} - \frac{2S}{\sqrt{4S^2 + 4Z^2}}} \quad (1)$$

Where

ρ = resistivity of soil in ohm-meters.

R = resistance measured on the instrument in ohms.

S = Probe spacing in meters.

Z = depth to which probes are driven, in meters.

(ii) When Z is less than $1/15^{\text{th}}$ of the probe spacing; the foregoing equation can be further simplified to

$$\rho = 2\pi SR \quad (2)$$

- (iii) For very large probe spacings equal to station radius “R”, which might easily be several hundred feet, 4-electrode method with equal probe spacings of that order is hardly practicable. Further, One short-coming of this method has been the rapid decrease in magnitude of potential between the two inner probes, when probe spacing is increased to relatively large values. This has often resulted in inadequate sensitivity and inability to obtain low resistivity readings at wide probe spacings because of the range of limitations of test instruments.

4.1.3.6 Formulae for unequal probe spacings

- (i) A method of expanding the range of measurement and thus improving sensitivity, is by increasing the potential probe spacing as described by L.S. Palmer and A.L. Kinyon. The spacing is increased equally in each direction, keeping each potential probe a like distance from its adjacent, current probe as shown in Fig. 3 and the resistivity is calculated from the formulae.

$$\rho = \pi R \frac{S^2 + S}{Q} \quad (3)$$

Where

ρ = the measured resistivity of soil in ohm-meter
 S = distance from C_1 to P_1 and C_2 to P_2 in meters
 Q = distance from P_1 to P_2 in meters
 R = instrument reading in ohms

- (ii) The above equation can also be written in the following form.

$$\rho = \frac{1 - \alpha^2}{2\alpha} . aR \quad (4)$$

Where

α = ratio of distance between potential electrodes to that between current electrodes
 A = one-half distance between current probes

Testing Kit

A soil resistivity testing “Kit” should consist of

- | | | |
|-----|--|---------|
| i) | 4-terminal Megger Earth Tester range 0-2; 10;100;1000;10000 ohms | 1 No. |
| ii) | Electrodes, about one meter long | 10 Nos. |

Note : The electrodes should have cross-bars welded near the top of the rod of facilitation their extraction from the ground.

- | | | |
|------|--|-------------|
| iii) | Leads, P.M.C./ insulated; 2.5 mm ² (1/1.80 Al.) | |
| | 150 meters reel | 1 No. |
| | 75 meters reel | 2 Nos. |

- iv) Short instrument leads.
- v) Sledge hammer, 5 to 8 lbs. 2 Nos.
- vi) Measuring tape 100 ft... 1 No.
- vii) Tools-pliers, wrenches, clips etc.

Note: For test connections; test procedure and correction factors if any; reference should always be made to the instruction booklet supplied with the instrument.

4.1.3.7 Earth Resistivity Curves

For a homogeneous soil, the value of resistivity thus obtained will be independent of the probe spacing. In actual fact, the ground is never homogeneous. There may be wide horizontal changes and significant vertical variations in the soil structure. However, as the lateral changes in the composition of soil are usually small and gradual, compared with vertical ones; the soil resistivity is normally considered as a function of depth only.

Further in a 4-probe method, the penetration of current and hence the resistance is roughly limited to a depth corresponding to the probe spacing. Thus more frequently than not, the resistivity as measured by the 4-probe method will vary with probe spacing. This variation usually indicates, a soil resistivity, which varies with depth. A plot of the measured resistivity should therefore be drawn against the probe spacing known as “Earth Resistivity Curve”. At a particular site, a number of such curves are drawn for different locations as shown in Fig. 4.5 and an average curve is evolved. This average resistivity curve is then analysed.

Resistivity measurement records should include temperature data and information as to the dry ;or moist condition of the soil at the time the resistivity is measured. Metallic objects (like rails, pipes, wires etc.) buried, or in contact with the soil can invalidate readings made by the method described above, if they are close enough to alter the test current flow pattern appreciably. All data available on buried conductors known or suspected to be in the area studied should therefore be recorded and tests should be done at such locations twice, with probes in two mutually perpendicular directions.

4.1.3.8 Uniform (Homogeneous) Soil

If the variation in the resistivity is less than 30%; ;the soil in the vicinity of test location can be considered homogeneous and an average value determined from the resistivity curve is adopted for design purposes. If the variation is more than 30%, the soil cannot be treated as uniform and the analysis of the curve is needed.

4.1.3.9 Non-Uniform Soil

In the non-uniform soil, where the soil resistivity varies markedly with probe spacing, a designer would like to know the value of apparent soil resistivity “ ρ_a ” that he should adopt for the design purposes; so that the calculated resistance of the grounding system approximately equals the measured resistance after the installation of the grounding system. This may be done in accordance with C.B.I.P. (Central Board of Irrigation Power) manual No.

4.1.4 Conductor for earthing mat and work steel flats with proper allowance for corrosion are used. – Standard sizes of conductor for earth mats as per IS 1730-1989 as follows:

- | | | | |
|------|-------------------------|------|------------------------|
| i) | 10 x 6 mm ² | ii) | 20 x 6 mm ² |
| iii) | 30 x 6 mm ² | iv) | 40 x 6 mm ² |
| v) | 50 x 6 mm ² | vi) | 60 x 6 mm ² |
| vii) | 50 x 8 mm ² | vii) | 65 x 8 mm ² |
| ix) | 75 x 12 mm ² | | |

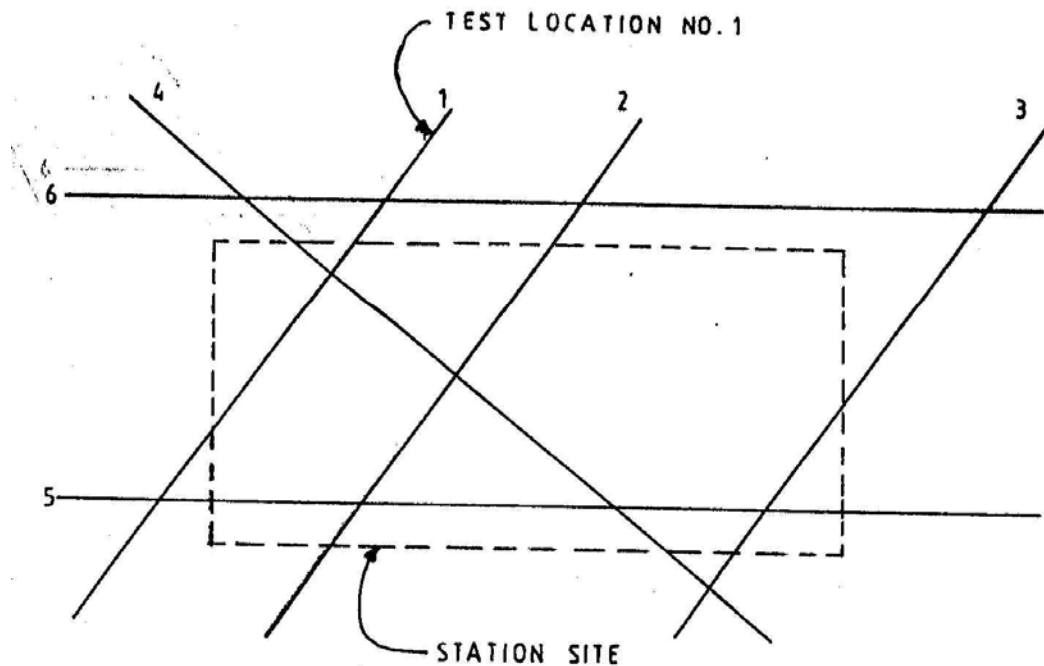


Fig. 4.2 Resistivity Test Locations

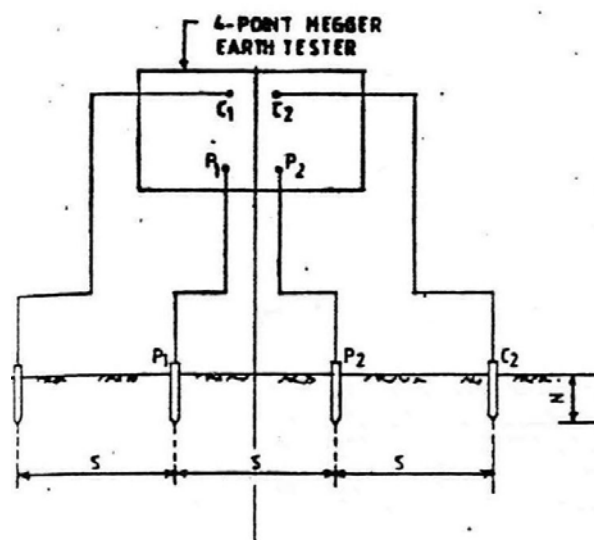


Fig. 4.3 Measuring Earth Resistivity with Equal Probe Spacings

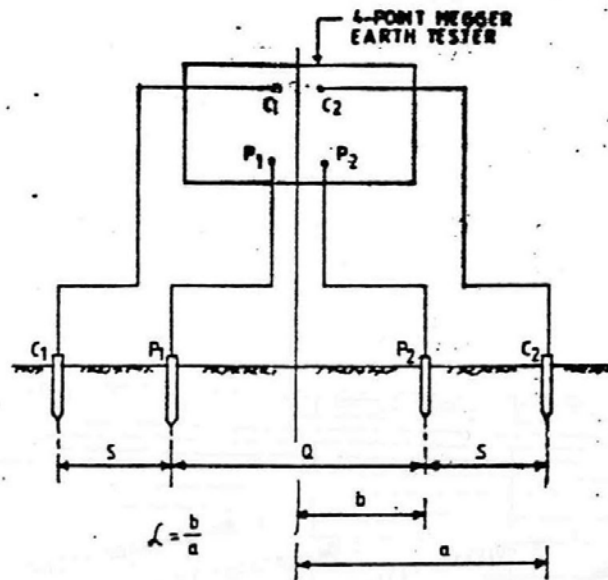


Fig. 4.4 Measuring Earth Resistivity with Unequal Probe Spacings

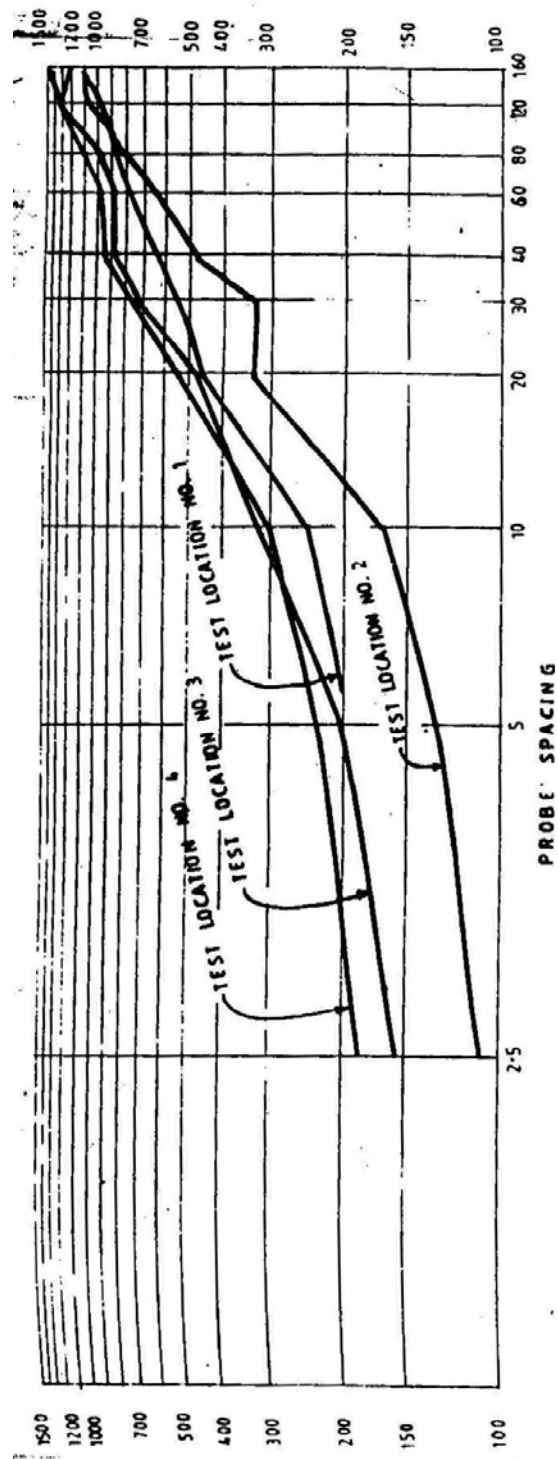


Fig. 4.5 Resistivity test Curves for the Month of June

4.1.5 Installation of Grounding System

4.1.5.1 Introduction

This instruction lays down the method of grounding system including layout of grounding system in small and large hydro stations. These instructions primarily pertain to

the grounding system with steel grounding strips as the main conductor. The instruction outlined herein are issued to:

- i. Assist the work of designer by avoiding repetition of grounding details of layout drawings, as these details can be better referred to in here, with considerable saving in time.
- ii. Assist the field authorities to arrive at on the spot decisions necessary during installation.

4.1.5.2 Code Applicable

The grounding shall generally be carried out in accordance with the requirements of Indian Electricity Rules as amended upto-date & in accordance with I.S. 3043-1987 as far as practicable.

4.1.5.3 Installation of Grounding System

General

- i. Grounding conductors shall consist of mild steel strips for ground net-work and mild steel rounds for ground rods.
- ii. Grounding strips used for end connections to the equipment are galvanised.
- iii. Connectors like bolts, nuts, etc. used for grounding the equipment are galvanised.

Ground Mats and Test Terminal Boxes

- i. All grounding strips in the ground mats are laid in position as per typical methods shown in Annexure-I figure 7&8, unless otherwise stated. When the grounding strips have been laid in trench, it shall be covered with excavated base material mixed with clay if possible and filled upto half the depth of the trench. The remaining half of the trench shall be filled with lean concrete so that the strip remains securely in position. A thick coat of bitumen may be applied over it if necessary so that it does not bond with the concrete which may be placed over it.
- ii. The ground rod are fixed in position first by drilling a vertical hole of about 70 mm dia into the ground, then placing the rod centrally inside. Drilled base material mixed with clay, if available, are then poured into the hole all around by little and compacted at short intervals by ramming with a suitable dia hollow C.I. pipe having a socket at the lower end. In locations where there is clay or soft soil, the ground rods can be driven in the ground by an augur (figure 6).
- iii. In the installation of grounding strip the field authorities are in a better position than the designer to judge whether the mat is adequately anchored. They should feel free to add additional anchors but should never use less than those indicated on the drawings.

- iv. For rust protection, welded joints in the soil shall be thoroughly brushed, provided with a coat of shalimastic H.D. paint and wrapped with asphalt saturated cotton fabric tape/hessian cloth impregnated with shalimastic H.D. Paint followed by another coat of shalimastic H.D. paint.

Alternatively welded joints may be protected by grouting concrete of not less than 40 mm thickness.

Grounding Net-Works

- i. Installation of grounding strips are carried out in accordance with the grounding system network drawings, but field may deviate to clear possible obstructions keeping in view the technical requirements.
- ii. The route of embedded grounding strips between two connected points are by the shortest distance.
- iii. Main grounding strips inside the power plant building are laid surface embedded on the walls as per Figure 13 so that these can be tapped easily later on for connection to the individual equipment, which may or may not have been covered in the net work drawings.
- iv. Embedded equipment such as frames for lighting distribution boards, power outlets, misc. raceases etc., are grounded by electricity welding the grounding strip to such equipment. For all other equipment, which is to be installed at a later stage, grounding strip stub of at least 3000 mm length is provided near such equipment for grounding. For equipment fixed on the wall, stubbing should be from the wall and not from the floor or the tapping for this purpose shall be taken from the surface embedded grounding strip on the walls by an exposed grounding strip. It means that any tapping for grounding purpose taken only from grounding ring laid surface embedded on the walls.
- v. Cable racks on the walls and in cable trenches is welded directly to the grounding strips provided for the purpose. Cable racks installed on the floor and fixed under the ceiling is grounded at two points. (preferably entrance ends) and the different sections of the racks is bonded separately by a grounding .. to ground the entire cable rack effectively.

4.1.5.4 Jointing Of Grounding Strips

All joints between grounding strips and between grounding strips and ground rods shall be by electrical welding. At the time of welding, the jointing surface is cleaned by sand blasting or by other convenient means. The joint is clamped tightly to ensure that a good surface contact exists. Typical details of welded joints are shown in figure 1, 2, 3, 5 & 8.

4.1.5.5 Connections To Equipment

- i. Exposed surface of all electrical equipment must be grounded and non-electrical items like mat hand-rails, hauch cover frames. Cable rack support etc., should be grounding. In reinforced concrete structure most structural elements such as windows, frames, grills and louvers need not be grounded. Economy does not permit grounding of metal parts.
- ii. The frame of every generator, motor, circuit breaker and the metallic parts (not intended as conductors) of all transformers, and regulating or control apparatus connected with the supply shall be grounded by two separate and distinct connections.
- iii. The metal conduits, armour and/or sheath of a cable may be used as ground conductor and should be earthed at one point only (preferably at the source end) in the following cases : -
 - a. Conduit, armour and/or lead sheath of single phase cable.
 - b. In long runs, insulating sleeves are occasionally installed in the lead sheath, thus breaking up long sections and reducing sheath potentials. Each section of the lead sheath should be grounded. Grounding the same lead sheath of a single phase cable at both ends intentionally or accidentally may over heat the cable and should be avoided.
- iv. Three phase cables shall have the lead sheaths grounded at both ends in all cases.
- v. Metallic junction or pull boxes not containing protective equipment, and in which conduits are installed with a socket and metallic bush are not considered a break, when the voltage is below 240 volts to ground, but shall be so considered for higher voltages.
- vi. All junction and pull boxes in the runs of non-metallic conduits as well as these containing overload protective devices are individually grounded.
- vii. All paint, enamel, and scale is removed from the point of contact on metal surfaces before making ground connections.
- viii. In switchyard any items of equipment not covered by grounding system layout drawings and which are so located that there is some chance of a high-tension conductor flashing to or coming in contact with them must also be grounded with individual connections.
- ix. Where some arrangement for grounding is already provided on the equipment by manufacturers, that arrangement should be used for grounding if suitable for the size of grounding strips specified in the net-work drawing concerned. The mode of connection may not be the same as shown in typical equipment connections.
- x. The bases of lightning arrestors are directly connected to the grounding test terminal box (G.T.T.B.) of SYSTEM by grounding strips as short and straight as practicable to ensure minimum impedance.
- xi. For lightning arrestors mounted near the transformers, grounding strips are located clear of the cable and coolers in order to avoid possible leakage caused by arcing.
- xii. Typical grounding strips connections to various equipment are shown in Figure 4, 9, 10 & 11.

4.1.5.6 Precautions

- i. Grounding strips should never be run through a steel conduit or through an opening in the floor or walls of magnetic material. It may be run in either fibre conduit or conduit of non-magnetic material.
- ii. Grounding strips should never be laid close to or parallel to generator single-phase main-leads or single core power leads and the distance or separation should not be less than 300 mm. This will be shown on the drawings concerned.
- iii. Current transformer secondary circuit should never be grounded at more than one point.

4.1.5.7 Ground Mat Resistance

After the grounding system is laid, actual measurement shall be taken and remedial measures if any required will be devised by the field to bring down the resultant grounding resistance within safe limits.

NOTES

1. All dimensions are in mm unless otherwise stated
2. All joints between ground strips and ground rod should be made electrical welding. at the time of welding the jointing surface should be cleaned by sand blasting or by other convenient means. The joint should be clamped tightly so that a good surface contact exists.
3. For straight joints between ground strips an overlapping not less than twice the width of plate should be made for welding typical angle joints and t-joints are shown in figure-3 and figure-4 respectively. Typical welded connection between ground rod and ground strip is shown in figure-9.
4. Main grounding strips ring in side the power plant building should be laid surface embedded on the wall as shown in fig-14. So that these can be tapped easily later on for connection to individual equipments, which may or may not have been covered in the network drawing.
5. The frame of every generator, motor, control panels and the metallic parts of all transformer connected with the supply should be grounded by two separate and distinct connections.
6. Any tapping for grounding purpose shall be taken only from grounding ring surface embedded on the walls.

Annexure –1 Installation Details

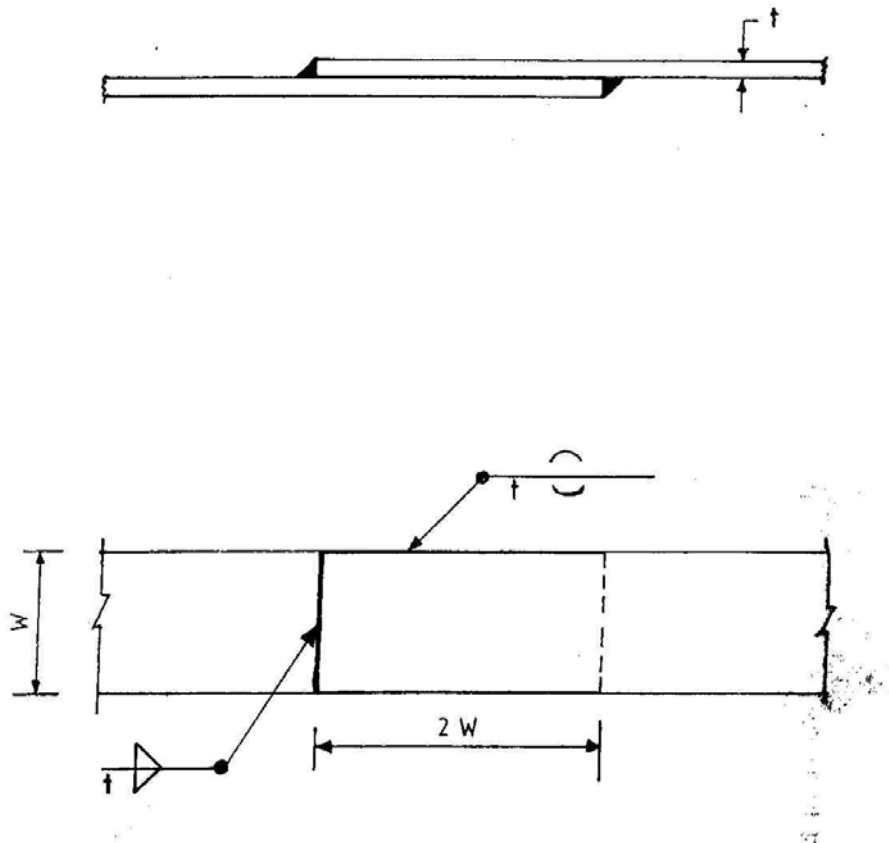


Fig. 4.6 - Welding Detail of Straight Joint (Typical)

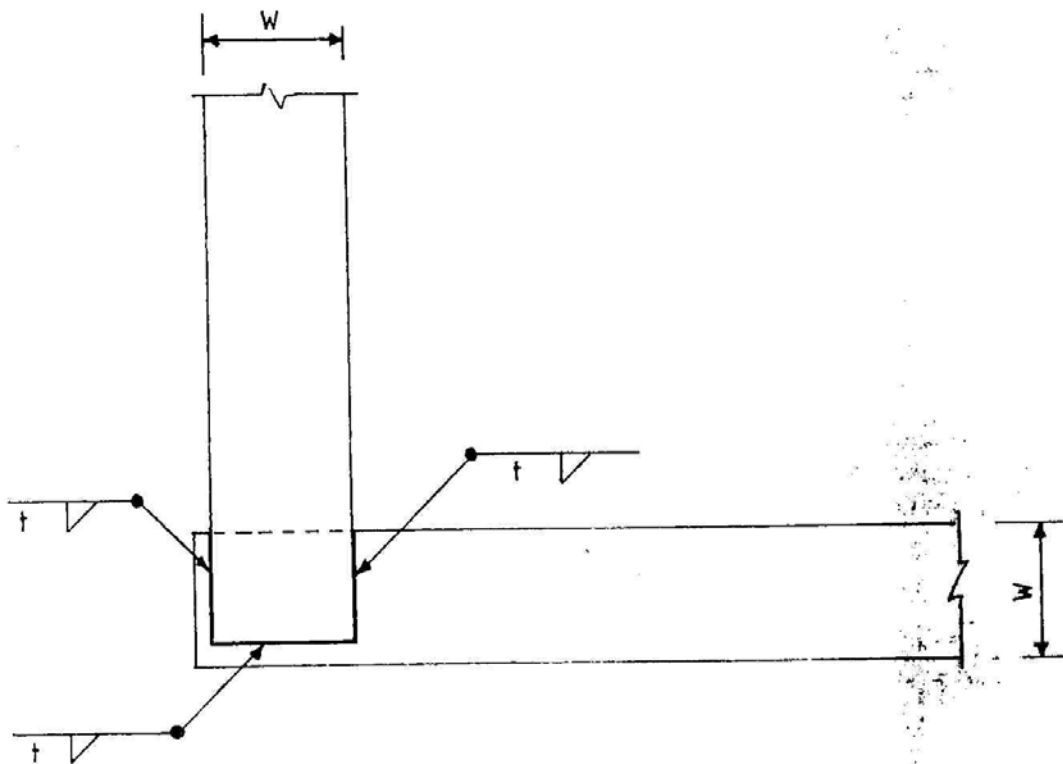


Fig. 4.7 - Welding Detail of Angle Joint (Typical)

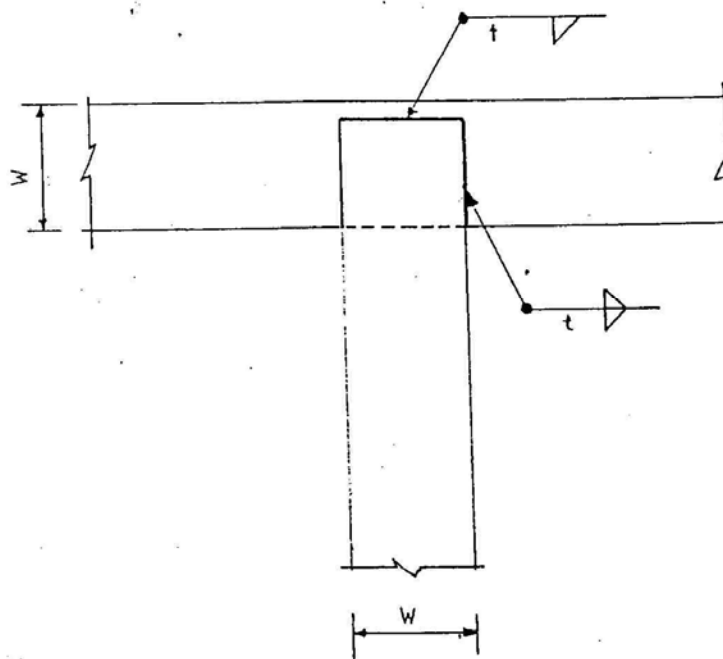


Fig. 4.8 - Welding Detail of Tee Joint (Typical)

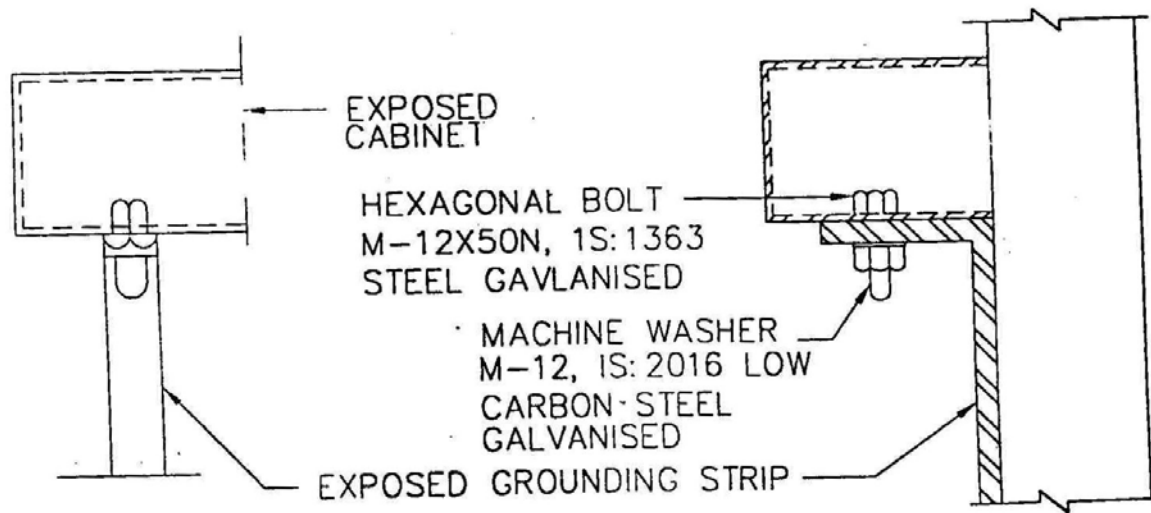


Fig. 4.9 - Welding Connection to Exposed Cabinet

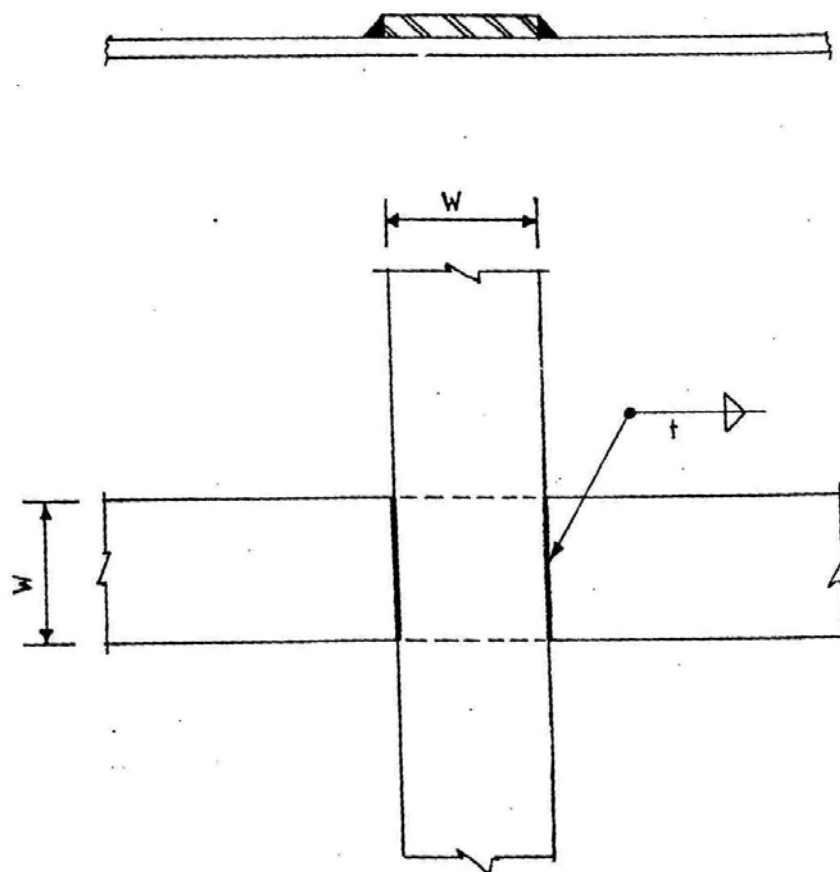


Fig. 4.10 - Welding Detail of Cross Joint (Typical)

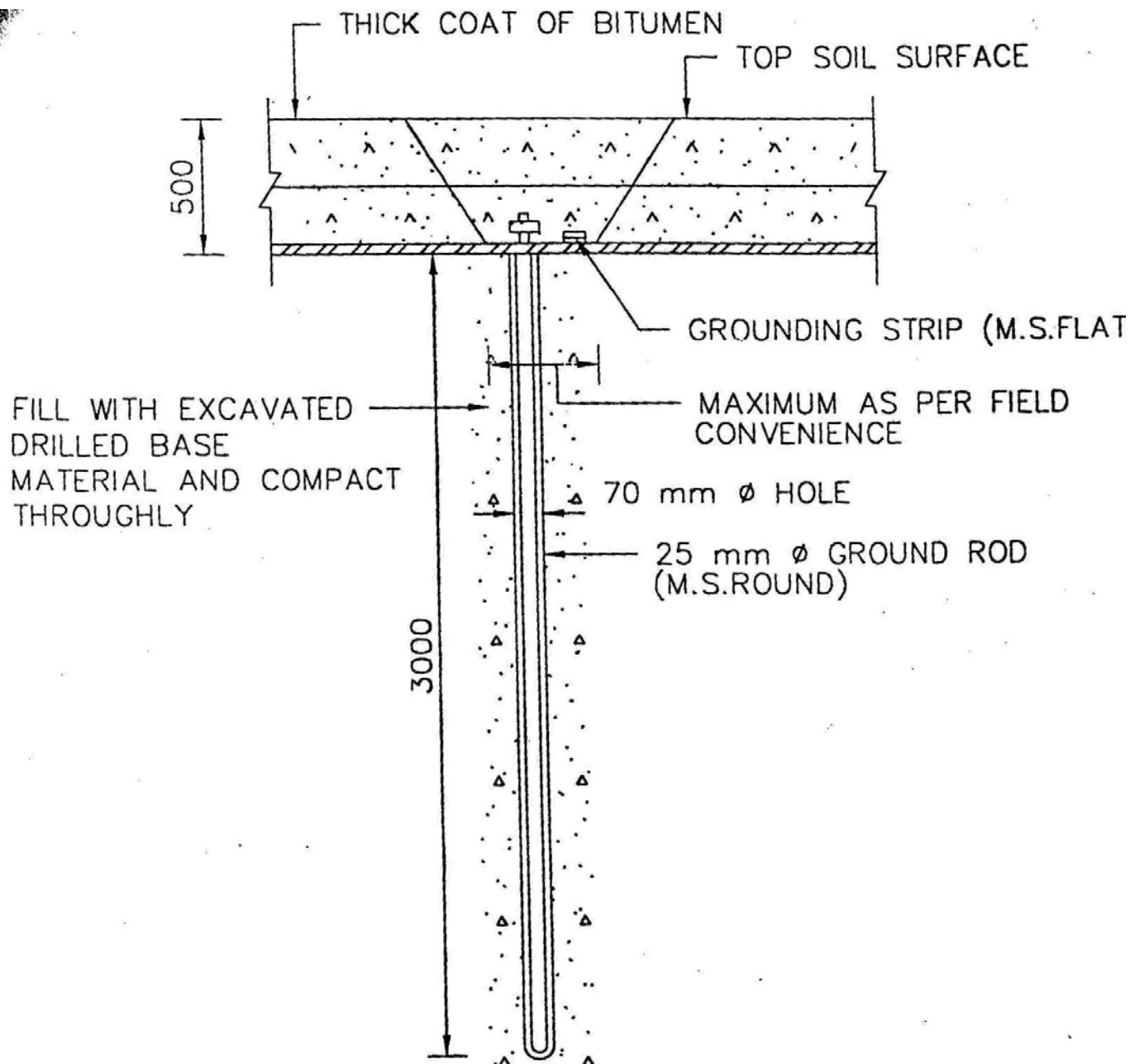


Fig. 4.11 – Installation of ground Rod (scale 1 : 25)

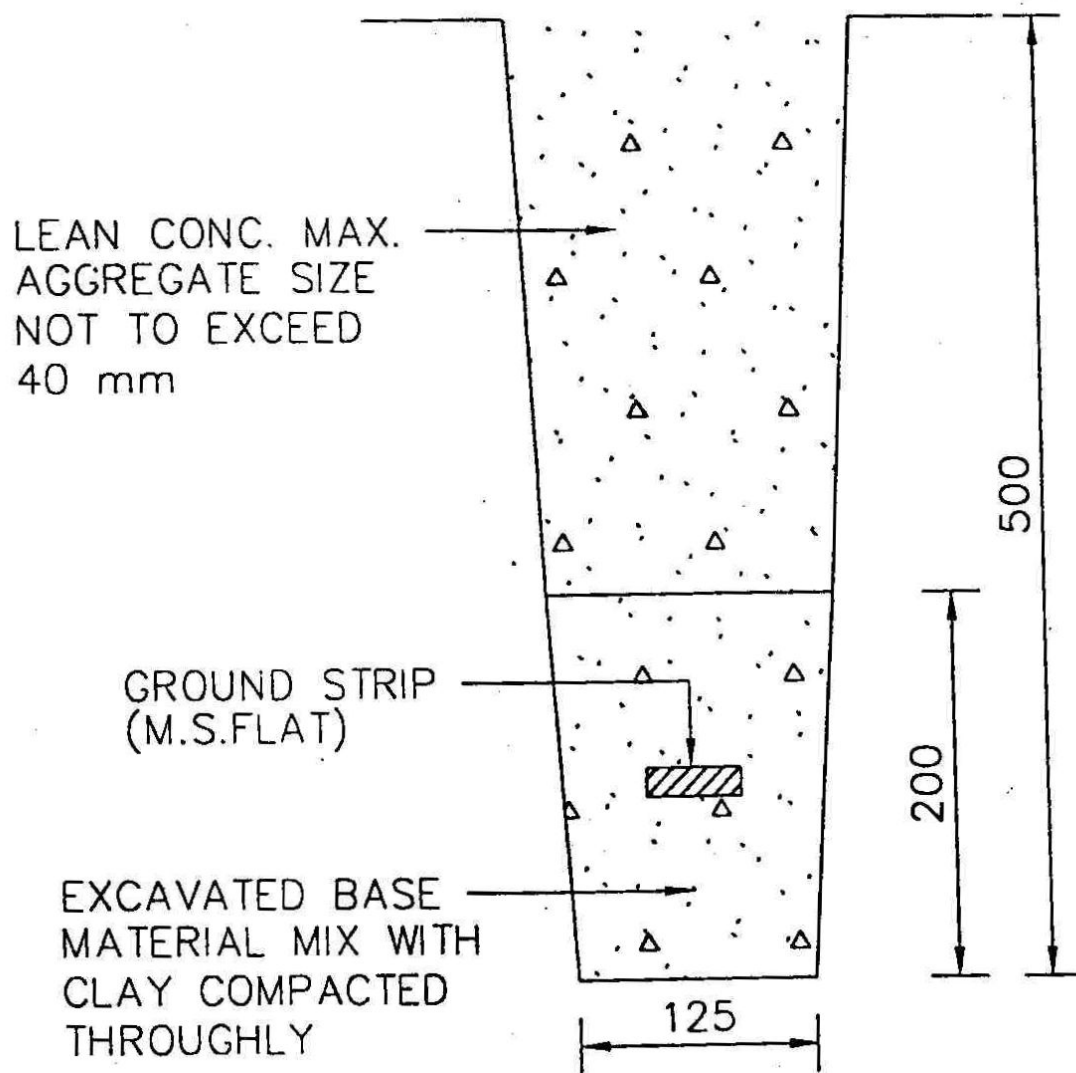


Fig. 4.12 – Installation of Ground Strip of Ground Mat (scale 1: 5)

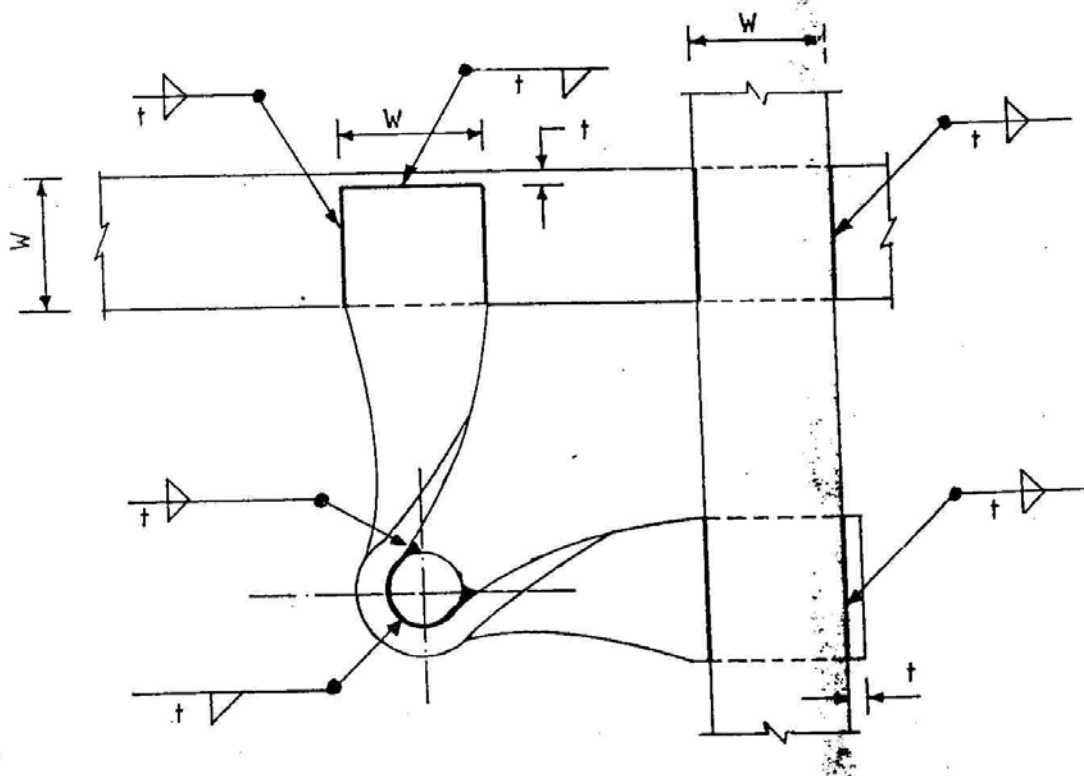


Fig. 4.13 – Welding Detail of Connection Between Ground Rod and Grounding Strips (typical)

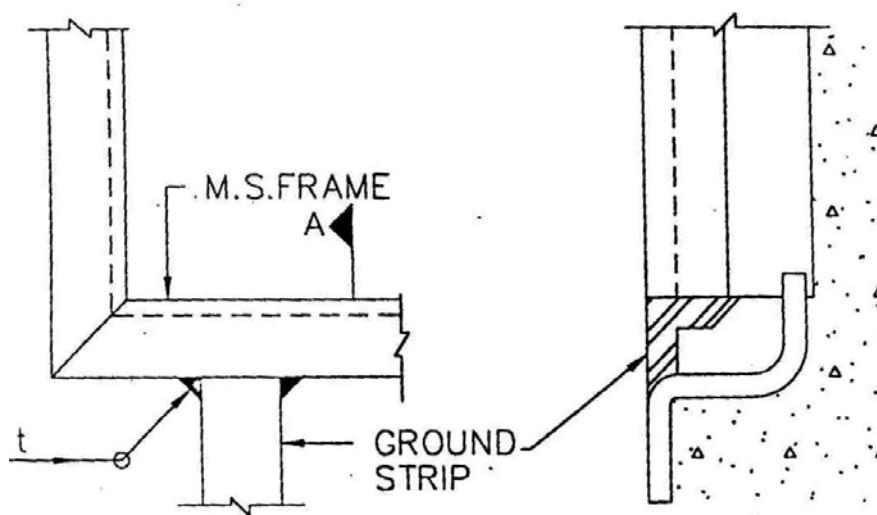


Fig. 4.14 – Welded Connection to Recess Frame

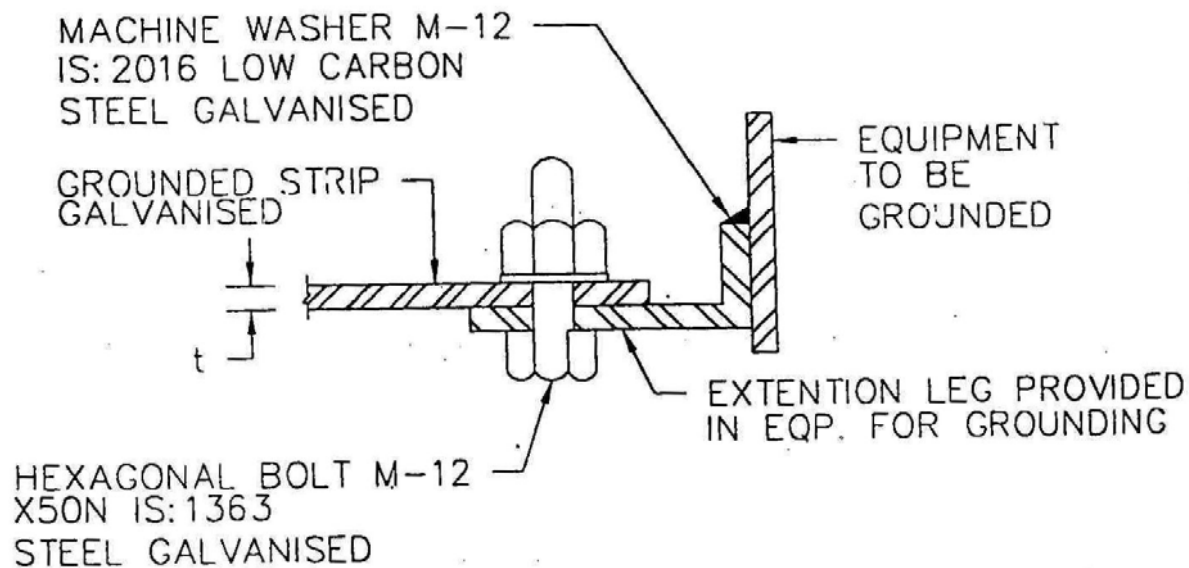


Fig. 4.15 – Bolted Connection to Extension Leg

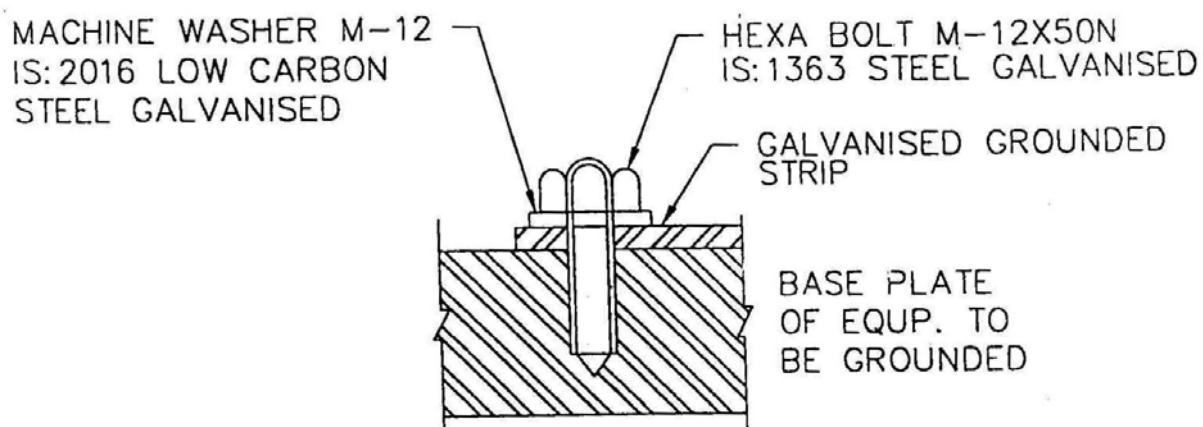


Fig. 4.16 – Bolted Connection to Base Plate

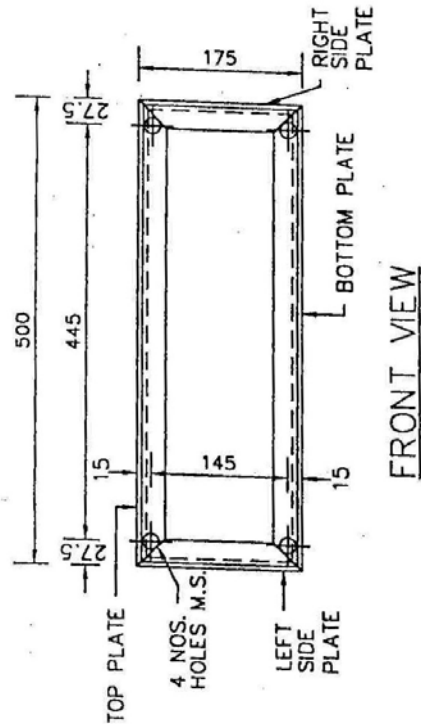
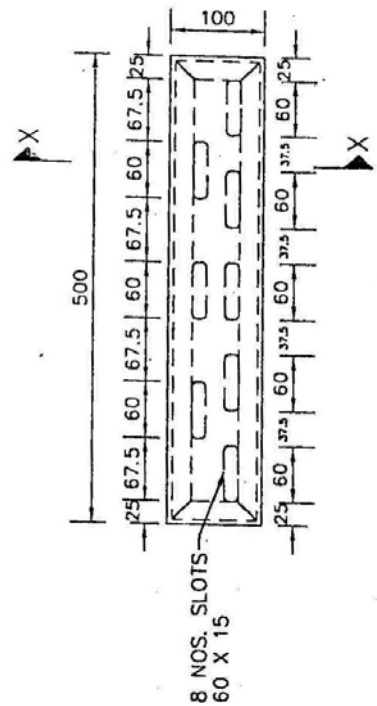
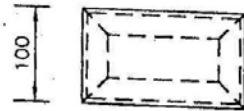
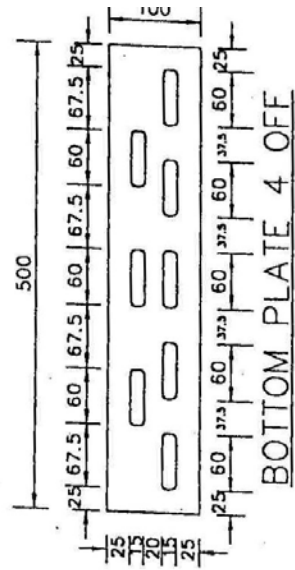
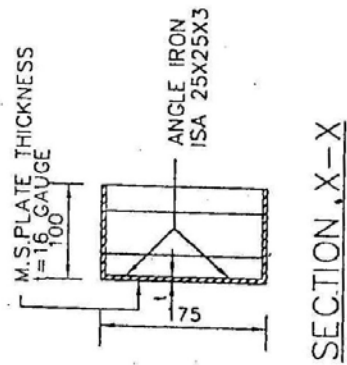
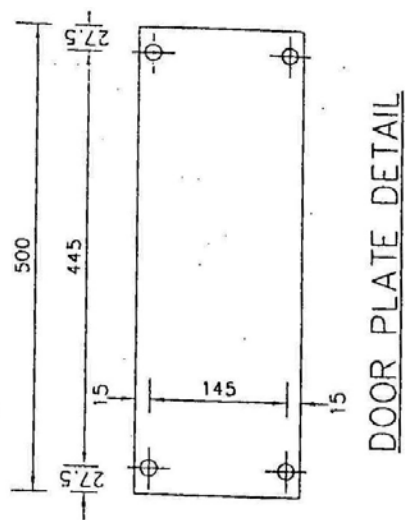


Fig. 4.17 – Details GTTB

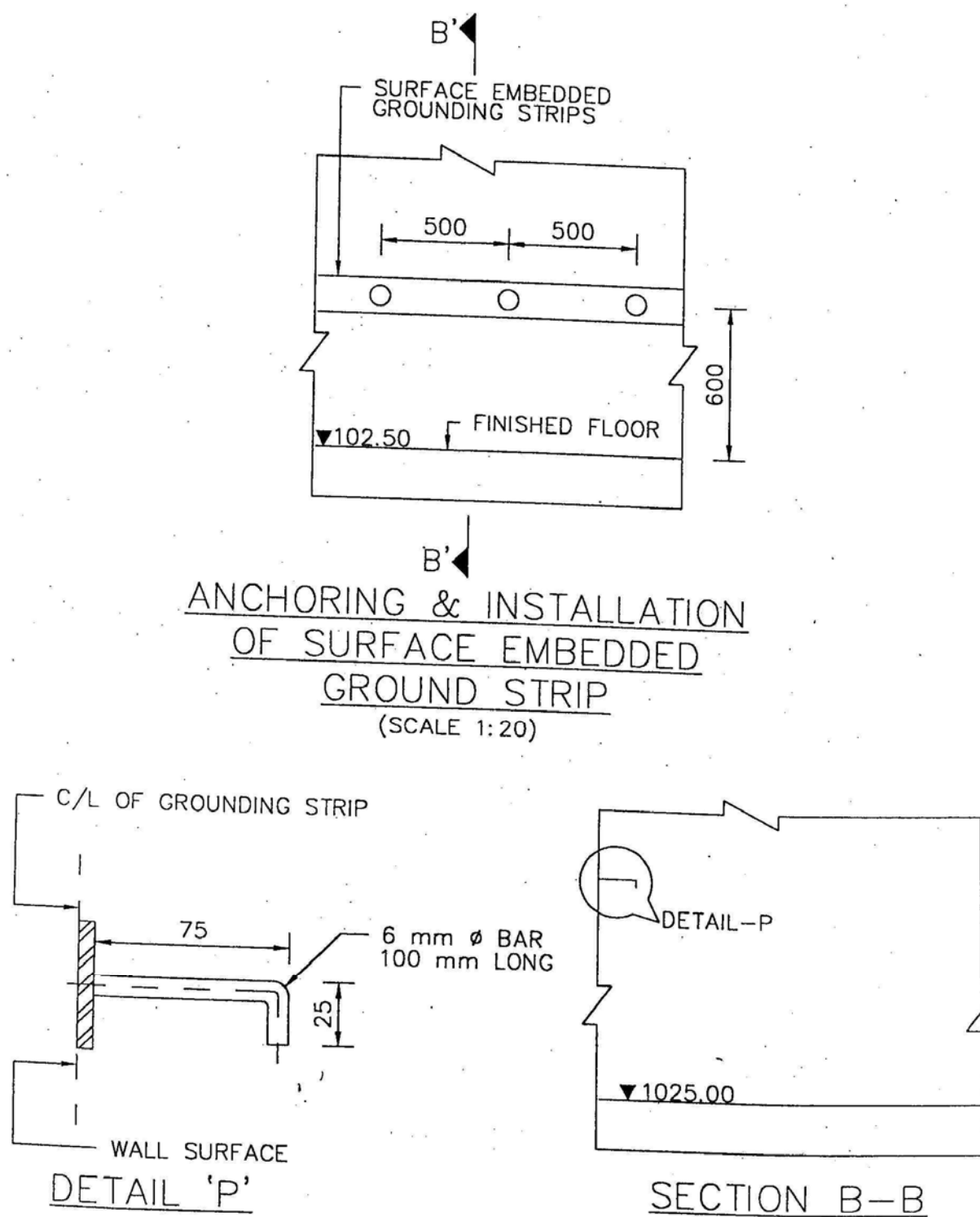


Figure 4.18

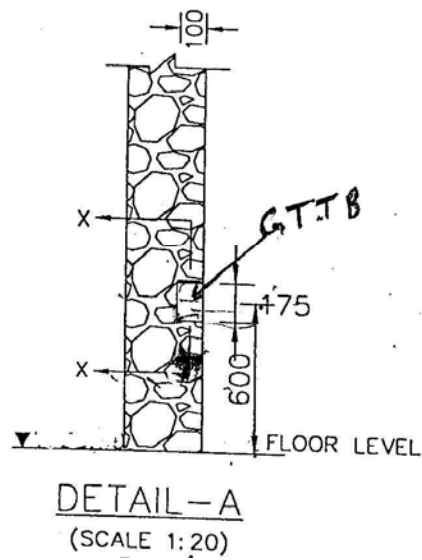
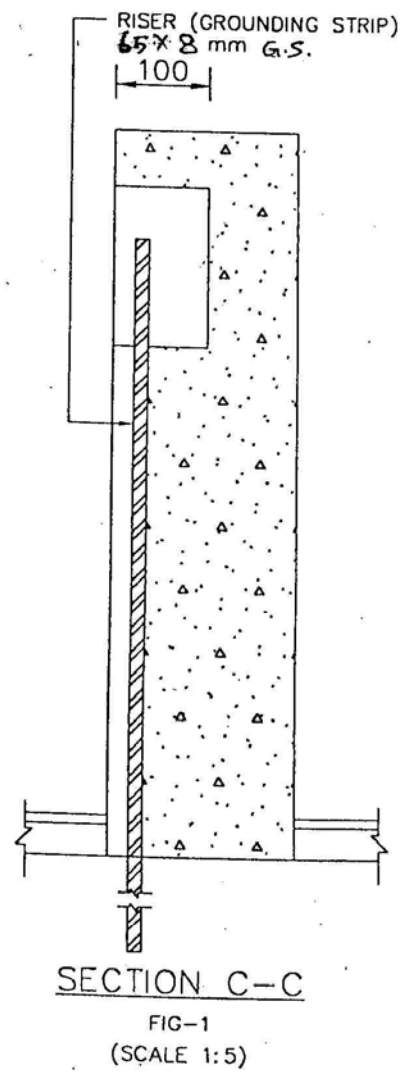
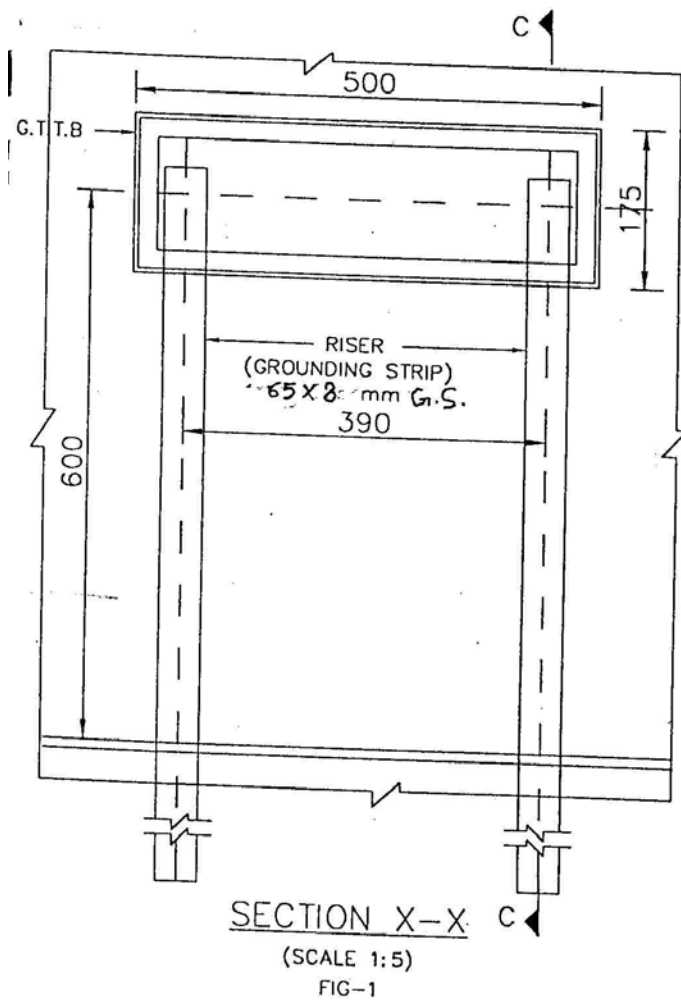


Figure 4.19

4.2 GENERATOR OPERATING, PRINCIPLE AND E. M. F. EQUATION

Electromechanical energy conversion takes place whenever a change in flux is associated with mechanical motor. Accordingly two major components of the generator are the rotor and the stator. The rotor is the rotating assembly to which the mechanical torque of the turbine shaft is applied. By magnetizing or “exciting” the rotor, a voltage is induced in the stationary component, the stator. The principal control mechanism of the generator is the exciter-regulator which sets and stabilizes the output voltage. The speed of the generator is determined by the turbine selection.

4.2.1 Generalized Picture of a Synchronous Machine

A synchronous machine consists of magnetic circuit, electrical circuits, and mechanical supports.

The magnetic circuit consists of duplicate poles, which are alternately north and south magnetically; and it is, in general, necessary to consider only one pair of poles in developing the electrical characteristics of a synchronous machine.

Figure 4.1 shows the simplified version of an ac synchronous generator with a 2-pole field winding on the rotor and a single coil aa'' on the stator. This type of rotor poles are known as salient (projecting) poles; and are excited by means of dc fed to the connected field winding. The current is fed to the rotor via two slip-rings and carbon brushes as shown in fig. 4.1.

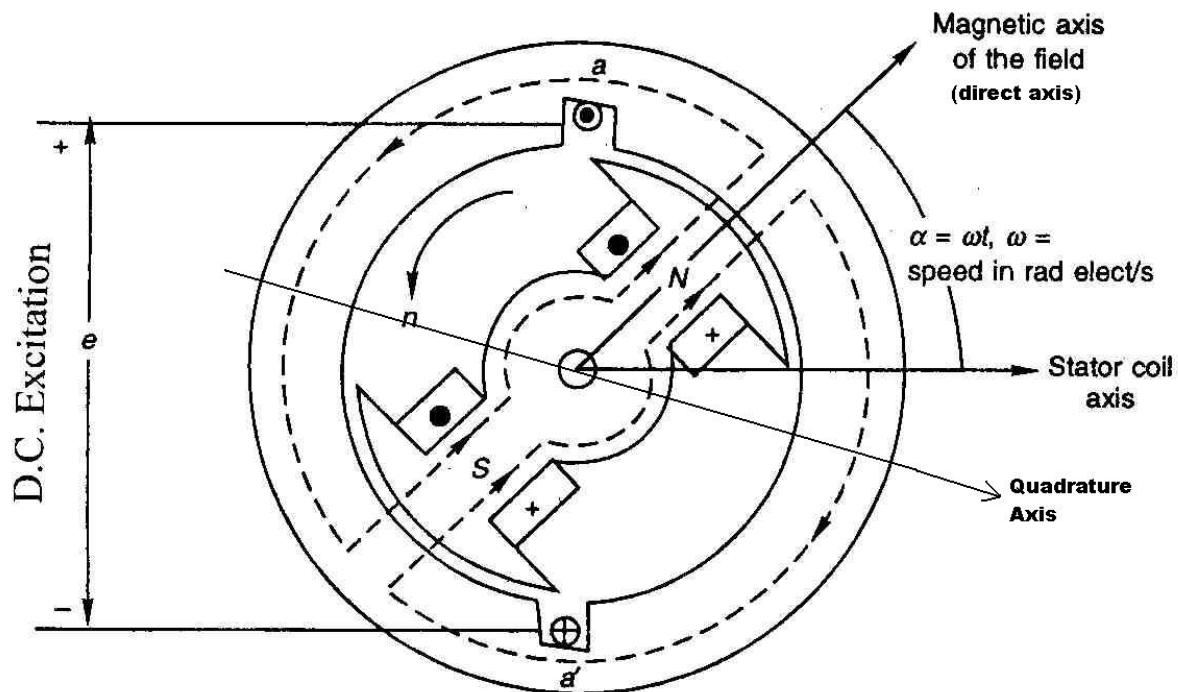


Fig. 4.20 Elementary Synchronous Generator –Salient Pole 2-Pole rotor

4.2.2 Electrical and Mechanical Degree

It is customary to refer to a cycle as 360 elec. deg because the voltage wave is sinusoidal and one cycle of a sine wave is 360 deg. Thus one pair of poles always represents 360 elec. deg, although the number of mechanical degrees a pair of poles occupies on the periphery of the rotor is only 360 deg divided by the number of pairs of poles.

4.2.3 Synchronous Speed

Two poles must pass a given point on the stator every cycle, so that:

$$\text{Rpm} = \frac{\text{cycles per minute}}{\text{pairs of poles}}$$

Standard frequency of power supply is 50 cycles/sec. Accordingly synchronous speed of generator in India in RPM (revolution per minute) = $\frac{60 \times 50}{\text{pair of poles}}$

Synchronous speed for 2 pole (1 pair) machine = 3000 rpm

Speed of hydro generator is determined by the hydro turbine to which it is coupled. Hydro generators are slow speed machines.

Bhakra generators are 36-pole machine with a synchronous speed of 166.7 rpm $\left(\frac{3000}{18} \right)$.

4.2.4 EMF Equation- Wave Shape and harmonics

Electromagnetic Induction

The law of electro-magnetically induced emf may be stated in two ways: (a) Voltage is proportional to rate at which a moving conductor cuts flux: (b) voltage is proportional to rate of change of flux linkage in a circuit. For alternator emfs, (a) will ordinarily be more convenient.

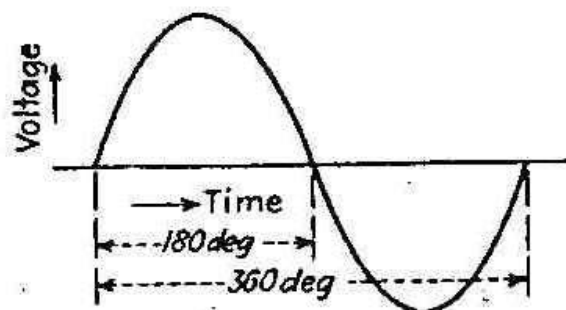


Fig. 4.21 One Cycle of the Voltage Wave of a Synchronous Machines

Hydro-generators are low speed multipole synchronous generator. For deriving emf equation, we will consider a two pole machine. The flux density in the air gap is assumed

sinusoidal and is shown in fig. 4.2.3 and a single full pitch coil (slot side space separation π radian 180° electrical).

$$\text{Flux density } B = B_p \cos \theta$$

Where B_p is peak value of flux density (center of rotor pole) and θ is the angle in radians measured from rotor pole axis.

Flux linkages are $N\phi$ where ϕ is flux per pole and N is the number of turns per pole. Flux per pole is the integral of flux density over the pole area. For a two pole machine having r is the radius at air gap and l is the axial length of the stator flux per pole.

$$\phi = \int_{-\pi/2}^{\pi/2} B_p \cos \theta (lr d\theta)$$

$$\phi = 2 B_p lr$$

as the rotor moves, flux linkages vary the cosine of angle α between the magnetic axes of stator coil and rotor. When rotor is moving at constant angular velocity ω the flux linkages λ are

$$\lambda = N\phi \cos \omega t$$

the emf induced in the stator coil is

$$e = -\frac{d\lambda}{dt} = \omega N\phi \sin \omega t$$

Thus the maximum value of induced emf is $\omega N\phi$. The rms value E is

$$E = \frac{\omega N\phi}{\sqrt{2}} = \frac{2\pi f N\phi}{\sqrt{2}}$$

$$E = 4.44 f N\phi$$

When the winding is distributed in slots, the above expression must be multiplied by a factor k_b (known as breadth factor or distribution factor). Since the windings are short pitched, the expression must be multiplied by another factor k_p (known as pitch factor). Thus the rms value of induced emf is

$$E = 4.44 f N\phi k_b k_p \quad (1 a)$$

$$\text{or } E = 4.44 f N\phi k_w \quad (1 b)$$

where

E = rms emf per phase, volts

F = frequency, Hz

ϕ = flux per pole, Wb
 N = number of turns in series
 k_b = breadth factor
 k_p = pitch factor
 $k_w = k_b \times k_p$ = winding factor

Equation (1) is the emf for fundamental frequency. To distinguish between the emfs of various harmonics, it is better to write this emf as E_1 , flux per pole as ϕ_1 and winding factor as k_{w1} . Thus

$$E_1 = 4.44fN\phi_1k_{w1} \quad (2)$$

For harmonic emf per phase is E_n flux per pole is ϕ_n frequency is nf and winding factor is k_{wn} . Thus

$$E_n = 4.44nfN\phi_nk_{wn} \quad (3)$$

4.3 HYDRO GENERATOR POWER ANGLE CHARACTERISTICS

Hydro generators are salient pole machines. In this machines the reluctance of the magnetic circuit along the polar (or direct) axis is much less than the reluctance along inter polar (or curvature) axis. Figure 4.3.1 shows a salient pole synchronous generator feeding an infinite bus. V is the bus voltage, E is the excitation voltage of generator, V_t is the terminal voltage of generator and X is the reactance of the connecting to the bus. The resistance of generator and line are negligible.

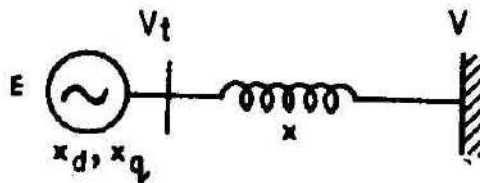


Fig. 4.22

The current I can be resolved into I_d and I_q . The phasor sum of V , $j I_d$ and $j I_q X$ gives the generator terminal voltage V_t . The phasors $j I_d X_d$ when added to V_t give the excitation emf E as shown in fig. 4.3.2.

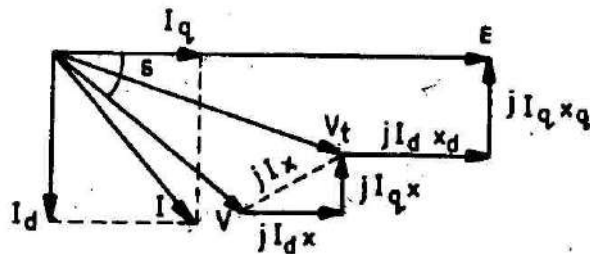


Fig. 4.23

The voltage drops $jI_d X$ and $j I_d x_d$ can be combined as $j I_d X_d$ and the voltage drops $j I_q X$ and $j I_q x_q$ can be combined as $j I_q X_q$. Thus the total d- and q-axis reactance are

$$X_d = X + x_d$$

$$X_q = X + x_q$$

The phasor diagram after combining these voltage drops is shown in fig. 4.3.3. The total power delivered by the generator can be found by resolving the bus voltage V into $\sin \delta$ (which is in phase with I_d) and $V \cos \delta$ (which is in phase with I_q). Thus

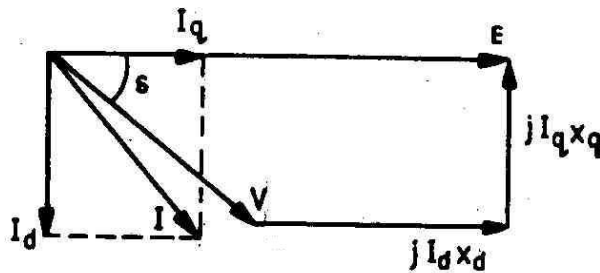


Fig 4.24

$$P = 3I_d V \sin \delta + 3I_q V \cos \delta \quad (1)$$

Form fig. 4.3.3, the currents I_d and I_q are given by

$$I_d = \frac{E - V \cos \delta}{X_d} \quad (2)$$

and

$$I_q = \frac{V \sin \delta}{X_q} \quad (3)$$

Substituting Eqs. (2) and (3) into Eq. (1)

$$P = 3(V) \left[\frac{E - V \cos \delta}{X_d} \right] \sin \delta + 3(V) \left[\frac{V \sin \delta}{X_q} \right] \cos \delta$$

$$\text{or } P = \frac{3VE}{X_d} \sin \delta + 3V^2 \left(\frac{X_d - X_q}{2X_d X_q} \right) \sin 2\delta \quad (4)$$

The first term in Eq. (4) is the same as that in a cylindrical rotor generator. The second term is the additional power due to saliency and is known as reluctance power (or toque). This second term does depend on field excitation and is present even when field

current is zero. Its maximum value occurs at $\delta = 45^\circ$. The power angle even curve is shown in fig. 4.3.4. The maximum power occurs at an $\angle \delta$ which is less than 90° .

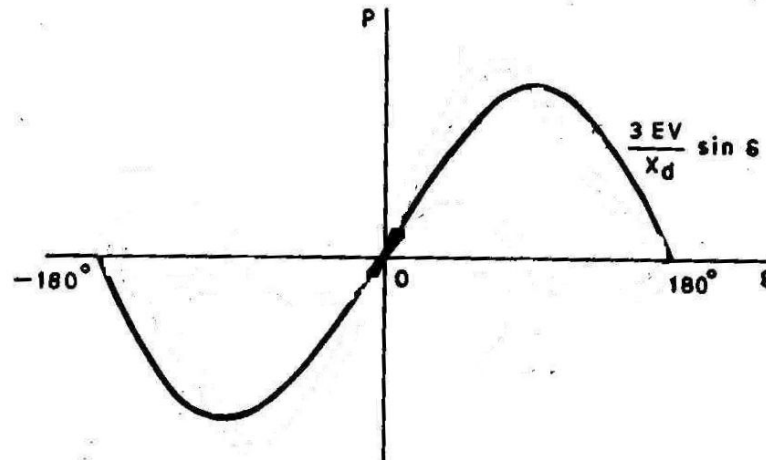


Fig. 4.25

Since torque developed equals power output divided by ω_s torque is given by

$$\text{Torque} = \frac{3VE}{\omega_s(X_d)} \sin \delta + \frac{3V^2(X_d - X_q)}{2\omega_s X_d X_q} \sin 2\delta$$

4.4 VOLTAGE REGULATION

Regulation of synchronous generator is defined as ‘The rise in terminal voltage with constant field current, when, with the generator operated at rated voltage and at rated speed, the specified load at the power factor is reduced to zero, expressed as percent of rated voltage’. The power factor of the load to which the regulation refers should be specified.

Voltage regulation is of great importance to designs and operating engineers for stable interconnected operation. Further High/low voltages may damage the connected equipment. National standards specify the limits of voltage withstand of the HV equipment. Accordingly voltage regulation of the generator must ensure that the connected equipment or the generator is not damaged. For a large hydro generator following characteristics as regards voltage regulation were specified. There are typical values.

- | | | |
|----|---|---|
| 1. | Rated continuous rating at
0.9 lagging power factor and at
normal rated terminal voltage | kVA 10,000 |
| 2. | Continuous overload capacity | 10 % |
| 3. | Terminal voltage at which the maximum
Continuous rating must be achieved | 11 kV |
| 4. | Minimum terminal voltage under
Operating continuous with unloaded system | 10 % lower than the
normal rated voltage |
| 5. | Excitation at maximum leading KVA
expressed as percentage of that required
at rated output and power factor | Not less than 12 % |

- | | | |
|----|--|--|
| 6. | Terminal voltage at which the maximum Continuous rating must be achieved | 5 % higher than the normal rated voltage |
|----|--|--|

Voltage regulation as specified is generally achieved by suitable design of generator and excitation system of the generator.

4.4.1 The terminal voltage under load conditions is different from that under no load condition. Accordingly rise in voltage (when load is thrown off) or the drop (when the load is applied) is due to the following causes.

- a) Armature reaction
- b) Armature resistance
- c) Armature leakage reactance

Armature reaction and leakage reaction in actual practice is replaced by a fictitious reactance X_a called synchronous reactance which can be determined experimentally for a generator and asked as a guaranteed technical particular of the generator to be supplied.

Figure 4.4.1 shows the equivalent circuit of one phase of hydro generator with synchronous reactance (X_a) and armature resistance R_a .

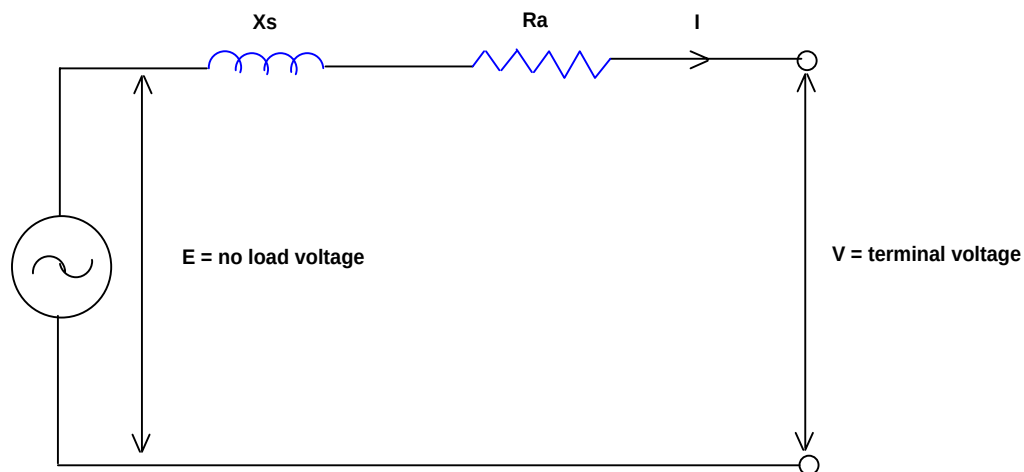


Fig. 4.26

$$E = V + I (R_a + jI X_s) \quad (\text{under steady state conditions})$$

Where R_a = Armature resistance
 X_a = Synchronous reactance

Accordingly synchronous reactance can be used to calculate voltage regulation.

4.4.2 Characteristics Curves of Generator for Regulation

Voltage regulation in generators is achieved by saturation of the magnetic circuit.

Open Circuit Characteristics Curve: A typical characteristics curves of generator for open circuit (no load) field current and terminal voltage at rated speed per phase is shown in fig.

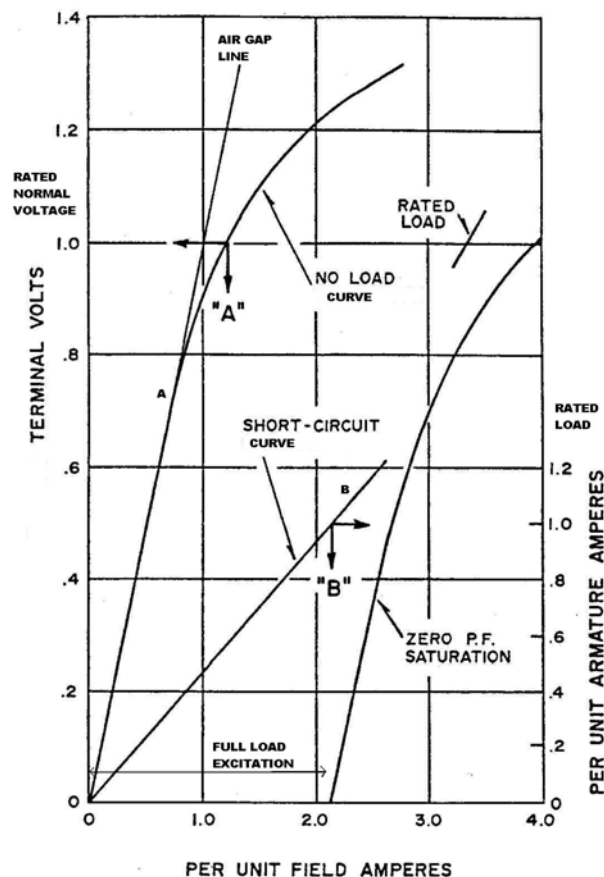
4.4.2 and is called no load characteristics higher values of field current near rated voltage saturation of magnetic circuit occurs.

Short Circuit Characteristics Curve: Field current required in the same phase when the terminals are short circuit for armature current say up to 1.2 times full load current is shown in fig. 4.4.2 as B curve. Short circuit characteristics curve shows relation between short circuit armature and field current.

When the machine is short circuited the emf generated is consumed as a voltage drop in the synchronous impedance (because the terminal voltage is zero). The curve is straight line because the power factor is zero and armature reactance is negative.

$$\text{Synchronous Impedance} = \frac{\text{Open circuit voltage for certain excitation}}{\text{Short circuit current for same excitation}}$$

Zero power factor saturation curve: is also shown as curve C in the fig. 4.4.2



4.5 SHORT CIRCUIT RATIO

Short circuit ratio of a synchronous generator is the ratio of field current required to produce rated open circuit voltage to the field current required to produce rated stator current when the generator terminals are short circuited.

$$\text{Short circuit ratio (SCR)} = \frac{\text{Field current required to produce rated voltage at open circuit}}{\text{Field current required to produce rated current on 3-phase short circuit}}$$

Short circuit ratio is the reciprocal of saturated synchronous reactance. Short circuit ratio has an important effect on the performance of the machine and the cost. A lower value of SCR means greater change in field current to maintain constant terminal voltage and lower value of steady state stability limit. Lower SCR means smaller size, weight and cost of the generator. Advent of fast excitation system has reduced importance of SCR for the design of generators. Normal short circuit ratios are given below. Higher than normal short circuit ratio will increase cost and decrease efficiency.

Generator Power factor	Normal short circuit
0.8	1.0
0.9	1.10
0.95	1.17

In general, the requirement for other than nominal short-circuit ratios can be determined only from a stability study of the system on which the generator is to operate. If the stability study shows that generators at the electrical location of the plant in the power system are likely to experience instability problems during system disturbances, then higher short-circuit ratio values may be determined from the model studies and specified.

4.6 PARALLEL OPERATION OF SYNCHRONOUS GENERATOR

In hydro power station the numbers hydro generating units to be installed are determined from economic considerations. Accordingly need for parallel operation of generators is required for following reasons.

- i) The total load requirement cannot be met by a single hydro generating unit
- ii) Parallel operation increases reliability of electric supply. An outage of one generator will not cause total loss to the load.
- iii) If generators are operating in parallel, one or more of them can be shut down for preventive maintenance turn by turn.
- iv) Parallel operation of alternators leads to economy in operating costs. The less efficient machines can be shut down when the load requirement is less.

When two or more alternators are operated in parallel, they are as if coupled together by an elastic coupling and they must run at exactly the same frequency as long as they are coupled.

4.6.1 Conditions for parallel Operation

The following conditions must be fulfilled before an incoming alternator can be paralleled to the bus bars:

- ii) The terminal voltage of the incoming generator must be the same as that of bus bars – adjustment by excitation

- iii) The frequency of incoming alternator must be the same as that of bus bars - adjustment by turbine governor
- iv) The phase of the voltage of incoming alternator must be identical with the phase of the bus bar voltage, with respect to the external circuit, i.e. opposite in phase with respect to the local circuit through the armature and the bus bars.
- v) The phase sequence of the voltage of incoming alternator must be the same as that of bus bar voltage.

The condition of same phase sequence is checked by the phasing out test during the commissioning of the alternator. The remaining three conditions have to be checked each the time alternator is to be put in parallel with bus bars.

4.6.2 Synchronizing

Synchronizing of a generating unit in a powerhouse is done as per following detailed procedure so as to avoid shock to the incoming machine/system by out of phase closing of incoming circuit breaker.

- i) Phase sequence is checked at the time of initial commissioning
- ii) Same terminal voltage – adjustment of incoming machine voltage by voltage regulator (excitation system)
- iii) Same speed – adjustment of speed by turbine governor
- iv) Same phase position - Closing of the circuit breaker of incoming machine when the respective phase of the incoming machine is the same position as the running machine.

Fig. 4.6.1 shows two machines in a powerhouse one running and connected to the bus having phases R Y B and incoming machine having phases $R'Y'B'$. The breaker of the incoming machine is open and called paralleling breaker. The breaker must be closed when R and R' are in same position. Fig. 4.6.1 shows line-to-neutral voltages of $R'Y'B'$ of the incoming alternator and RYB line-to-neutral voltage of the running machine (bus bars). As the two frequencies are not exactly equal, these two sets of phasors change phase with respect to each other at $2\pi(\Delta f)$ rd/sec, where Δf is the difference in frequencies. The exact instant of switching is when the two systems are in phase. This is done by using a synchroscope. A synchroscope is an instrument which measures the phase difference between voltage of one of the phases (say a) of incoming alternator G_1 and the corresponding phase (i.e. A) of bus bar. The dial synchroscope shows 0° (i.e. in phase) at the top and 180° at the bottom. The switch S_1 is closed when synchroscope indicates zero phase difference.

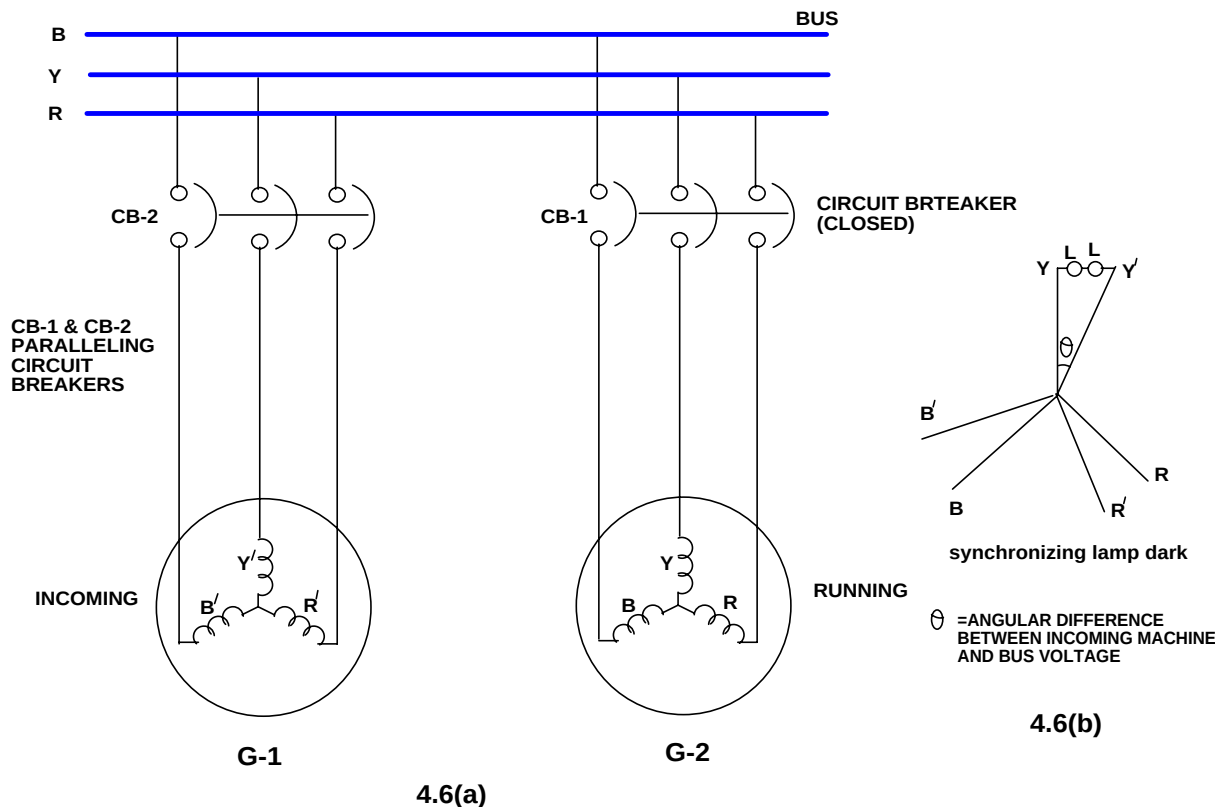


Fig. 4.27 (a) & (b)

When synchroscope is not available. Lamps or voltmeter may be substituted for indication of synchronism as shown in fig. 4.6.1 (b) when R and R' are in phase there is no voltage and the lamps are dark and synchronism. Since the voltage across each lamp can be twice the system voltage the lamps should have a voltage rating of twice the system voltage. For generators at higher voltages or unit connected through transformer to high voltage bus the synchroscope, the lamps are connected through voltage transformers. Auto synchronizers are used in automatic controlled hydro stations. A typical manual cum automatic synchronizing scheme

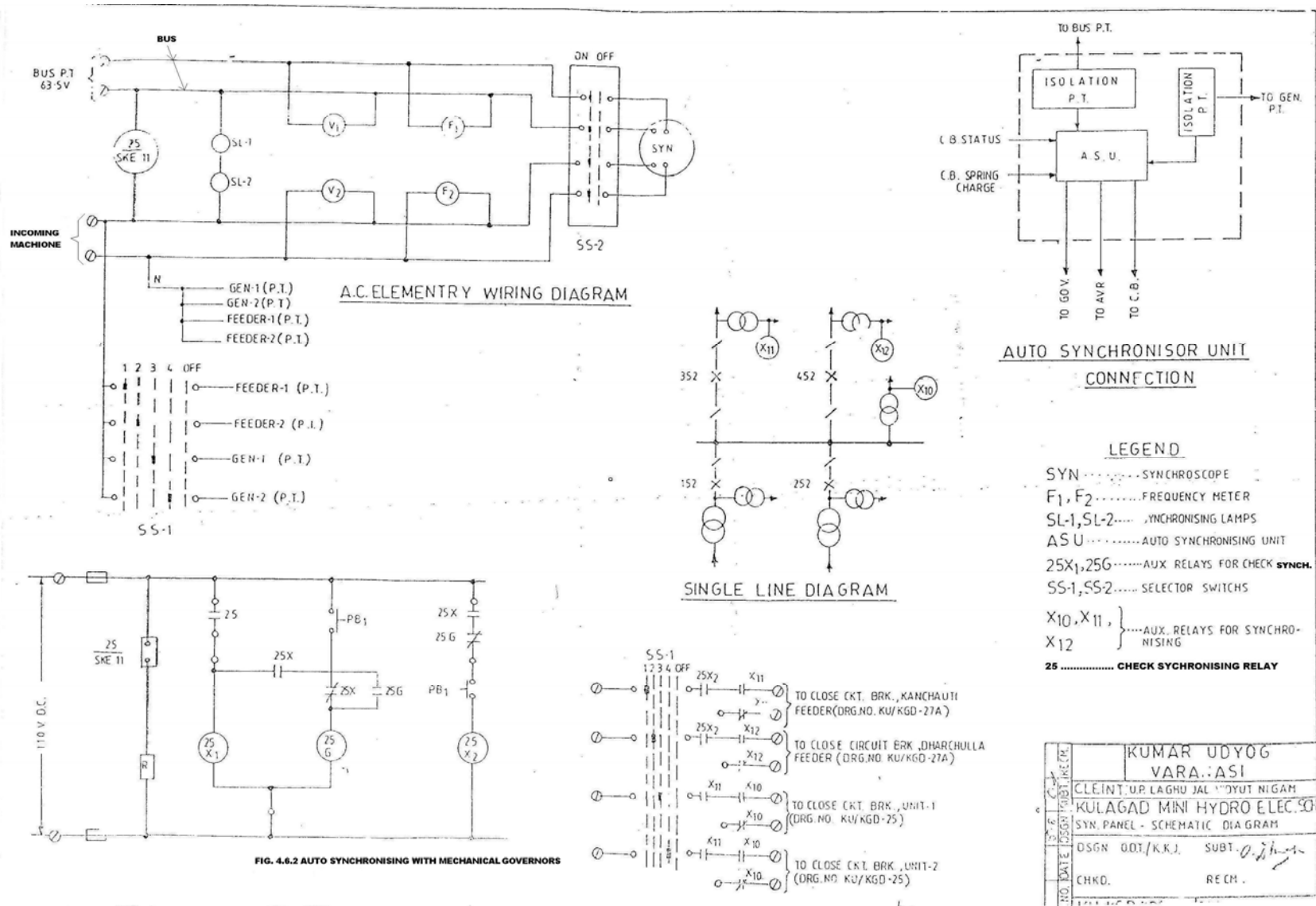


Fig. 4.28 Manual/Automatic Synchronising

is shown in 4.6.2. A synchronising check relay is provided inadvertent closing signal when the on the phase difference series.

A typical synchronizing panel is generally hinged and contains following.

- i) A double frequency meter – one for running machine and one for incoming machine.
- ii) A double voltmeter – one for running machine and one for incoming machine.
- iii) A synchroscope
- iv) 2 synchronising lamp (dark)
- v) Synchronising check relay (25)
- vi) Knobs for adjusting frequency (speed) and voltage of incoming machine.

In some cases of computer controlled station synchronizing functions is performed by the plant computer based automation system.

4.6.3 Division of kW Load

Manual control of hydro generators for active (kW) load sharing is achieved by following provisions in the turbine governor control.

- a) Speed droop setting
- b) Speed level setting i.e. speed at no load
- c) Wicket gate limit setting

Speed droop is defined as percentage drop in speed from no load to full load.

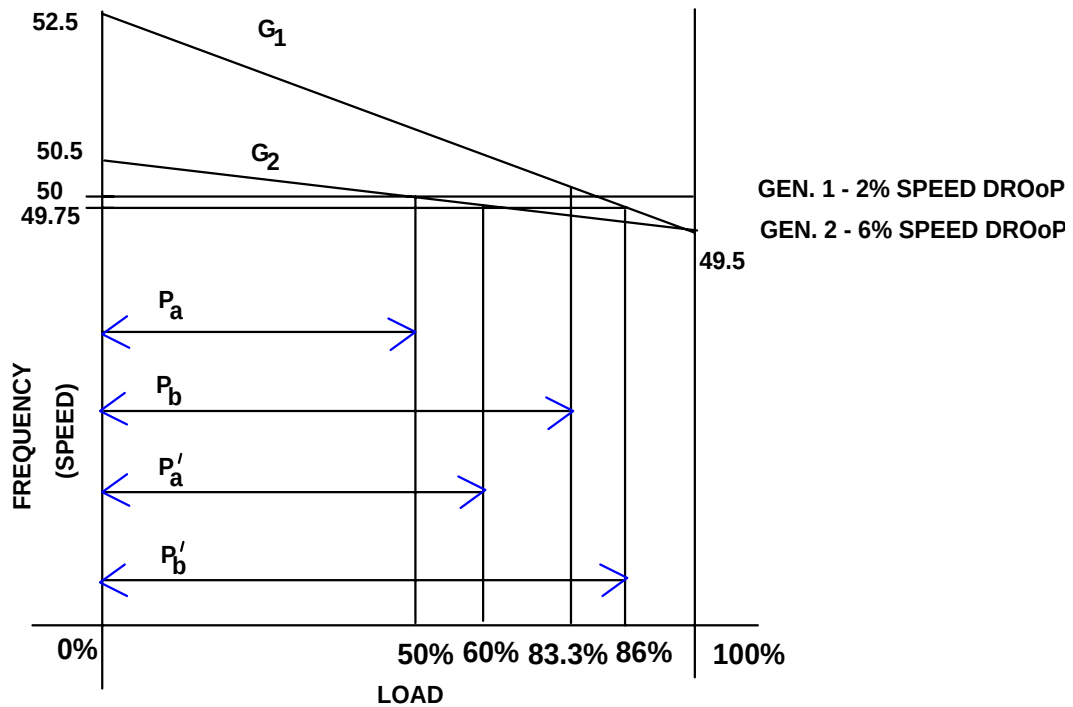
Speed level setting is defined as speed at no load which is adjusted manually say every half an hour by the operator.

Gate limit setting is the maximum wicket gate/nozzle opening or the power which can be taken by a turbine and hence generator.

Active load is shared in the inverse proportion of speed droop setting subject to max. wicket gate limit.

Consider two similar alternators driven by separate prime movers, of which the speed characteristics are shown in fig. 4.6.3. Then if the speed is that represented by the horizontal line SS, the powers supplied by the two prime movers will be P_a and P_b , respectively. The division of load will be wholly dependant upon the speed characteristics of the prime movers, i.e. upon the governors as explained in the fig. 4.6.3.

In case of computerized governing systems all the function are performed by the computer. In some cases even efficiency loading is determined by the computer and the optimum loading provided accordingly.



Gen. 1 – Speed droop setting (turbine governor) 2%
Speed setting (at no load) = 50.5

Gen. 2 – Speed droop setting (turbine governor) 6 %
Speed setting (at no load) = 52.5

At 50 cycles load on gen. 1 = 50%
Load on gen. 2 = 83.3%

Fig. 4.29 – Active Load Sharing

Two 100 kW generator (G_1 and G_2) are operating in parallel. It is desired that G_1 should take system load fluctuation. It is set for 2% speed droop (governor). Generator G_2 which is not required to take part in load sharing is set for 6% speed droop (Governor) speed setting (at no load) of the two machines by governor is 50.5 for Gen. 1 and 52.5 for Gen. 2 for frequency 50 cycles.

Accordingly for system frequency 50 cycle the load sharing will be 50% on gen. 1 and 83.3% on gen. 2.

System increases in load with the same setting (no load) resulting in system frequency drop to 49.75 will result in increase in load on m/c by 25 kW & on m/c of 8.33 kW i.e. inverse ratio of speed droop setting.

After half an hour speed no load setting is adjusted manually to bring speed to 50 cycles.

In case G_1 is fixed at a gate limit to 85% then the load sharing by the machine G_2 will be accordingly higher.

4.6.4 Division of reactive load

The effect of changing the excitation on either machine is to change the division of reactive current; e.g., starting with equal loads and currents, if the excitation of a is increased, it will take more of the lagging reactive current, and b will take less. Any inequality of excitation is equalized by a circulating reactive current which transfers the excitation from the overexcited machine to the under excited one. The terminal voltage will always be determined by the total excitation of both machines and by the magnitude and power factor of the load.

When the voltage of a power plant is controlled by a voltage regulator, acting on the exciter bus from which the fields of all the parallel connected units are supplied, the percent increase in excitation for a given increase of load will obviously be the same on all the alternators. But if one alternator has a close regulation, and another poor regulation, and if in the first case they shared the reactive and active currents in proper proportion, with increased load, the close-regulation machine will be relatively overexcited and will take more than its share of the lagging reactive current.

4.6.5 Synchronizing Power, Torque

The power output of a cylindrical rotor alternator is

$$P = \frac{3VE}{x_s} \sin \delta$$

Let the load angle increase by γ . The increased power P' is

$$P' = \frac{3VE}{x_s} \sin(\delta + \gamma)$$

The difference between P' and P is the synchronizing power P_s

$$P_s = \frac{3VE}{x_s} [\sin(\delta + \gamma) - \sin \delta]$$

Since γ is small, $\cos \gamma \cong 1$ and $\sin \gamma = \gamma$. Then

$$P_s = \frac{3VE}{x_s} (\cos \delta)(\gamma)$$

Synchronizing power per electrical radian

$$= \frac{3VE}{x_s} \cos \delta$$

Alternatively, for a particular value of excitation, the relationship between a small change in load angle $\Delta\delta$ and the corresponding change in additional power ΔP is given by

$$\frac{\Delta P}{\Delta \delta} = \frac{dP}{d\delta} \cong \frac{3VE}{x_s} \cos \delta$$

The slope $\frac{dP}{d\delta}$ is the synchronizing power per electrical radian. It is also known as stiffness ratio of the machine. P_s is maximum at no-load and zero at $\delta = 90^\circ$. For $\delta > 90^\circ$, P_s is negative, indicating unstable operating region. To ensure that the generator has reasonable synchronising power, δ is kept about 40° or so.

For a salient pole machine having x_d and x_q as direct and quadrature axis reactance, the power output is

$$P = \frac{3VE}{x_d} \sin \delta + \frac{3V^2(x_d - x_q)}{2x_d x_q} \sin 2\delta$$

4.7 Induction Generation – Construction & Working Principle, slip speed, self excited induction generator standalone generator

(Notes by Shri S. N. Singh of AHEC – Short term course on “Hydropower Development Engineering (Electrical)” for Teachers of Polytechnics in Uttarakhand July 14-18, 2007)

4.8 INDUCTION GENERATOR

Induction generator is also called as Asynchronous generator or induction motor used as induction generator (IMAG).

An induction motor is called an induction generator when it is sued with negative slip i.e. speed of the rotating magnetic field is less than the rotor speed.

4.9 CONSTRUCTION

An induction generator consists essentially of two main parts as shown in Fig. 1.

(i) Stator:

The stator of induction generator is same as that of synchronous generator. The stator carries a 3- phase winding. Windings are wound for a definite numbers of magnetic poles.

(ii) Rotor:

The rotor of induction generator is different from that a Synchronous generator. The rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors (heavy bars of Copper or Aluminum). The rotor conductors are electrically welded or bolted and short circuited at each end by Copper or Aluminum rings called end rings.

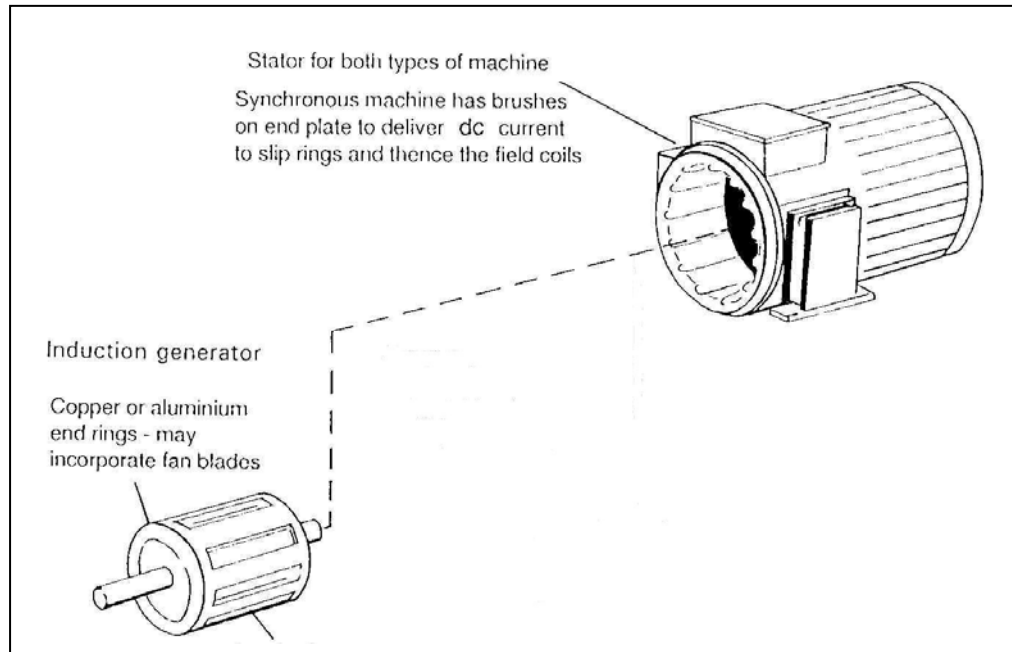


Fig. 4.30: Main part of induction generator

4.10 WORKING PRINCIPLE

(a) Supply (Grid) connected induction motor operations:

When three phase stator windings are fed 3-Phase supply then a magnetic flux (stator field) of constant magnitude but rotating at synchronous speed is set up. The synchronous speed of the field is given by

$$n_s = 120 f/p$$

Where,

$$\begin{aligned} f &= \text{Electric Supply frequency} \\ p &= \text{no. of stator poles} \end{aligned}$$

The rotating magnetic field ϕ_s created by the stator, cuts the rotor bars (rotor at standstill) and induces voltage into rotor bars. When rotor is at standstill, the frequency of this induced voltage is same as the rotating magnetic field frequency. Due to short-circuited rotor bars (by means of the end rings) the induced current, will flow through the rotor. This current produces a rotating flux wave ϕ_r similar to one of the stator. Fig:2 below presents a simple induction machine with only one phase shown. The stator and rotor fields interfere with each other and the resulting field creates a force couple or torque on the rotor bars. The torque on the rotor is directed in such a way that the rotor will turn in the direction of the rotating stator field. Figuratively, we can say that the rotor follows the main field ϕ_s in order to catch up to it. However, there must always be a relative motion between the rotating stator

field ϕ_s and the rotor bars; if the rotor bars rotate at the same speed as the rotating field, i.e. at synchronous speed n_s , the rotor conductors would no longer be cut by the flux lines. As a consequence, there would be no induced current and no corresponding rotor field ϕ_R and hence no torque. That is why the induction machine is also called asynchronous machine as the rotor must rotate below (or above) synchronous speed to produce electro-magnetic torque. Even if the motor is run with the load uncoupled, a small torque is required to overcome friction and other losses of the machine and the rotor will rotate slightly below synchronous speed.

SLIP SPEED

The difference between the synchronous speed n_s and the rotor speed n_r is called slip speed n_g and represents the speed of the rotating field viewed from the rotor. Relating n_g to the synchronous speed, we obtain the so-called slip s :

$$n_g = n_s - n_r \quad (1)$$

$$s = \frac{n_s - n_r}{n_s} \quad (2)$$

Slip s may be negative, i.e. the rotor speed n_r is above synchronous speed; the machine operates as a generator driven by a turbine or a diesel engine and generates electric current in the stator windings.

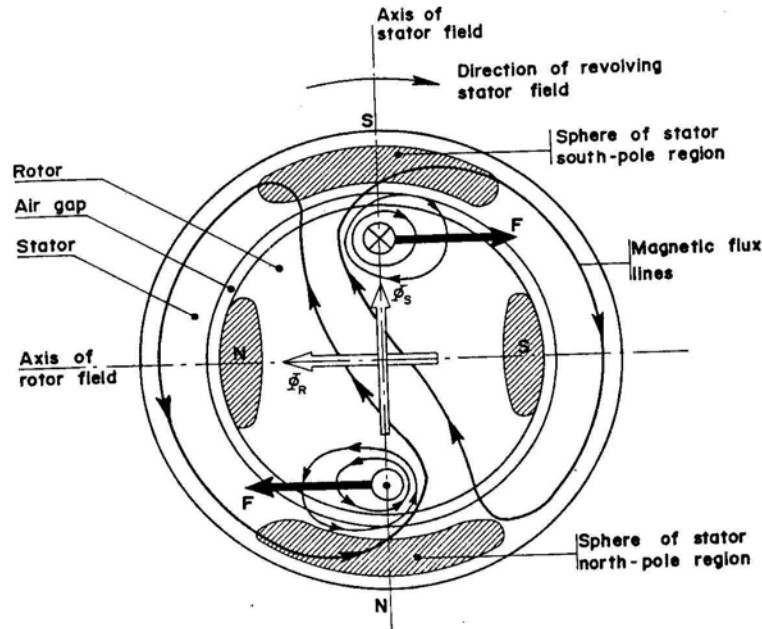


Fig. 4.31: Development of torque in an induction motor (schematically for a single rotor coil)

(b) Supply (grid) connected induction generator operation:

If the same supply connected induction motor is now driven (with the help of hydro turbine or pump as turbine i.e. PAT) at above synchronous speed, so that slip becomes negative i.e.

$n_s - n_r$ = Negative (i.e. $n_r > n_s$), a torque is supplied to the rotor rather than by the rotor and the induction motor acts as an induction generator, supplying power to the network (grid).

However, it still takes its magnetizing current ($I \sin \phi$) from the grid in order to create the rotating field.

The Induction generator operates only at a super-synchronous speed, a speed above synchronous speed corresponding to supply frequency and number of poles of the machine. The generator voltage & frequency are controlled by electrical system with which it is connected. Since the voltage and frequency are independent of generator, automatic voltage regulating equipments and speed governor are not usually required. The induction generator draws its excitation current (reactive power) from the electrical system with which it is connected. It is essential that electrical system must be strong supply lagging kVA. Therefore this type of generator cannot operate in isolation. The working of induction motor as well as induction generator is shown in Fig. 3& 4 respectively.

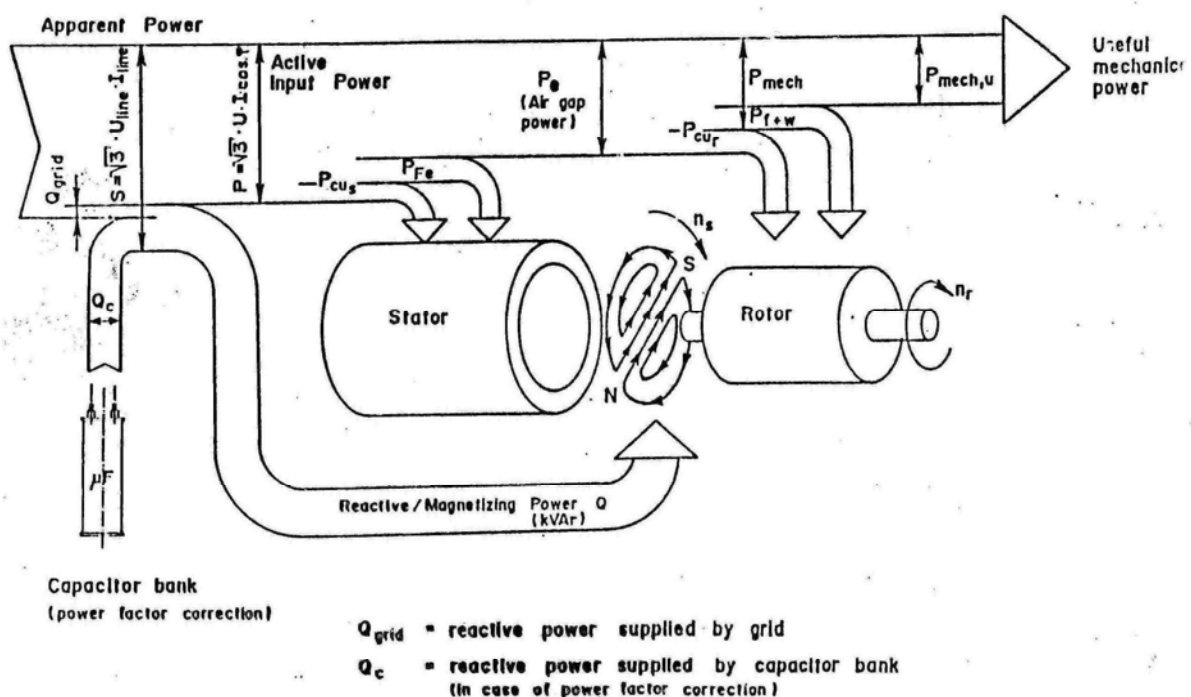


Fig. 4.32: Working of Induction Motor

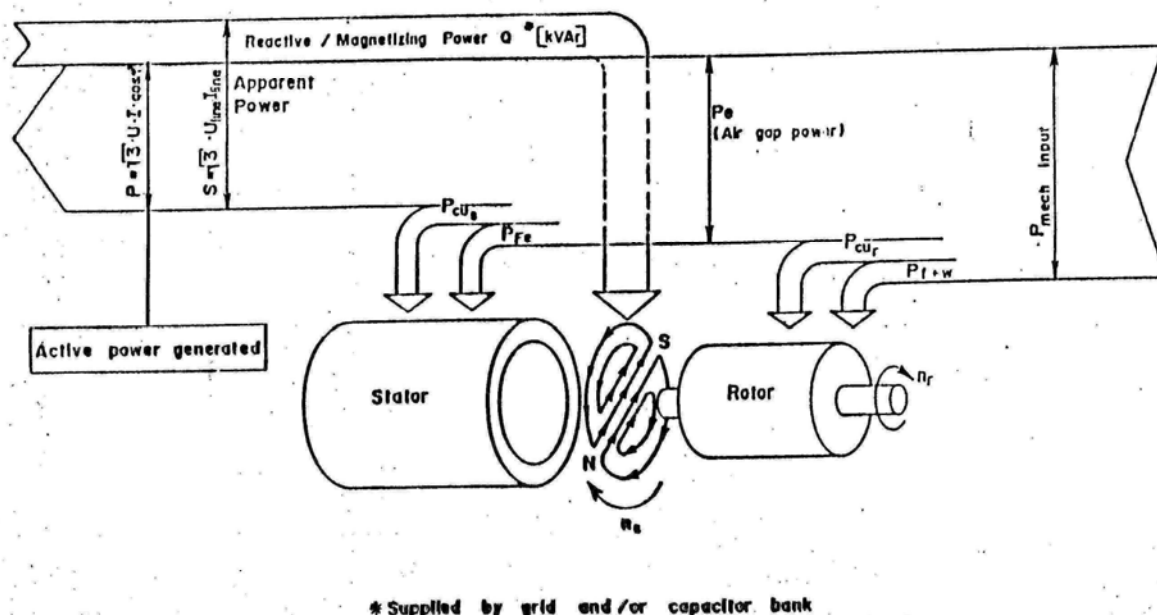


Fig. 4.33: Working of Induction Generator

4.11 INDUCTION MACHINE CHARACTERISTICS

The typical torque - speed characteristics of induction machine is shown in fig. 5. The machine will work as motor when rotor speed is below synchronous speed and generator when speed is above synchronous speed.

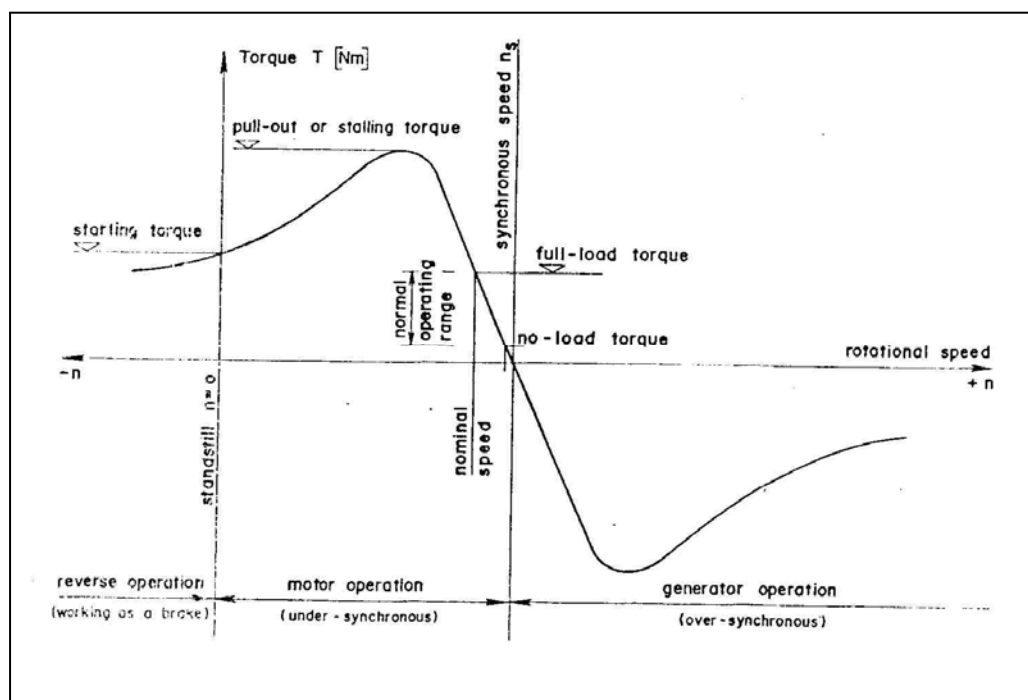


Fig. 4.34: Typical torque-speed characteristics of a squirrel-cage induction machine

4.12 SELF EXCITED INDUCTION GENERATOR OR STAND ALONG GENERATOR

In stand –alone operation, a battery of capacitors must be connected in parallel to the stator winding which will supply necessary reactive power to the induction generator. It will then work as a self- excited generator. Figure 6 (a) and (b) shows a schematic circuit diagram of a self –excited asynchronous generator.

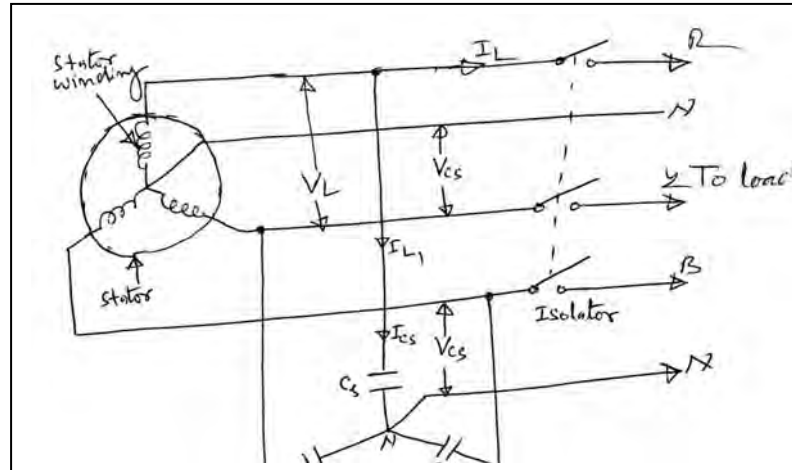


Fig. 4.35: (a) Self excited 3 phase induction generator with star connected capacitors.

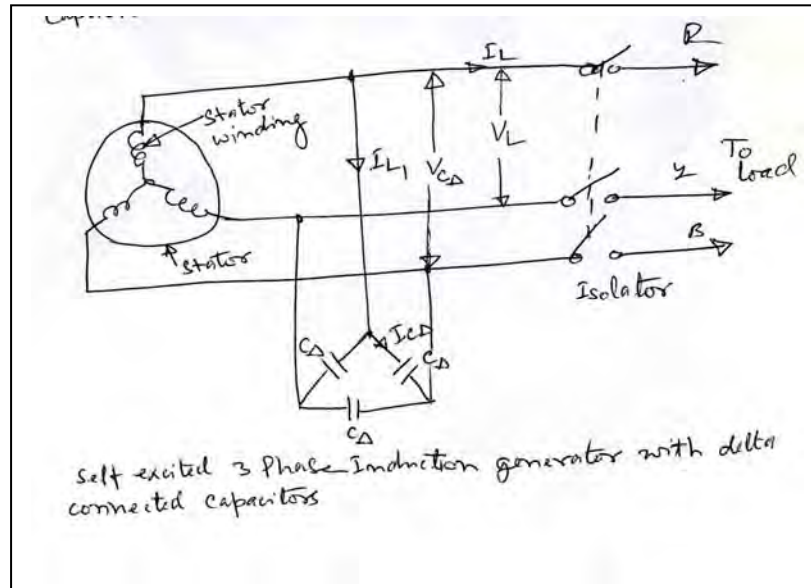


Fig. 4.36: (b) Self excited 3 phase induction generator with delta connected capacitors.

If the capacitors are connected in star than three times as much capacitance is required than for delta connection. An induction motor of a given rating cannot deliver the same electrical power in generator mode as it would absorb from a grid in motor operation since the losses (copper, iron, friction and windage) reduce the output. Theoretically, the mechanical input power could be increased to make up for the losses and arrive at overload the machine, i.e. overheating and finally burn the stator winding. Therefore, generator operating conditions are determined by the stator current which must not exceed the rated motor current which the windings are designed for.

4.13 POWER

There are three types of electrical power as listed below:

- (i) Real power or Active power: This power is used for doing actual work and this power is given as $P = \sqrt{3} V_L I_L \cos \phi$
- (ii) Reactive Power : This is a wattless power and use for magnetizing purposes. This power is given as $Q = \sqrt{3} V_L I_L \sin \phi$
- (iii) Apparent power: The apparent power is the ratio of real power to the power factor i.e. apparent power = Real power/power factor.
Where, V_L , I_L and $\cos \phi$ are line voltage, line current and power factor respectively.

4.14 POWER FACTOR

- (i) Cosine of the angle between phase current and phase voltage is known as power factor.
- (ii) Power factor is the ration of real power (kW) to apparent power (kVA) component consider fig. 7.

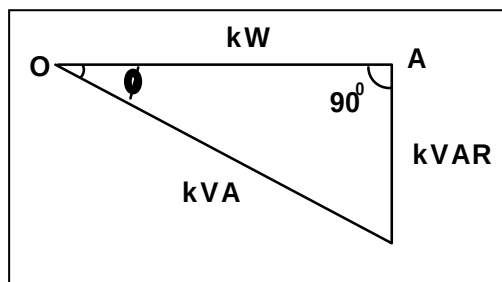


Fig. 4.377: Power triangle

OA = kW component or real power
AB = kVAR component or apparent power

$$\text{Power factor } \cos \phi = \frac{kW}{kVA}$$

$$\text{kVAR} = \text{kVA} \sin \phi$$

- (a) Leading power factor: The power factor will be leading if the phase current is leading the phase voltage.
- (b) Lagging power factor: The power factor will be lagging if the phase current is lagging the phase voltage.

4.15 EFFECT OF LOW POWER FACTOR

Consider an alternator (single phase) having full load rated capacity of 1000A at 500V.

$$\therefore \text{Rating of the alternator} = \frac{VI}{1000} = \frac{1000 \times 500}{1000} = 500 \text{ kVA}$$

If the alternator is operating :

- (a) at unity power factor

$$\begin{aligned} \text{kW} &= \text{kVA} \times \cos \phi \\ &= 500 \times 1 = 500 \end{aligned}$$

- (b) at 0.8 power factor

$$\text{kW} = \text{kVA} \times \cos \phi = 500 \times 0.8 = 400$$

Thus alternator is supplying only 80% of its full load capacity (at unity power factor) although the alternator is fully loaded i.e. developing maximum current 1000 A at 500 V. So in order to supply 500 kW at 0.8 power factor alternator must be overloaded. In this case

current carrying capacity of the alternator winding will be $I = \frac{P}{V \cos \phi} = \frac{500 \times 1000}{500 \times 0.8} = 1250 \text{ A}$

i.e. the alternator would be overloaded and the conductors connecting the alternator to load would be made of much larger cross section to carry the overload current. Thus the size of a given type of alternator is decided by on the basis of kVA output and not by kW basis.

For 500 kW output the kVA rating of alternator will be:

- (a) at 0.6 p.f. $\text{kVA} = 500/0.6 = 833.33$ large size
- (b) at 0.8 p.f. $\text{kVA} = 500/0.8 = 635.00$ small size

Since $\text{kVA} = C_0 D^2 L n$

Where,

C_o = out put coefficient
 L = length of rotor of alternator
 D =diameter of rotor of alternator

Hence, for a given power if power factor is lower then cost of generation and transmission will be more. Due to this reason supply under taking is always stress upon the consumers to increase their power factor.

4.16 METHODS OF IMPROVING (CORRECTION) POWER FACTOR

Following are the methods of improving the power factor.

- (a) With the use of capacitors: They are connected in parallel with the supply main and take current leading by 90° from the mains (voltage) which neutralizes the reactive lagging component of the load current.
- (b) With the help of a synchronous condenser :- The synchronous condenser is also called as synchronous motor. This is the only motor which can work at leading power factor at the same time. This can supply mechanical power. It is preferable to use synchronous motor in comparison with Induction motors where ever possible.
- (ii) Phase Advancers: These are special commutator machines, which improve the power factor of induction motor.

4.17 ECONOMICS OF POWER FACTOR CORRECTION OR IMPROVEMENT

The low P.F. means larger size of generating plant and transmission & distribution equipment. Hence electric supply undertakings penalize industrial consumer for his low power factor by charging increased tariff for kVA maximum demand basis in addition to useful kWh charge. For the same kW demand if the P.F. is improved, kVA demand will reduce and the consumer will pay less for his kVA demand charge. On the other hand, he will have to pay some amount for P.F. improvement apparatus (static capacitors or synchronous capacitors). As such he would choose to work his installation at such a power factor that the total charge has to pay is a minimum.

The most economical power factor for a consumer can be found as kW demand constant basis or constant kW assumption:

Suppose a consumer is taking power of P kW at a power factor of $\cos\phi_1$, as shown in Fig.8.

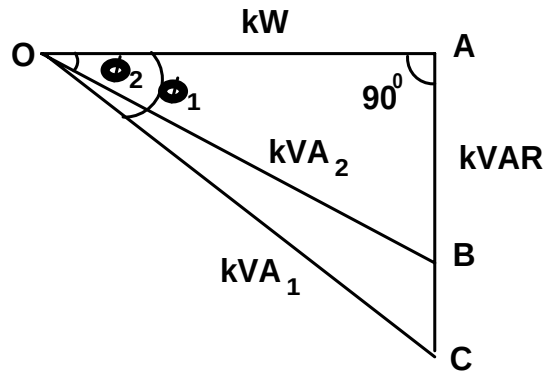


Fig 4.38: The most economical power factor for a consumer on constant kW assumption basis.

Then kVA demand is $OC = kVA_1 = P / \cos \phi_1$ and
kVAR is $AC = P \tan \phi_1$

Let by installing static capacitors or synchronous capacitors the improves this p.f. to $\cos \phi_2$ (his power consumption P remains same)

$\therefore$ New kVA demand = $OB = kVA_2 = P / \cos \phi_2$

$\therefore$ Reduction in kVA demand

$$\begin{aligned} &= kVA_1 - kVA_2 \\ &= OC - OB \\ &= \frac{P}{\cos \phi_1} - \frac{P}{\cos \phi_2} \quad \text{---(1)} \end{aligned}$$

If Rs. x is the demand charge per kVA /annum then saving in demand charge

$$\begin{aligned} &= \text{Rs. } x \times \left(\frac{P}{\cos \phi_1} - \frac{P}{\cos \phi_2} \right) \\ &= \text{Rs. } Px \left(\frac{1}{\cos \phi_1} - \frac{1}{\cos \phi_2} \right) \quad \text{--- (2)} \end{aligned}$$

Against this saving, the kVAR to be provided by power factor improvement apparatus (synchronous capacitors)

$$\begin{aligned} BA &= CA - CB \\ &= P \tan \phi_1 - P \tan \phi_2 \\ &= P (\tan \phi_1 - P \tan \phi_2) \end{aligned}$$

If Rs. y is the annual working cost (i.e. interest and depreciation etc on capital investment) per KVAR of improvement plant, then its cost per annum

$$\begin{aligned} &= \text{Rs } y P (\tan \phi_1 - P \tan \phi_2) \quad \text{--- (3)} \\ \therefore \text{ Net annual saving from equations (2) \& (3)} \end{aligned}$$

$$S = P_x \left(\frac{1}{\cos \phi_1} - \frac{1}{\cos \phi_2} \right) - P_y (\tan \phi_1 - \tan \phi_2)$$

This net saving is maximum when $\frac{ds}{d\phi_2} = 0$

$$\therefore \frac{ds}{d\phi_2} = \frac{d}{d\phi_2} \left[P_x \left(\frac{1}{\cos \phi_1} - \frac{1}{\cos \phi_2} \right) - P_y (\tan \phi_1 - \tan \phi_2) \right]$$

$$= -P_x \sec \phi_2 \tan \phi_2 + P_y \sec^2 \phi_2 = 0$$

$$\text{or } x \tan \phi_2 = y \sec \phi_2$$

$$\text{or } \sin \phi_2 = \frac{y}{x}$$

Thus the sine of most economical angle is equal to ratio of annual cost of phase advancing plant to annual tariff per kVA of max demand.

$\therefore$ The most economical

$$\begin{aligned} p.f. \cos \phi_2 &= \sqrt{1 - \sin^2 \phi_2} \\ &= \sqrt{1 - \frac{y^2}{x^2}} \\ &= \frac{1}{x} \sqrt{(x^2 - y^2)} \end{aligned}$$

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4.18 Power Factor – Most Economical Power Factor, Real Power Factor, Operate Power Factor, Leading and Lagging Power Factor, Power Factor Correction Methodology

4.18.1 Power Factor

Hydroelectric energy is generated transmitted distributed and utilized as alternating current. Alternating current systems consist of two component resistance and reactance. Reactance can be either inductive or capacitive and require reactive power in addition to active power. Active power contributes to energy consumed and is provided by the hydro turbine. Reactive power does not contribute to energy but must be generated or consumed in almost every component of the system i.e. generation, transmission, distribution and load. Loads (electrical appliances) are mostly inductive and must be supplied with lagging reactive power.

Total power (apparent) to be supplied consists of two components i.e. active power (kW) and reactive power (kVAR) as shown in figure 4.8.1. Reaction power component is positive in case of lagging currents (inductive) and negative in the case of lagging current (capacitive).

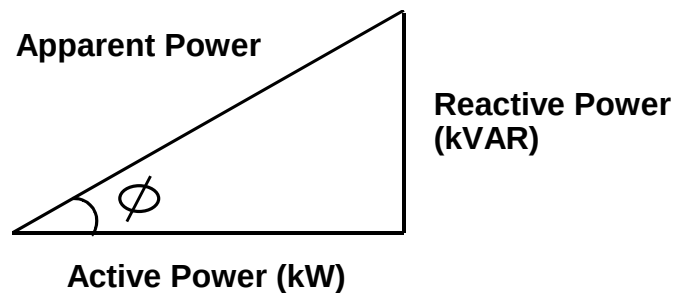


Fig. 4.39

Mathematically

Active power (kW) = Apparent power (kVA) x Cos ϕ

$$\text{kW} = \text{kVA} \times \text{Cos } \phi \quad \text{-----} \quad (1)$$

Cos ϕ is the power factor

Power factor of the some common industrial and domestic loads is given in table 1.

Type of load	Power factor (lagging)
Fluorescent lamps	0.6 o 0.8
Fans	0.5 to 0.8
Arc welders	0.3 to 0.4
Induction motors (most widely used in industries and agriculture)	0.5 to 0.85

Power factor of industrial consumers and agriculture pump sets generally ranges between 0.60 – 0.75 and overall power factor is generally below 0.7 unless corrective measures and taken.

$$\text{Apparent power in kVA} = \frac{\text{Active power in kW}}{\text{Power factor}}$$

Accordingly for doing useful work (kW), apparent power kVA to be generated, transmitted and distributed increases in inverse ratio to the power factor.

Size of generating plants, transformers, switchgear, cables and conductors are all determined by the kVA capacity, a low p. f. would mean the installation of larger equipment all along the line for a given kilowatt capacity.

Also, with constant voltage, current is inversely proportional to the power-factor i.e. device will draw twice as much current at 0.5 p. f. as at unity p. f. for the same power. Since

heat loss is proportional to square of current, the same can be said to be inversely proportional to square of power factor i.e.

$$\text{Heat loss} \propto \frac{1}{(p.f.)^2}$$

i.e., a low p. f. would mean increased heat losses which appears as transmission and distribution T & D losses in a system.

In the case of transmission lines, a p. f. would mean greater voltage drop and higher regulation apart from increased lines losses.

It is therefore economical to supply this reactive power closer to the load in the distribution system.

4.18.2 Power Factor Improvement

It would be observed from fig. 4.8.3 that the apparent power has an element of reactive power, which lags 90° behind the useful power. Improvement in p. f. can be brought about by the use of device which utilize reactive power with a leading power factor, thus reducing the over all reactive component in the system (fig. 4.8.3). Power factor is equal to unity, when the lagging reactive component of current is completely neutralized, i.e. I_C is equal to I_{L1} in fig. 4.8.3.

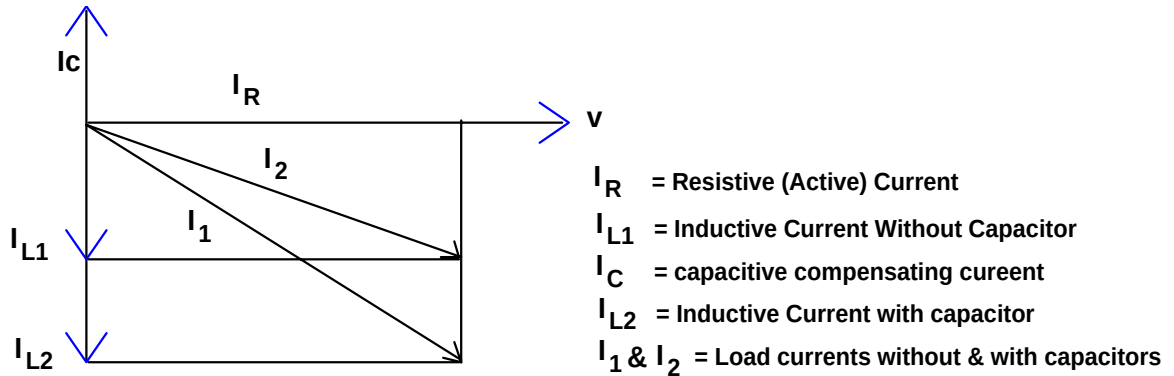


Fig. 4.40

Example

A 11 kV feeder cable is rated to carry normal load of 1000 kW at 90% load factor or 1110 kVA $\left(\frac{1000}{0.9} \text{ kW} \right)$. If load of the area has a power factor of 70% and the feeder has achieved a capacity of 1110 kVA, the load is of 777 kW (1110 x 0.7). The circuit may be brought up to its rated kW load at 90% power factor by a capacitor installation equal to the difference between the reactive component of 1000 kW at 70% and the same component at 1000 kW at 90% load factor. At 70% power factor of load at 1000 kW may be worked out as follows:

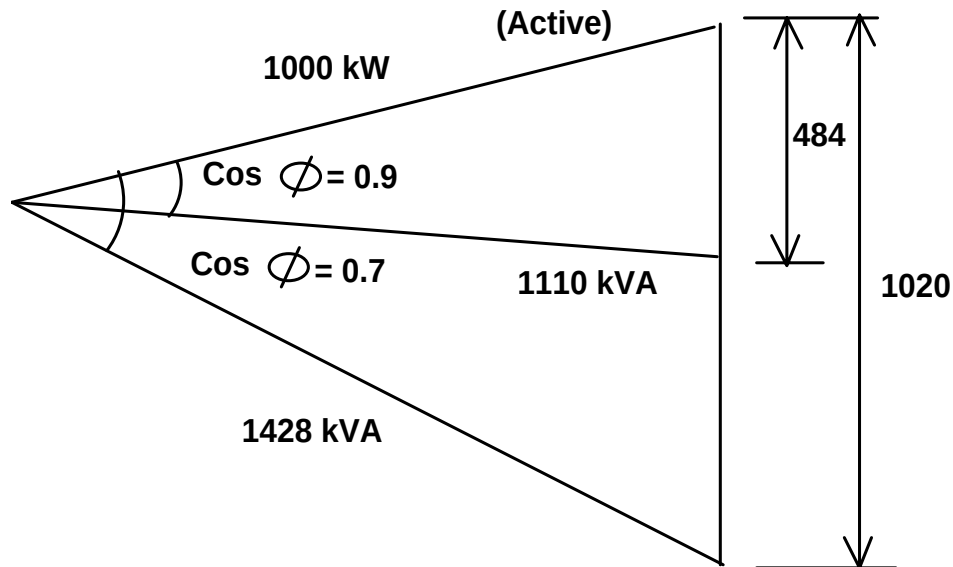


Fig. 4.41

Reactive component at $\cos \phi = 0.7$ is $1428 \times \sin \phi = 1428 \times 0.714 = 1020 \text{ kVA} \dots (1)$

Reactive component at $\cos \phi = 0.9$ is $1110 \times \sin \phi = 1110 \times 0.436 = 484 \dots (2)$

capacitor rating required = $(1) - (2) = 536 \text{ kVA}$

Load power factor of 0.7 will reduce the kVA capacitive for 1000 kW load from 1428 kVA at 70% power factor to 1110 kVA at 90% power factor and release $1428 - 1110 = 318$ kVA of feeder and feeder capacity.

Table 4.8.1: gives multiplying factors to kW load for p f improvement

Initial power factor	Proposed Power Factor		
	0.85	0.9	0.95
0.6	0.714	0.849	1.005
0.7	0.400	0.536	0.691
0.76	0.183	0.319	0.473
0.80	0.130	0.266	0.421

Example

Suppose it is desired to improve power factor 0.7 to 0.9 for feeder carrying 100 kW load (143 kVA)

Load in kW = $143 \times 0.7 = 100 \text{ kW}$

Multiplying factor from table 4.81 = 0.536 kW

KVA rating of capacitor = $100 \times 0.536 = 53.6 \text{ kVA}$

4.18.3 Device for Power Factor Improvement

Shunt capacitor are normally used for power factor improvement because of low cost, high efficiency and negligible maintenance (no moving parts).

For synchronous motors drawing leading current from the system when overexcited and not driving any load can also be used for power factor improvement/voltage regulation. High cost low efficiency and higher operating and maintenance cost generally prohibit this use.

Hydro generators at tail and of power system are sometimes equipped for this additional duty for supplying/absorbing reactance power. In these cases tailrace level is depressed by compressor to reduce losses.

4.18.4 Most Economical Power Factor

While the distribution losses and the cost of cables and switchgear are minimum at unity power factor this is not necessarily the most economical p. f. from the consumer's point of view. The investment on power-factor improvement equipment is relatively high as it approaches unity, because capacitors of much larger ratings are required for bringing about the same improvement in p. f. when it is near unity than when it is low. Accordingly capacitor installation is economical when the cost of corrective equipment is less than the cost of the circuit and substation capacity thereby released. In general the cost of capacitor equipment is lower when applied on the higher voltage (11 kV) of the system. At higher transmission voltage it is sometimes more practical to provide synchronous condenser operation of hydro generators.

It can be shown that where tariff consists of a charge on maximum demand in kVA, and a charge on the units consumed, the most economical power factor is given by the formula,

$$\text{Power factor} = \left\{ 1 - \left(\frac{Y}{X} \right)^2 \right\}^{\frac{1}{2}}$$

Where Y = yearly cost of owning capacitors i.e. yearly interest and depreciation on the capital cost of capacitors

X = maximum demand tariff charge per year per kVA

Widely varying results are obtained by the above formula depending upon the assumed life of capacitors and the tariff in force.

In actual practice, it is quite economical to work with an average power factor of 0.92 - 0.95, as the advantages accruing from a higher p. f. are offset by the additional investment on capacitors. In USA p f is improved to 0.85.

Shunt capacitor are normally used for power factor improvement.

4.18.5 Shunt Reactive Power Compensation at Sub Station Level

Since most loads are inductive and consume lagging reactive power, the compensation required is usually supplied by leading reactive power. Shunt compensation of reactive power can be employed either at load level, substation level, or at transmission level. It can be capacitive (leading) or inductive (lagging) reactive power, although in most cases as explained before, compensation is capacitive. The most common form of leading reactive power compensation is by connecting shunt capacitors to the line.

Shunt Capacitors at Sub Station Level

Voltage Regulation: The main reason that shunt capacitors are installed at substations is to control the voltage within required levels. Load varies over the day, with very low load from midnight to early morning and peak values occurring in the evening between 4 PM and 7 PM. Shape of the load curve also varies from weekend, with weekend load typically low. As the load varies, voltage at the substation bus and at the load bus varies. Since the load power factor is always lagging, a shunt connected capacitor bank at the substation can raise voltage when the load is high. The shunt capacitor banks can be permanently connected to the bus (fixed capacitor bank) or can be switched as needed. Switching can be based on time, if load variation is predictable, or can be based on voltage, power factor, or line current.

Reducing Power Losses: Compensating the load lagging power factor with the bus connected shunt capacitor bank improves the power factor and reduce current flow through the transmission lines, transformers, generators, etc. This will reduce power losses (I^2R losses) in this equipment.

Increased Utilization of Equipment: Shunt compensation with capacitor banks reduces kVA loading of lines, transformers, and generators, which means with compensation they can be used for delivering more power without overloading the equipment.

4.18.6 Capacitor Installation

Standard capacitor units in 3 phase banks are employed. They should be protected by lightning arrestors. The capacitors are full on and off. According the capacitor should be put off on light loads for voltage regulation. Standard capacitor bank rating at LT specified by Rural Electrification standards are as follows.

Transformer Rating (kVA)	3-phase Capacitor Bank Rating kVAR
25	9
63	27
100	36

The capacitor units are switched on and off as per requirement by automatic control units to regulate voltage and line losses as shown in REC drawing 4.8.6.

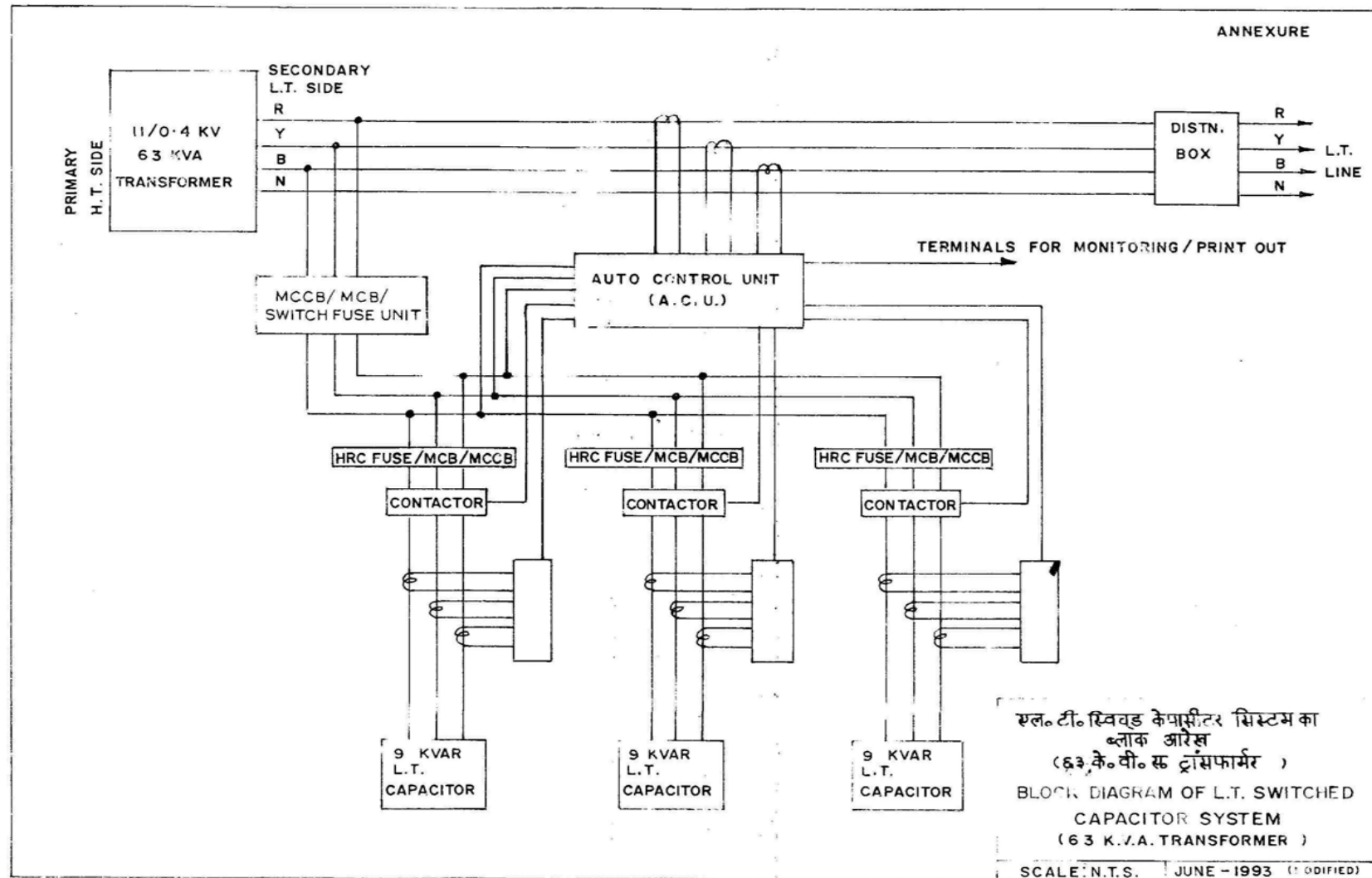


Fig. 4.42

4.18.7 Switched 11 kV Capacitor Banks

Scheme recommended by Rural Electrification Corporation (REC) for automatic operation of 11 kV capacitor switches capacitor banks is shown in drawing 4.8.7.

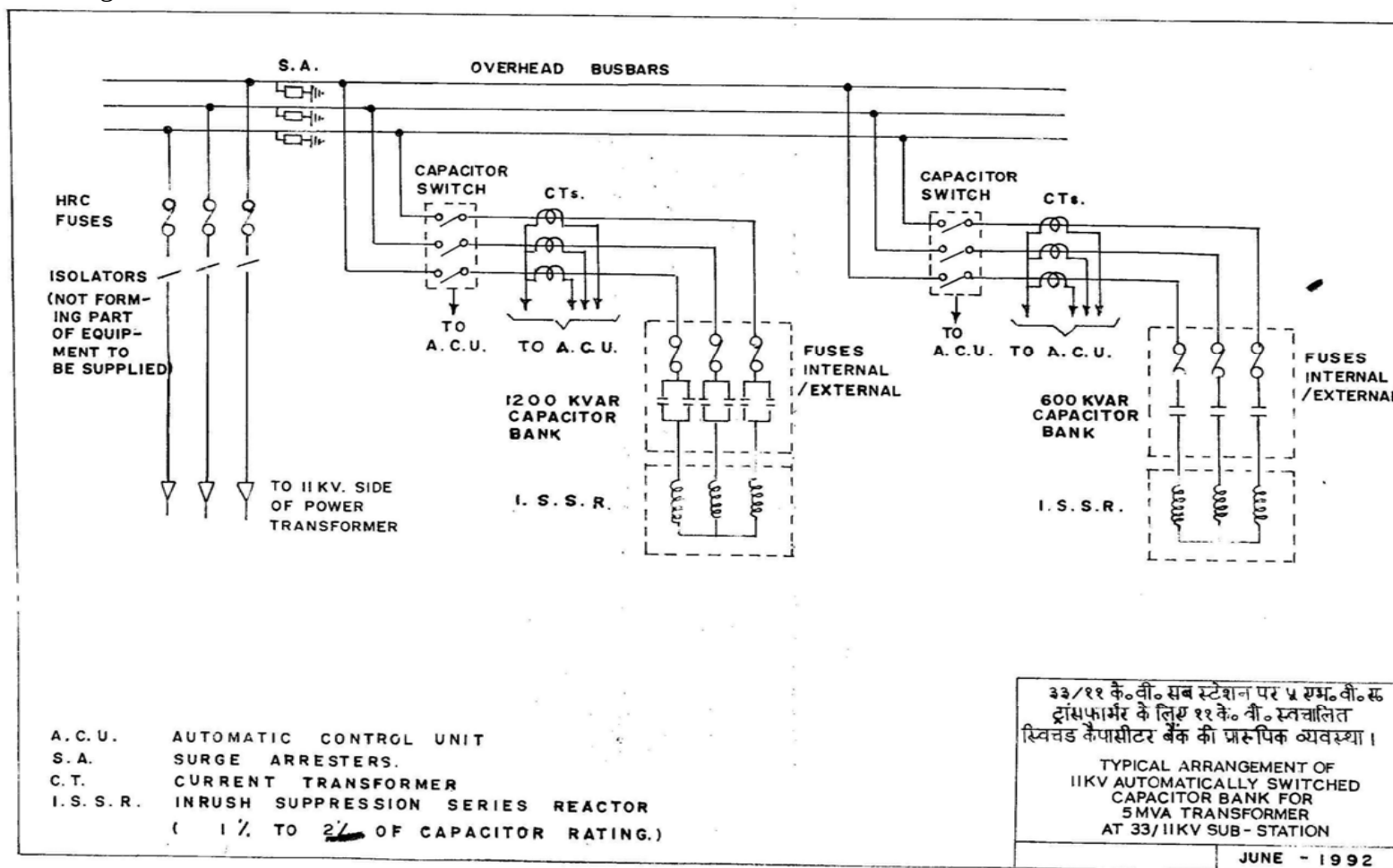


Fig. 4.43

Following scheme is recommended for automatic operation of 11 kV capacitor switches/capacitor banks on rural lines.

S. No.	Transformer Capacity	Capacitor Bank Size	Capacity to be switched on	Status of capacitor switches when load kVAR in transformer reaches	Status of capacitor switches when load kVAR drops to
1.	1 x 3.15 MVA	1200 kVAR split into 600 kVAR +	600 kVAR	700 kVAR (switch-I ON, Switch –II OFF)	600 kVAR (Switches I & II OFF)
		600 kVAR	1200 kVAR	1300 kVAR (Switches I & II ON)	1200 kVAR (switch-II OFF, Switch –I ON)
2.	1 x 5 MVA	1800 kVAR split into 600 kVAR +	600 kVAR	700 kVAR (switch-I ON, Switch –II OFF)	600 kVAR (Switches I & II OFF)
		1200 kVAR	1200 kVAR	1300 kVAR (Switch I OFF, Switch- II ON)	1200 kVAR (switch-II OFF, Switch –I ON)
			1800 kVAR	1900 kVAR (Switches I & II ON)	1800 kVAR (switch-I OFF, Switch –II ON)

Notes

1. For more than one transformer, a separate capacitor bank for each transformer shall be provided.
2. The required 11 kV CTs and PTs for measurement of load kVAR are normally available at the sub-station and will not form part of the equipment to be supplied against this specification.

4.19 SWITCHYARDS

- A. **Transformer:** Types, construction –rating – star & delta connection, parallel operation; phase group of 3-phase transformer.

4.19.1 General

Transformer is a highly efficient device to transfer energy in an AC system from one circuit to another circuit. Power transformer is used in hydro electric power plants to step up the voltage from generation level to transmission/sub transmission level and step down at the load end sub station as shown in fig. 4.9.1. In the figure generator are shown unit connected to transformer without intervening circuit breaker. Auxiliary transformer (distribution type) are also used in power house to feed unit and station auxiliaries etc.

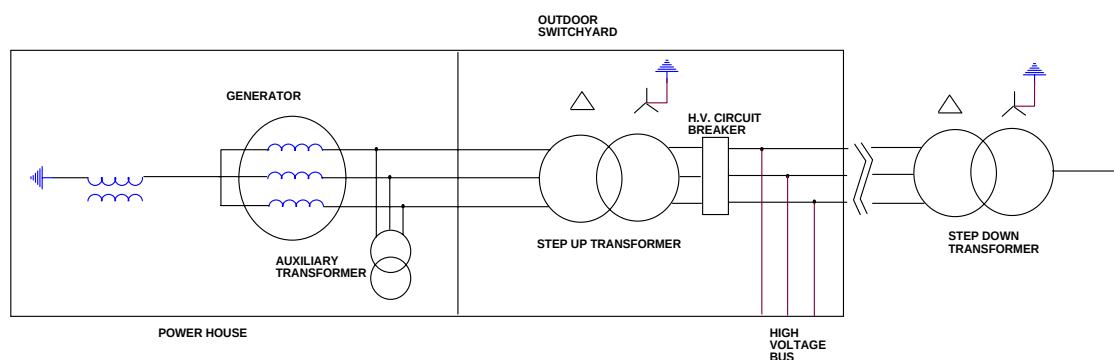


Fig. 4.44

A transformer converts alternating voltage and current in one winding into alternating voltage and current at different values in another winding by electromagnetic induction. Current will flow through load when the switch in the secondary circuit is closed. The frequency remains unaltered during transformer.

4.19.2 Classification of Transformers

Transformers and their characteristics generally used in hydroelectric system together with considerations as regards their design application and operation is as follows:

- i) **Power transformers:** are used on primary transmission lines for the transmission and distribution of relatively large quantities of energy.
- ii) **Distribution Transformer:** used for distribution of energy to powerhouse auxiliaries and in some cases local areas.
- iii) **Auto Transformer:** is a transformer in which part of the winding is common to both primary and secondary circuits. Part of the load in receiver circuit is supplied directly from the supply circuit through the primary winding, the remainder being supplied indirectly through the secondary winding by electromagnetic induction. It is generally used in switchyard to interconnect busses at different voltage levels.
- iv) **Instrument Transformer:** is a transformer designed to represent the conditions of current or voltage and phase position in the secondary circuit. Instrument transformers are classified according to their accuracy under specified conditions. An instrument

transformer may be a current transformer or a potential (voltage) transformer. These transformers are used in protection, metering and control discussed in that chapter.

4.19.3 Types of Transformers

Indoor transformers is a transformer which, because of its construction must be protected from weather.

Outdoor transformer is a transformer of weatherproof construction. Oil immersed is a transformer whose core and coil are immersed in the oil. Classification of oil immerse transformer according to cooling method is discussed 4.9.4.

4.19.4 Cooling of Transformer

Transformer cooling system for generator transformers specified in accordance with IS: 2026 (part II) are identified according to the cooling method employed. Common letter symbols for use in this connection are as follows:

(i)	Cooling Medium	Symbol
a.	Mineral oil or equivalent flammable synthetic insulating liquid	O
b.	Water	W
c.	Air	A
(ii)	Kind of Circulation	
a.	Natural	N
b.	Forces (oil not directed)	F
c.	Forced (directed oil)	D

Transformer is identified by four symbols for each cooling method for which a rating is assigned by the manufacturer.

1 st Letter	2 nd Letter	3 rd Letter	4 th Letter
Kind of cooling medium indicating the cooling that is in contact with the windings	Kind of circulation	Kind of cooling medium indicating the cooling medium that is in contact with the external cooling systems	Kind of circulation

Following cooling systems are used in hydro electric stations.

Symbol	
ONAN	Oil Immersed Natural Air Cooled
ONAF	Oil Immersed Forced Air Cooled
OFAF	Oil Immersed with forced oil circulation Forced Air Cooled

ODAF	Oil Immersed with Forced Directed oil circulation and for Air Circulation
OFWF	Oil immersed with forced oil circulation cooled by water circulation

Transformers when located in powerhouse should be sited so that unrestricted ambient air circulation is allowed.

4.19.5 Transformer Rating

The maximum transformer rating should match maximum generator rating with forced cooling in dual rating transformers, which are commonly employed. The rating of these dual rated transformers is usually as follows:

ONAN/OFAF OR ONAN/ODAF

ONAN	-	60%
OFAF	-	100%
ODAF	-	100%

OFWF transformers do not have self cool rating. Standby cooling capacity should be provided for different type of forced cooling as follows as per Central Board of Irrigation and Power Manual on Transformer.

(a)	ONAN/OFAF or ODAF	-2 – 50% group 2 – 100% pump of which one will be standby, 2 – Standby fans one in each 50% group or 3 – 50% group with independent pump and fans out of which one group to act as standby.
(b)	OFWF or ODWF	- 2 – 100% heat exchangers out of which one is standby

4.19.6 Transformer Principle

The essential components in a transformer are a magnetic core of laminated iron and two windings, the primary and the secondary, placed around it. The winding that is connected to the source of power is known as the primary winding and the one that is connected to the load is known as the secondary winding as shown in fig. 4.9.2. Multi-winding special transformer are not discussed.

The alternating flux produced by the primary winding links with the secondary winding and induces an alternating e.m.f. in the latter, the magnitude of which depends upon the ratio of the turns in the two windings.

The voltage, current and power in the secondary circuit are given by the following relationships:

$$\frac{\text{Input Voltage } V_1}{\text{Turns on primary winding}} = \frac{\text{Output Voltage } V_2}{\text{Turns on secondary winding}} = K$$

Output voltage V_2 Turns on secondary winding

Where

K = turns ratio (voltage V_1 and V_2 refer to primary and secondary phase voltage)

$$\frac{\text{Input current}}{\text{Output current}} = \frac{I_1}{I_2} = \frac{1}{K}$$

Power input = power output + loss

Losses are iron losses (in the core) and copper losses in the winding. Efficiency is very high 1 of the order 99% in power transformers.

Transformer are broadly classified as step up transformer and step down transformer. Usually and step up transformers generating stations are delta/star and at step down transformers are delta/star as shown in fig. 4.9.2.

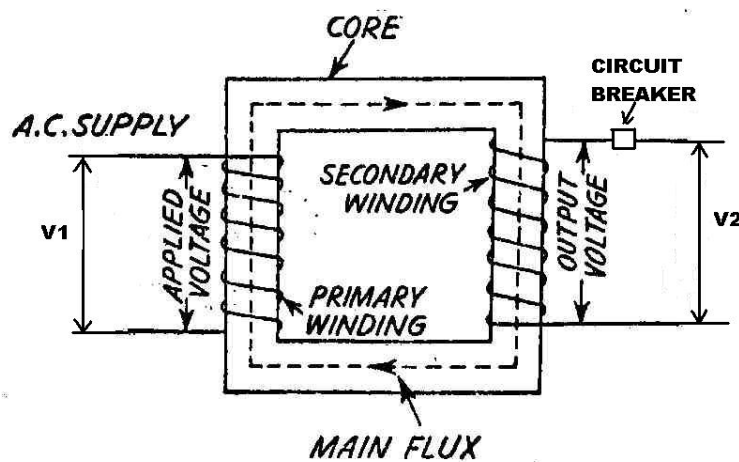


FIG. 4.45

4.19.7 Type of Construction

There are two types of transformer in common use.

- i) **Core type:** Core is constructed of insulated iron sheet laminations to keep the iron losses low. The laminations are inter-leaved at ends to form the frame of the required shape and size. The two common constructions are (i) Shell type, and (ii) Core type.

Shell type, the core iron surrounds the windings completely. Their use is confined to small single-phase transformers.

In the core type, the iron is surrounded by the windings. This construction is used for all sizes of single and three phase transformers.

The vertical members of the core are called 'limbs' and the horizontal ones 'yoke'.

As a general rule the core type construction is more economical for small high-voltage transformers than the shell-type construction, the dividing line for size being dependant on the voltage. In the matter of relative weights of iron and copper, the two types tend to merge into each other if steps are taken to alter the construction so that their features are more nearly alike.

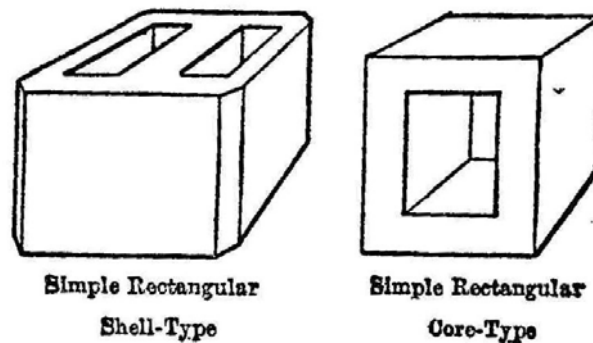


Fig. 4.46

4.19.8 Transformer Connection

Connection of Phase Winding

The star, delta connection of a set of phase windings of a three phase transformer or of windings of the same voltage single phase transforms associated in a three phase bank are indicated by the letters Y, D for the high voltage winding and y, d or z for the intermediate and low voltage windings. If the neutral point of a star or zigzag-connected winding is brought out, the indications are YN or ZN and yn or zn respectively.

Phase Displacement between Winding

Phase displacement is expressed as the clock hour to number. The vector relating to the high voltage winding is taken as the vector of origin. Examples of vector diagrams showing the use of the clock-hour figure are given in 4.9.8 and shown in table 4.9.8.

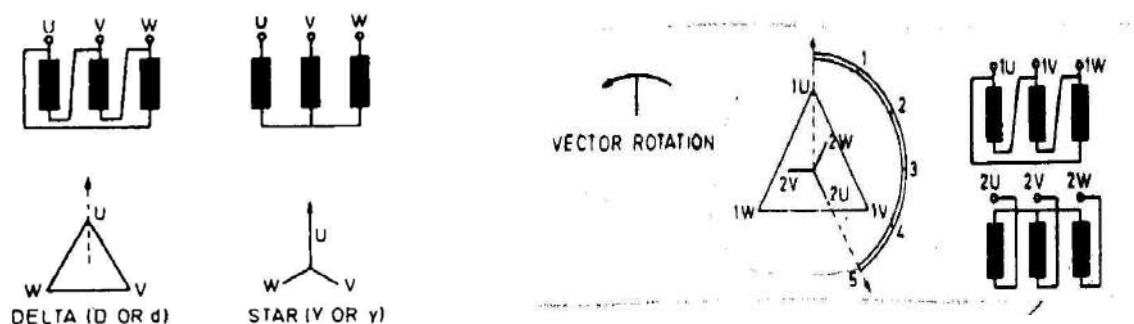


Fig. 4.47

Table 4.9.8 Vector symbols of transformers

Group No.	Winding Connection		Phase Displacement	Clock-Hour Number	Vector Symbol
	Primary	Secondary			
1	star delta delta	star delta zig-zag	0^0	0	Yy^0 Dd^0 Dz^0
2	star delta delta	star delta zig-zag	180^0	6	Yy^6 Dd^6 Dz^6
3	delta star star	star delta zig-zag	-30^0	1	Yy^1 Yd^1 Yz^1
4	delta star star	star delta zig-zag	$+30^0$	11	Yy^{11} Yd^{11} Yz^{11}

Three phase transformer connection in general use as per IS: 2026 (part IV) –1977 and the angle of shaft associated with them are shown in Figure 4.9.4.

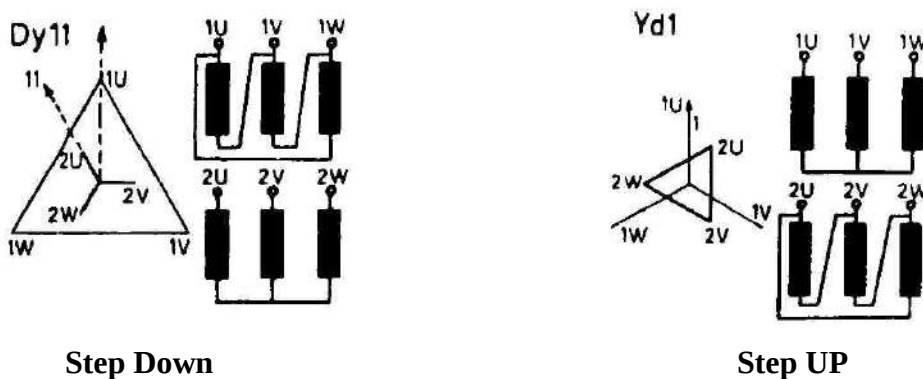


Fig. 4.48

Connections commonly adopted in hydroelectric station are as follows step up transformer.

These are shown in figure .. as per IS: 2026 (part IV)

4.19.9 Parallel Operation of Transformers

Transformers are said to be connected in parallel when their primaries and secondaries are connected to same circuits.

Transformers will operate in parallel satisfactory, if they have,

- i) the same primary and secondary voltages

- ii) the same tap-ratio
- iii) the same percentage impedance, and,
- iv) belong to the same vector groups

Two transformers may have their windings connected star/star and yet it will not be possible to operate them in parallel if one belongs to group I and the other to group 2, unless the internal connections of the secondary winding of one of the transformers are changed.

A transformer of Group 3 can be operated in parallel with a transformer of Group 4 by transposing the external connections of one of the transformers as shown in fig. .. No internal change of connection is required in this case.

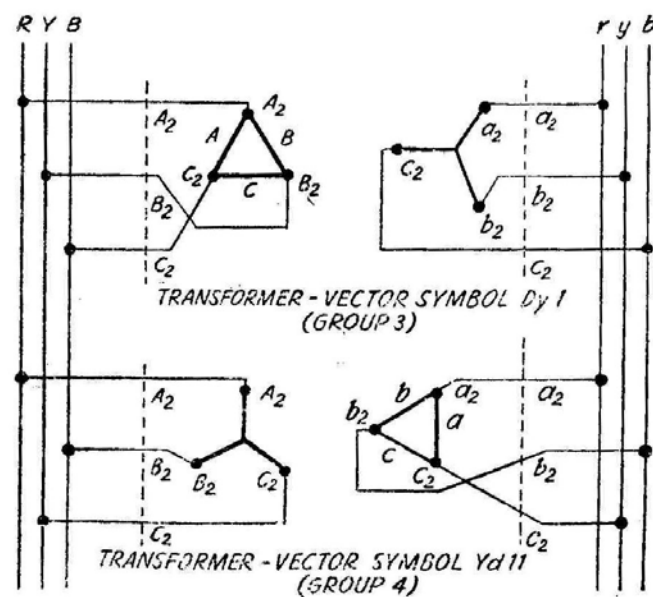


Fig. 4.49

Where information regarding vector groups may not be available, the ability of transformers to operate in parallel can be checked by the method shown in fig...

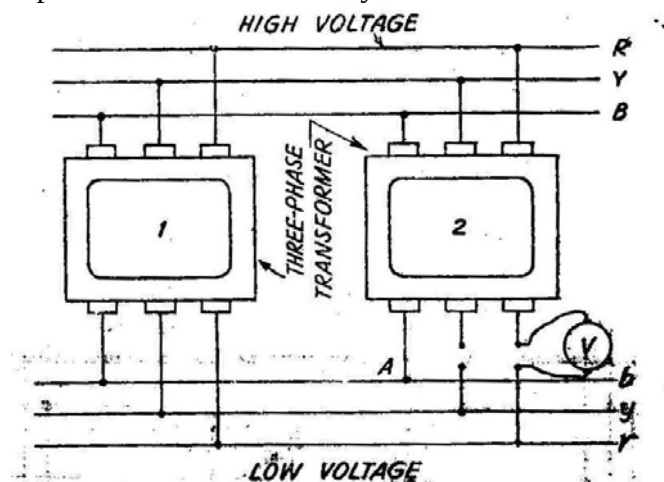


Fig 4.50

Transformer 1 is hooked on to the lines on both the primary and the secondary sides. Transformer 2 is connected on the HT side and one of its secondary leads is connected to the LT bus as at point A. The voltage readings are then taken between the unjoined leads and the bus bars. If the readings are not zero, the same procedure is repeated by connecting the load 'A' to the other secondary terminals of transformer 1. If no combination gives zero on the voltmeter, the two transforms will not operate in parallel without change of connections.

4.19.10 Component

A typical power transformer used at Sikasar HE Project for stepping power generated at 6.6 kV to 33 kV for interconnection with grid is shown in figure 4.9.4. major component are discussed below.

- i) **Steel tank:** Steel tank is used for housing the core and the windings and for mounting various accessories required for the operation of the transformer. Tank main body designed to withstand vacuums and fitted with lifting and haulage facility. Provision for attaching radiators, coolers an tap changing equipment are mode. Tank of adequate strength is provided.
- ii) **Tap Changing Switch:** It is the device for changing the voltage ratio of the windings to allow for variations of voltage on the primary side. Taps are brought out from the high voltage windings to the tap-changing switch.
- iv) Conservator Or Expansion tank
- v) Breather
- vi) Thermometer
- vii) Pressure Relief or Explosion Vent Pipe
- viii) Valves

Cores

The core are constructed from high grade silicon steel laminations

Windings

Windings and impulse withstand should be as per IS: 2026 and proper insulation. Windings are braced to withstand transport, short circuit and switching shocks.

Cooling

Radiators and coolers are provided as require ed.

Tap Changing

Terminal

Bushing insulators and terminal are provided as required and as per I.S. standard.

Temperature indicating and other device e.g. as follow as provided for protection, monitoring etc.

It consists essentially of two independent circuits linked with a common magnetic circuit. Thus energy at low voltage may be transformed into energy at high voltage or vice versa. The winding of transformer connected to the supply circuit is referred to as the primary winding, and those windings of the transformer connected to the receiver circuit are called secondary windings.

- B. Switchyard –Protection** – Circuit Breaker, Short circuit current, Base kVA, Method of short circuit, kVA calculation, Fuse element, Current carrying capacitor of fuse element, Instrument Transformer, Current transformer, Basic principle of operation of circuit breakers, Types of circuit, oil circuit breakers, Oil less circuit breaker, relay – its type – electromagnetic induction type, electromagnetic attraction, thermal, moving, static, directional, over voltage and over current. **C – Power transformer** – differential protection, over current earth fault protection; SCADA – supervisory control and data acquisition

Introduction: - The subject matter relates to following aspects.

Switchgear is circuit opening devices including circuit breakers, disconnecting and load break switches.

Protective Gear is equipment necessary for recognizing locating and initiating the removal of a fault or abnormal condition for power system and includes a relay or group of relays and accessories. Accessories includes instrument transformers shunts, wiring and auxiliary devices etc.

Control Gear is control and monitoring of energy generated and includes starting, stopping, synchronizing and running control of hydro power stations including automation.

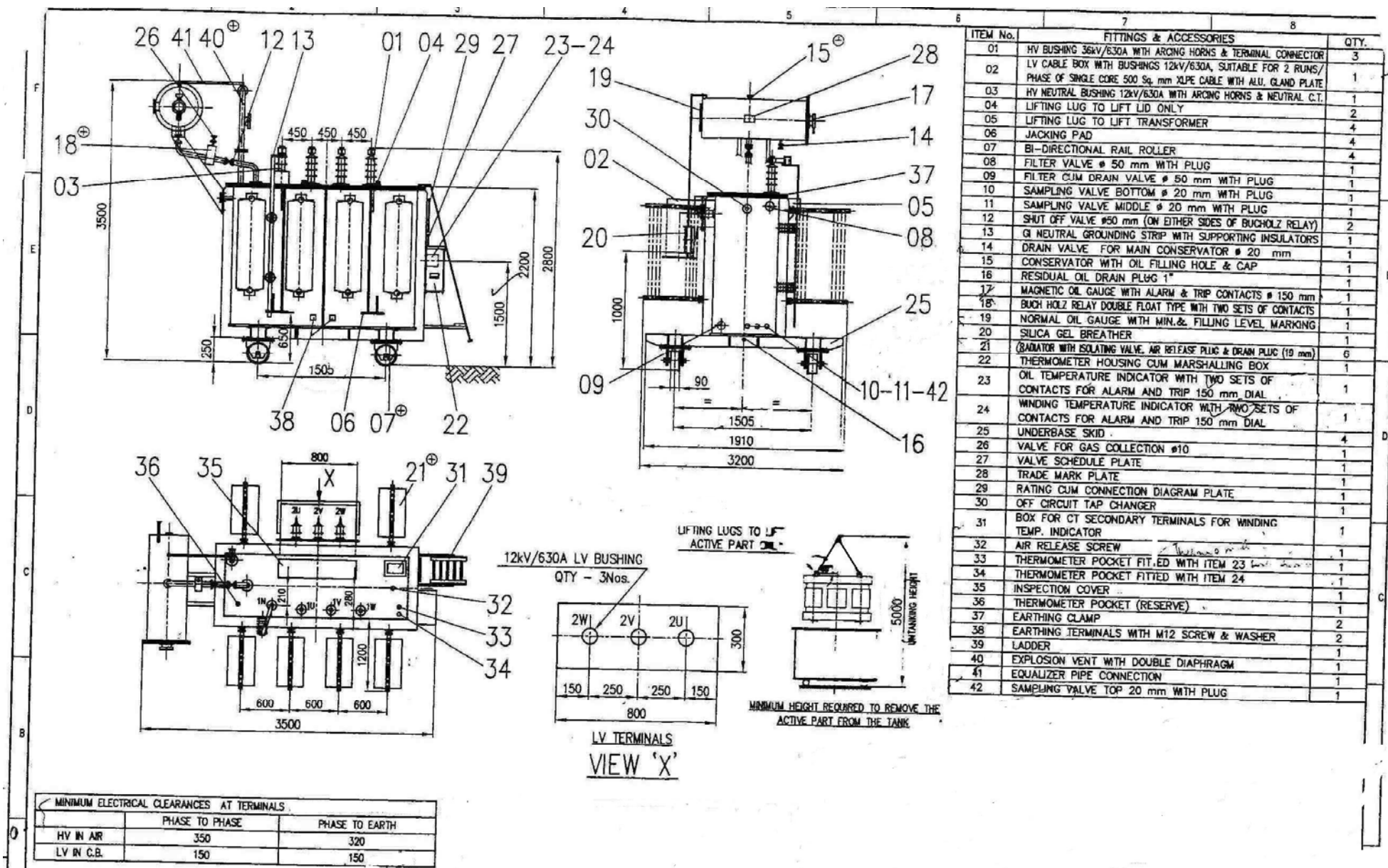


Fig. 4.51

4.20 Switchgear - Circuit breaker, Isolating Switches, Load Break Switches and Fuses

4.20.1 Circuit Breaker – Rating and Characteristics

A circuit breaker is defined as “a mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying and breaking for a specified time, and breaking currents under specified abnormal circuit conditions such as a short circuit”.

Low Voltage Circuit Breaker

Circuit breakers intended for service on a-c circuits upto 1000 volts and d-c circuits upto 1500 volts are classified as low –voltage breakers. Inherent requirement of these breakers are fast in operation, free from fire hazard, require little maintenance on repetitive service, and, because of the low voltage, simpler, more compact, and easier to handle. The breakers are covered by IS: 13947. Major types of low voltage circuit breaker are as follows:

Moulded case circuit breaker (MCCB): A circuit breaker having a supporting housing of moulded insulating material forming an integral part of the circuit breaker.

Air Circuit Breaker: A circuit breaker in which the contacts open and close in air at atmospheric pressure.

Vacuum Circuit Breaker: A circuit breaker in which the contacts open and close within a highly evacuated envelop.

Gas Circuit Breaker: A circuit breaker in which the contacts open and close in gas (SF₆).

Classification:

- i) The circuit breaker may be classified according to interrupting medium i.e. air break, vacuum break and gas breaker.
- ii) Design i.e. open construction or moulded case
- iii) Method of controlling the operating mechanism i.e. manual, electrical, stored energy etc.
- iv) Method of installation i.e. fixed, or withdrawable to achieve isolation from main circuit in with drawn position.

Rated operational voltage for these circuit breaker is 240 volts and 415 volts. Indian standards specify use of aluminium conductors. Allowable current rating for typical size of aluminium conductor is given in table 4.10.1.

Table 4.10.1: Standard Cross –section of aluminum conductors for typical values for test current up to and including 400 A

Rated of test current (A)	AC conductor size (mm) ²
8 – 12	1.5
15 – 20	4.0
25 – 32	10
50 – 65	25
85 – 100	50
150 – 175	95
200 – 225	150
350 - 400	300

Rated short circuit breaking and making capacity of the breakers as per IS: may be specified - 3 kA to 50 kA.

For low capacity lighting and auxiliaries in the powerhouse moulded case ‘thermal breakers are grouped in panel boards. They are usually operated manually and provide automatic inverse time overload tripping to protect circuit wiring against over loads and short circuits by direct acting series trips.

For more important and higher capacity circuits metal enclosed, drawout assemblies of air circuit breakers are used. These breakers may be operated either manually or electrically. Direct acting series overload trips or relays which will give selective isolation of a faulty circuit are used. The metal enclosed gear is factory assembled and tested and provides maximum reliability, safety and ease of maintenance with minimum interruption to service. These breakers may be used to provide control as well as running overload and short circuit protection for individual motor circuits.

High Voltage Power Circuit Breaker

Circuit breakers are generally classified according to the interrupting medium used to cool and elongate the electrical arc permitting interruption. The types are:

- Air
- Oil
- Air blast
- Vacuum
- SF6 gas

Following types of circuit breakers formerly used in high voltage outdoor substations are no longer in use and are being phased out.

Bulk oil circuit breakers (Dead Tank Design) – In these circuit breakers oil contents is used for arc extinction and also for insulating live parts from the tank which is dead and generally earthed (ground).

Minimum oil breakers (Live Tank Design) – In these circuit breakers oil is primarily used for arc extension and not necessarily for insulating live parts from earth (ground). The tank of these circuit breakers are insulated from earth ground. The circuit breakers are phase separated.

These circuit breaker widely used upto 72 kV level and are no longer being manufactured and are being phased out from existing installation.

Air blast circuit breaker – circuit breaking in these circuit breakers occurs in a blast of air under pressure. These circuit breakers were widely used upto 765 kV system. These circuits breakers are also being phased out.

Type of Circuit Breaker Following types of high voltage outdoor type circuit breakers are in use now-a-days.

- i) SF-6 – Sulphur Hexa Fluoride Breakers 36 kV to 765 kV class
- ii) Vacuum circuit breakers upto 36 kV class

Rated Characteristics

The main characteristics of a power circuit breaker including its operating devices and auxiliary equipment used to determine the rating are as follows :-

- Rated voltage
- Rated insulation level
- Rated frequency
- Rated normal current
- Rated short-time withstand current
- Rated short-circuit breaking current
- Rated short-circuit making current
- Rated operating sequence
- Rated characteristics for short-time faults, for three pole circuit breakers designed for direct connection to overhead transmission lines and rated at 52 kV and above.

Relevant National and important international standard in this connection are as follows: -

1. IS: 2516 – Specification for circuit breakers not exceeding 1000 V AC
2. IS: 13118 - Specification for high-voltage alternating current circuit breakers
3. IEC: 56- High voltage alternating current circuit breakers
4. IEEE: 37- IEEE AC high voltage circuit breakers

5. IEEE 37013 - AC high voltage generator circuit breaker rated on symmetrical current basis

Preferred rating of 3 phase circuit breaker as per IS: 2156 upto 11 kV are given in table 4.10.1 and for 33 kV and above as per table 4.10.2. The breaking capacity may be calculated as described subsequently.

Table 4.10.1

Preferred ratings of 3-phase Circuit Breakers

Rated voltage	Symmetrical Breaking Capacity	Rated capacity
KV	MVA	AMP
3.3	50 75 150 250	400 400,630 (800) 630,(800), 1250 1250, 1600
6.6	150, 250	400, 630 (800), 1250
11	150 250, 350 500 750, 1000	400, 630 (800) 400, 630 (800), 1250 630 (800), 1250, 1600 1250, 1600

Table 4.10.2

Rated voltage (kV)	Rated short-circuit breaking current (kA)	Rated normal current (A)							
36	8 16 40		630 630		1250 1250	1600 1600		2500	4000
72.5	12.5 20 31.5			800	1250 1250 1250	1600	2000		
145	12.5 20 25 40 50	800	1250 1250 1250	1600 1600 1600	2000 2000 2000 2000	3150 3150			
245	20 31.5 40		1250 1250	1600 1600 1600	2000 2000 2000	3150			

	50				2000	3150			
420	20			1600	2000				
	31.5			1600	2000				
	40			1600	2000	3150			
	50				2000	3150	4000		
525	40				2000	3150			
765	40				2000	3150			

Circuit Breaker Control

Control o circuit breakers requires following.

- Reliable tripping on faults to isolate the faulty system
- Trip free closing i.e. case of fault it should no be possible to close the breaker to avoid damage to the breaker.

DC Control:- Power breakers are controlled by DC from batteries in power station. It is a reliable source of control power. Commonly adopted trip free Dc control scheme for power breakers is shown in figure 4.10.1.

AC Control:- For smaller and low voltage circuit breakers manual closing and a. c. tripping is employed.

Series trip coil shown in figure 4.10.2 and shunt trip coil (fig. 4.10.3) are common.

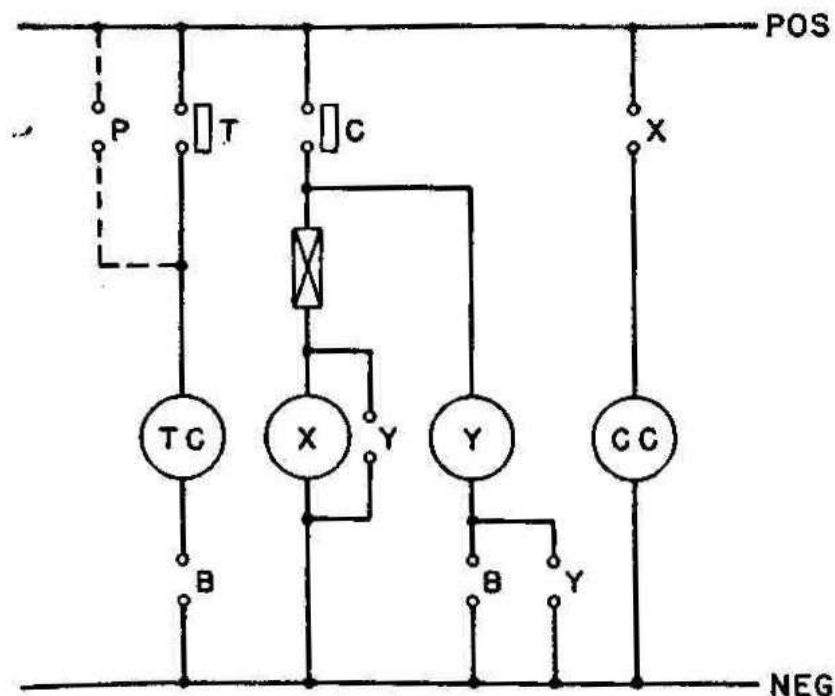


Fig. 4.52 – The X-Y scheme of circuit breaker control using a battery

C – Closing contact of control switch
 T – Tripping contact of control switch
 X - Closing contactor or relay
 CC – Closing coil of main circuit breaker
 Y – Releasing contactor or relay
 P – Typical protective relay contact
 B – Auxiliary switch (closed when main circuit breaker is closed)
 TC – D-C shunt trip coil of main circuit breaker

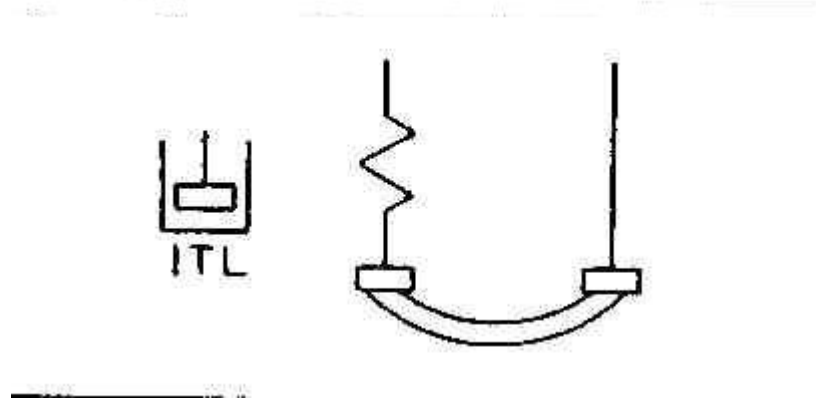


Fig. 4.10.2 – Series trip

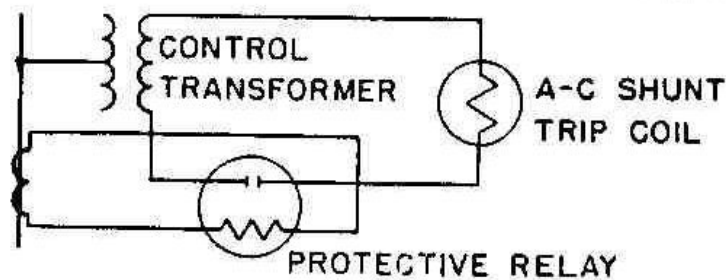


Fig. 4.53 – A-C Trip

Rated Short Circuit Breaking Current Characteristics of Circuit Breakers

The required breaking capacity of circuit breaker can be worked out if the size of the generator (or transformer) and its percentage impedance or reactance are known.

Since the resistance is small compared the reactance, fairly accurate results are obtained by using the latter only.

Required breaking capacity in kVA

$$\text{Rating of transformer in kVA} \times \frac{100}{\% \text{ reactance}}$$

Example. A 100 kVA transformer with 5% reactance (fig. 4.10.3.a) will be able to feed.

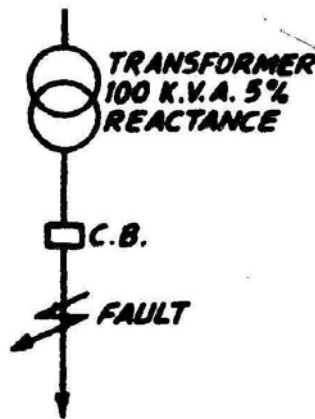


Fig. 4.54 (a)

$$100 \times \frac{100}{5} = 2000 \text{ kVA or 2 MVA}$$

into a fault ahead of it.

Similarly fault current in kilo-amps can be calculated from the formula:

$$\frac{\text{Rated current of transformer}}{1000} \times \frac{100}{\% \text{ reactance}}$$

The actual fault current will be less because of the impedance of the cables and the other intervening devices.

Transformers/Alternators in parallel (fig. 4.10.3 b)

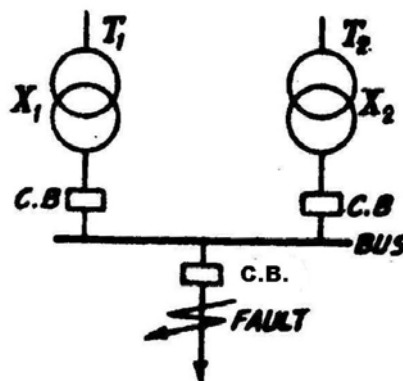


Fig. 4.54 (b)

The combined percentage reactance of two transformer operating in parallel can be worked out from the formula,

$$\text{Combined \% reactance} = \frac{X_1 X_2}{X_1 + X_2}$$

Where X_1 and X_2 are the % reactance of the two transformers, the resultant % reactance can be worked out from the formula:

$$\frac{1}{X} = \frac{1}{X_1} + \frac{1}{X_2} + \frac{1}{X_3} \text{ etc.}$$

where X is the combined % reactance and X_1, X_2, X_3 are the individual % reactance.

If the ratings of the transformers/alternators operating in parallel are different (fig. 4.11.3.c) their % reactance is first worked out with respect to an arbitrarily rating, which is a function of the individual ratings.

The continued percentage reactance is then worked out with respect to the assumed rating in the manner already described.

Example. Consider the transforms in fig. 4.10.3.c.

Assume basic rating as 10 MVA.

% reactance of 2 MVA transformer w.r.t. the new rating of 10 MVA

$$= 5 \times \frac{10}{2} = 25\%$$

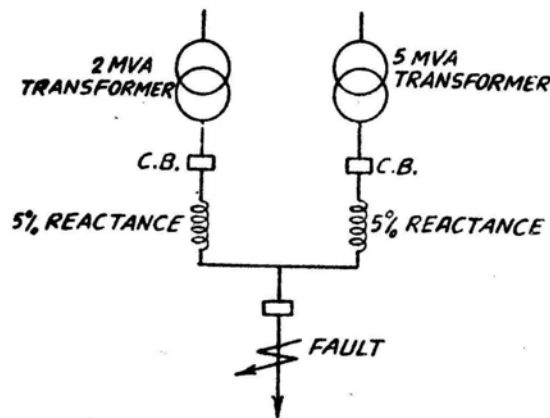


Fig. 4.54 (c)

% reactance of 5 MVA transformer w.r.t. the new rating of 10 MVA

$$= 5 \times \frac{10}{5} = 10\%$$

$$\text{combined \% reactance} = \frac{X_1 X_2}{X_1 + X_2}$$

$$= \frac{10 \times 225}{10 + 25} = \frac{250}{35} = \frac{50}{7} = 7.1\%$$

$$\begin{aligned} \text{Required rupturing capacity of breaker in MVA} &= 10 \times \frac{100}{7.1} \\ &= 141 \text{ MVA} \end{aligned}$$

% Reactance at Different Voltages. Percentage resistance, reactance, and impedance at one voltage can be transferred to % resistance, reactance and impedance at another voltage by the following formula:

% reactance at voltage V_2 = % reactance at voltage $V_1 \times \left(\frac{V_1}{V_2} \right)^2$. For example, a 5%

reactance at 6.6 kV will be equal to $5 \times \left(\frac{6.6}{33} \right)^2 = 0.2\%$ reactance at 33 kV.

Percentage resistances and reactance in series can be added in the same manner as actual resistance and reactance. However, percentage impedance have to be added.

The relationship between and reactance in series can be added in the same manner as actual resistance and reactance and impedance are given by the following formulae:

$$\text{Percentage resistance } P_r = \frac{I \times R}{E} \times 100$$

$$\text{Percentage reactance } P_x = \frac{I \times X}{E} \times 100$$

$$\text{Percentage resistance } P_z = \frac{I \times Z}{E} \times 100$$

Where

I = full load current

E = rated voltage

R = actual resistance
X = actual reactance
Z = actual impedance

Actual resistance, reactance and impedance can be worked out if the percentage values are known.

4.20.2 Disconnect Switch

A disconnect switch is a mechanical device used to change connections within a circuit or isolator a circuit from its power source, and are normally used to provide isolation of the substation equipment for maintenance. Typically a disconnect switch would be installed on each side of a piece of equipment to provide a visible confirmation that the power conductors have been opened for personnel safety. Once the switches are placed in the open position, safety grounds can be attached to the de-energized equipment for worker protection. Switches can be equipped with grounding blades to perform the safety grounding function.

Disconnect switches are designed to continuously carry load currents and momentarily carry higher capacity for short circuit currents for a specified duration (typically specified in seconds). They are designed for no load switching. Opening or closing circuits where negligible currents are made or interrupted, or when there is no significant voltage across the open terminals of the switch. They are relatively slow speed operating devices and therefore are not designed for arc interruption. Disconnect switches are also installed to bypass breakers or rather equipment for maintenance and can also be used for bus sectionalizing. Interlocking equipment is available to prevent inadvertent operating sequence by inhibiting operation of the disconnect switch operation until the fault and/or load currents have been interrupted by the appropriate equipment.

4.20.3 Load Break Switches

A load break switch is a disconnect switch that has been designed to provide making or breaking of specified currents. This is accomplished by addition of equipment that increases the operating speed of the disconnect switch blade and the arc resulting when switching load currents.

Disconnect switch can be supplied with equipment to provide a limited load switching capability. Arcing horns, whips, and spring actuators are typical at lower voltages. These switches are used to de-energize or energize a circuit that possesses some limited amount of magnetic or capacitive current, such as transformer exciting current or line charging currents.

4.20.4 Fuses

A fuse, in its simplest form, is a piece of thin metal wire, which opens the circuit in which it is inserted, by melting when current through it exceeds a certain value for a sufficient period. Melting or bowling is caused by the heat generated by the current. The part, which actually melts and opens the circuit is known as the fuse-element.

A fuse, being a thermal device, possesses inverse current time characteristics as shown in fig. 4.11.4 i.e. the operating time decreases as the fault current increases.

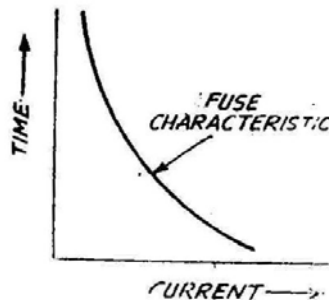


Fig. 4.55

Fuse Factor: It is the ratio of the minimum current at which a fuse will blow to its rated current, i.e.

$$\text{Fusing factor} = \frac{\text{Minimum fusing current}}{\text{Rated current}}$$

It is always greater than unity and is equal to 1.9 for the rewirable fuses and equal to 1.45 for the standard duty cartridge fuses, A 5 amp. rewirable fuse will operate when current through it exceeds $5 \times 1.9 = 9.5$ amps. for a sufficient length of period.

Types of Fuses

There are two types of fuses,

- i) Rewirable type and
- ii) Cartridge type

The specifications for re-wirable fuses are covered by IS: 2086. Standard ratings are 6, 16, 32, 63 and 100 amperes. Rewirable fuses are not permitted for higher ratings.

Rewirable fuses of 16 A and below are permitted to be used for breaking capacity upto 2 kA only and those upto 100 A rating for breaking capacity upto 4 kA only.

Rating of rewirable fuse elements in semi enclosed fuses is give in table 4.10.4.1.

Table 4.10.4.1

Current rating of fuse	Tinned copper wire		Standard alloy wire	Lead	Aluminum wire diameter
	Dia.	S.W.G.	Dia.	Dia.	
Amp.	mm.	S.W.G.	mm.	mm.	mm.
5.0	0.21	35	0.81	0.91	-
10.0	0.38	28	-	-	-
20	0.61	23	-	-	-
25	-	-	-	-	0.900
45	1.22	18	-	-	-
65	1.42	17	-	-	-
102	2.03	14	-	-	-
150	2.95	11	-	-	-

High Rupturing Capacity (HRC) Fuse

HRC fuses are used in circuit requiring high rupturing (breaking capacity). The specifications for medium voltage HRC fuses are covered by IS: 2208 – 1962.

Preferred Ratings of HRC Fuses are 2, 4, 6, 10, 16, 25, 30, 50, 63, 80, 100, 125, 160, 200, 250, 320, 400, 500, 630, 800, 1000 and 1250 amperes.

Selection of Fuses

The following considerations may be kept in view while selecting a fuse.

- i) It should not operate under conditions of momentary overloads and during switching surges which are experienced when starting a motor and switching on transformers, capacitors etc.
- ii) It must operate when sustained overload or short-circuit occurs.
- iii) There should be proper discrimination with the other protective devices. For purposes of protection, electric circuits are broadly classified.

Fuses for Motors

In the case of electric motors, the fuses have to be selected keeping in view the starting current, its duration and frequency.

If the current-time characteristics of the fuses and starting current-time curve of the motor are available, then a fuse with its characteristics lying just above the motor starting curve should be selected, so that it does not blow during starting (fig. 4.10.4.1)

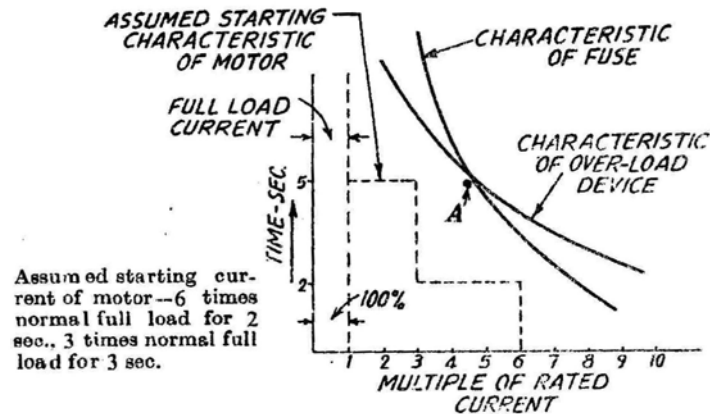


Fig. 4.56

Fuses as Back-up Protection by Fuses

HRC fuses are sometimes used as back up protection from circuit breakers. The characteristics of the fuse and the circuit breaker are so co-ordinated that all faults within the range of the breaker are cleared by it and the faults beyond its range are cleared by the back-up fuses. In fig. 4.10.4.2 curve 'a' is for the overload device, curve 'b' is the short circuit release characteristics of the breaker and curve 'c' the characteristic of the fuse. Line 'd' indicates the maximum breaking capacity of the breaker. It will be seen that the fuse takes over the protection duty before the maximum capacity of the breaker is exceeded.

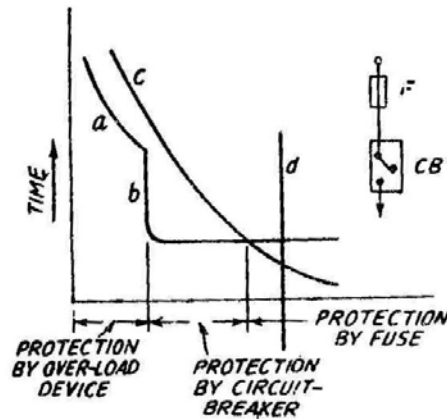


Fig. 4.57

High Voltage Fuses

High voltage fuses up to 33 kV have been used for the protection of feeders and transformers because of their low cost. Such fuses with rupturing capacity of 150 MVA and maximum current carrying capacity of 100 amp. have been used. Typical rating of D type fuse elements transformers etc. is shown in table 4.10.4.2.

Table 4.10.4.2

	Three-phase					
KVA Rating	Transformer protection			Feeder protection		
	11 kV	6.6 kV	3.3 kV	11 kV	6.6 kV	3.3 kV
10	3	5	7.5	2	2	5
25	5	7.5	15	3	5	10
100	15	20	40	7.5	15	30
250	30	40	75	20	30	60
400	40	60	100	30	50	75
1000	75	100	-	75	100	-

4.21 PROTECTIVE GEAR

Protective gear is equipment necessary for recognizing locating and initiating the removal of a fault or abnormal condition for power system. Relay protection is defined as follows:

“A relay or group of relays and accessories” intended in case of fault or abnormal conditions either to isolate a certain zone of an electrical installation (hydro generator, transformer, feeder etc.) or to actuate a signal.

Included in the term “accessories” are current and voltage transformers, shunts and wiring and auxiliary devices necessary to secure successful operation. It excludes circuit breakers.

Essential qualities of protection are:

- i) Reliability – to avoid to damage to the generating plant and equipment
- ii) Selectivity – to avoid un-necessary loss of circuit or plant
- iii) Speed
- iv) Sensitivity

Overlapping zones of protection (fig. 4.11.1) are provided to achieve the objectives and reliability against failure of protective equipment itself or even circuit breaker failure is provided by primary and backup protection.

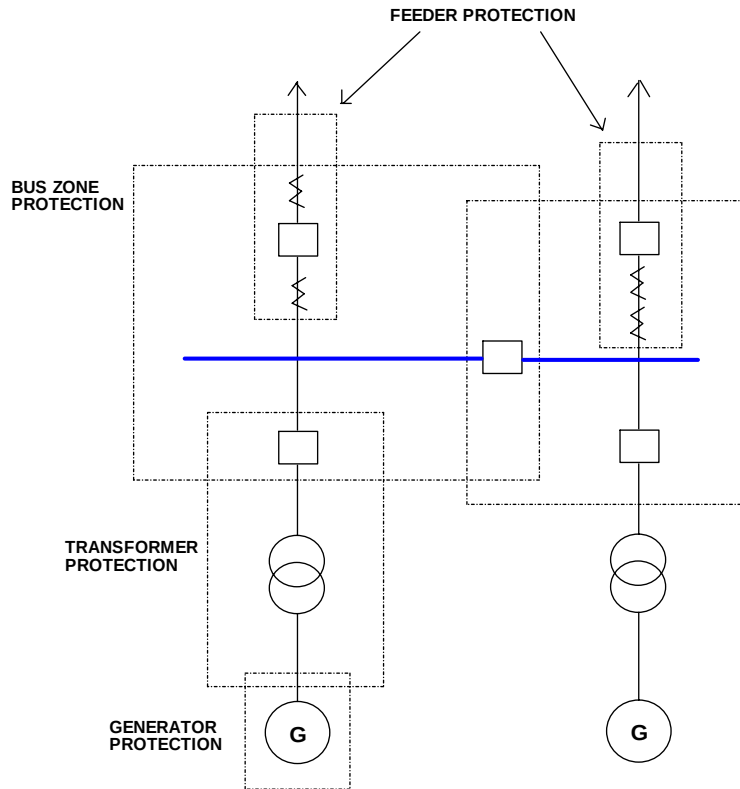


Fig. 4.58

Protective relay technology has changed significantly in recent years. Induction disk relays for each individual protective function were normally used. Individual solid state static relays for protective function were introduced in the decade 1980-1990 and IS 3231-1965 was accordingly revised in 1987. Microprocessor based multi function relays are now being introduced. Advantage claimed for these relays are as follows:

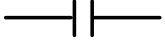
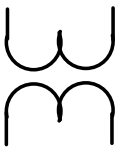
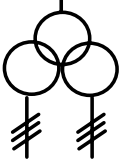
- i) Self monitoring of operating status on continuing basis and to alarm when to function.
- ii) Multiple protective functions in one relay reduce panel space and wiring end.
- iii) Self calibration by software programming
- iv) Programmable set point by software programming

Microprocessor relaying has gained widespread acceptance among both utilities and consumers. The relay functions are the same as those in electromechanical and solid-state electronic relaying, but microprocessor relays have features that provide added benefits. Microprocessor relays may have some disadvantages, however, so that there are additional considerations when these are applied to the utility-consumer interconnection. Only electro-mechanical induction disc type only are discussed.

4.21.1 Power and Control System Single Line Diagram and Schematic

Graphic Symbols

Single line diagrams representing 3 phase by single line are generally made as a starting point in designing protection systems for hydro plants i.e. generators; transformers; circuit breakers etc. Graphic symbols used to represent various elements are given in IS: 2032. Some generally used graphic symbols are given below. In case some other symbols are used same should be specified on the drawing.

ALTERNATING CURRENT, GENERAL SYMBOL		FUSE	
POSITIVE POLARITY		VOLTMETER	
NEGATIVE POLARITY		AMMETER	
WINDING, DELTA		WATTMETER	
WINDING, STAR		VARMETER	
WINDING		POWER FACTOR METER	
CAPACITANCE, CAPACITOR		INDICATING INSTRUMENT/RELAY (GENERAL SYMBOL)	
EARTH		RECORDING INSTRUMENT (GENERAL SYMBOL)	
FAULT		INTEGRATING METER	
GENERATOR		CURRENT TRANSFORMER	
TRANSFORMER		VOLTAGE TRANSFORMER	
3-PHASE TRANSFORMER WITH THREE SEPERATE WINDINGS-STAR-STAR-DELTA		NORMALLY OPEN AUX. CONTACT	
SWITCH		NORMALLY CLOSED AUX. CONTACT	
CIRCUIT BREAKER			

Device Numbers

Relays and protection used on schematic drawings are classified by 94 device function members used in generating station, sub station according to IEEE C37.2-1991. The use of prefixes and suffixes provide a more specific definition of the function. Commonly used device numbers are as follows. For complete list refer to IEEE publication 37.2.

5	-	Stopping device
12	-	Over speed or over frequency relay
14	-	Under speed or under frequency relay
21	-	Distance relay
23	-	Temperature control device
25	-	Synchronizing or synchronizing check device
26	-	Apparatus thermal device
27	-	A. C. under voltage or NO voltage relay
30	-	Annunciation relay
32	-	Reverse Power flow relay
37	-	Under current or under power relay
38	-	Bearing protective device
40	-	Field Failure relay
41	-	Field circuit breaker
46	-	Reverse phase or phase balance current relay
47	-	Phase sequence or phase balance voltage relay
50	-	Instantaneous over current relay
51	-	AC time over current relay
52	-	AC Circuit breaker
55	-	Power Factor relay
56	-	Field application relay
59	-	Over voltage relay
62	-	Time-delay stopping or opening relay
63	-	Pressure switch
64	-	Ground fault relay
65	-	Governor
67	-	AC directional over current relay
68	-	Blocking relay
71	-	Level switch
72	-	DC circuit breaker
76	-	DC over current relay
79	-	AC reclosing device
81	-	Frequency relay
85	-	Carrier or plot wire receive relay
86	-	Lock out relay
87	-	Differential protective (current) relay
89	-	Line switch

Suffix Letter

C	-	Closing relay/contactor
CS	-	Control switch
PB	-	Push button
U	-	“UP” position switch relay
X	-	Auxiliary relay
Y	-	Auxiliary relay
Z	-	Auxiliary relay
A	-	Air/amperes
C	-	Current
F	-	Frequency/flow/fault
J	-	Differential
L	-	Level/liquid
P	-	Power/pressure
PF	-	Power factor
Q	-	Oil
S	-	Speed
T	-	Temperature
V	-	Voltage
VAR	-	Reactive power
VB	-	Vibration
W	-	Water/watts

4.21.2 Instrument Transformer

Protective relays in a. c. power systems are connected in the secondary circuits of current transformers and potential transformers. The design and use of these transformers is quite different from that of well known power transformer. In current transformers, primary currents is not controlled by condition of the secondary circuit. Hence primary current is a dominate in the operation of current transformers. Current transformers are further classified into two groups:

1. Protective current transformers used in association with relays, trip coils, pilot wires etc.
2. Measuring current transformers – used in conjunction with metering instrument i.e. ammeter, wattmeter etc.

As a result, the ratio error is very important in protective current transformers, and phase angle error may be less important.

Voltage transformer is used for transforming voltage from one value to another (generally lower) value.

Both current transformers and voltage transformers come under the title Instrument transformers.

4.21.2.1 Current Transformer

Terminology

Protective Current Transformer – A current transformer intended to supply protective device (relay/trip coils).

Composite Error :- Under steady state conditions, the rms value of the difference, integrated over one cycle, between:

- a) the instantaneous value of the primary current and
- b) the product of the rated transformation ratio and the instantaneous values of the actual secondary current. (This includes the effects of phase difference, of any turns correction and of distortion of wave-form).

This is generally expressed as a percentage of the rms value of the primary current according to the expression given below:

$$\text{Composite error} = \frac{100}{I_p} \sqrt{\frac{1}{T} \int_0^T (K_n i_s - i_p)^2 dt}$$

Where

- I_p = primary current (rms value)
- T = duration of one cycle in seconds,
- K_n = rated transformation ratio,
- i_s = instantaneous value of the secondary current, and
- i_p = instantaneous value of the primary current

Rated Accuracy Limit Primary Currents

The value of the current assigned by the manufacturer as the highest primary current up to which the transformer will comply with the appropriate limits of composite error under specified conditions.

Accuracy Limit Factor

The ratio of the rated accuracy limit primary current to the rated primary current. The standard accuracy limit factors are 5, 10, 15, 20 and 30.

Excitation Current

The rms value of the current taken by the secondary winding of a current transformer when sinusoidal voltage of rated frequency is applied to the secondary terminals; the primary and any other windings being open-circuited.

Standard Accuracy Classes

For protective current transformer, the accuracy class is designated by the highest permissible percentage composite error at the rated accuracy limit primary current prescribed for the accuracy class concerned, followed by the letter 'P' (meaning protection). The standard accuracy classes for protective current transformers are 5P, 10P and 15P.

Knee-Point Voltage

That sinusoidal voltage of rated frequency applied to the secondary terminals of the transformer, all other windings being open-circuited, which when increased by 10%, causes the exciting current to increase by 50%.

Application of Protective Current transformers

The determination of the rating of a protective CT is dependant on its application and consequently the following parameters are worked out: rated burden, rated accuracy limit factor and accuracy class.

Rated Burden

The burden on a protective CT is composed of the individual burdens of the associated relays or trip coils, instruments(if used) and the connecting leads.

Normally, the standard VA rating nearest to the burden computed should be used,. But attention is drawn to the fact that a device may have different impedance under different operating conditions. The VA burden which is effectively imposed on the CT at rated secondary current is given the following formulas:

$$P_e = P_r \left(\frac{I_s}{I_r} \right)^2$$

Where

- P_e = effective VA burden on the CT
- P_r = VA burden of the device at current setting
- I_s = rated secondary current of the current transformer,
- I_r = current setting of the device

In selecting the most suitable standard rated output it is undesirable to specify a value which substantially exceeds the burden as computed above; to do so might result in a transformer uneconomic in cost or of unduly large dimensions. When the nearest standard VA rating is less than the total computed burden, it is usually satisfactory to adopt the former.

Rated Accuracy Limit Factor

In determining the appropriate accuracy limit factor for a given application, the important point to consider is the maximum value of primary current up to which maintenance of ratio is required, other factors however, are also involved. The capabilities of a protective current transformer are determined by the primary ampere turns, the core dimension and material, and they are roughly proportional to the product of the rated burden and the rated accuracy limit factor. With present day material and normal dimensions, this product has a maximum value about 150.

Correlation of Burden and Accuracy Limit Factor

Accuracy limit factor higher than 10 and rated burdens higher than 15 VA are not recommended for general purposes. It is possible, however to combine a higher rated accuracy limit factor with a lower burden rating and vice versa; but when the product of these two exceeds the resulting current transformer may be uneconomical and/or of unusually large dimensions. Moreover, it might not be possible to attain a product of 150 if the current transformers are of the wound-primary type with low ratio and high rated short-time thermal current.

Accuracy Class

The required accuracy class of protection current transformer is dependant upon the particular application and some guidance on its selection with particular regard to associated values of rated accuracy limit and rated burden is given in the following examples.

Instantaneous Overcurrent Relays and Trip Coils

In general a class 15P transformer will be sufficiently accurate. A secondary current greatly in excess of the values to cause operation serves no useful purpose, and rated accuracy limit factor of 5 should be adequate.

When such relays are set to operate at high values of overcurrent say from 5 to 15 times the rated primary current, the accuracy limit factor should be at least as high as the value of the setting used, the secondary current may never reach that value.

When a relay with a high setting from part of an equipment with a high total VA burden, it may be advantageous to operate the high-set relay from a separate current

transformer. This avoids the difficulty of having to provide a current transformer with a high burden combined a high accuracy limit factor.

For example, if a high set relay with a burden of 5 VA required an accuracy limit factor of 15 if the total burden is 20 VA, the product of these two quantities would be 300, which as indicated presents certain difficulties. If, however, this high-set relay is operated from a separate current transformer, that current transformer need only have a rated burden of 5 VA and an accuracy limit factor of 15, giving a product of 75, and the other current transformer operating the rest of the equipment, a rated burden of 15 VA and an accuracy limit factor of, say 10 giving a product of 150.

Moreover, the current transformers operating the high-set relay may be allocated an appropriately higher rated primary current, thereby reducing the required accuracy limit factor.

In these instances both transformers may be class 15P, one being designated 5 VA class 15P15 and the other 15 VA class 15P10.

Overcurrent Relays with inverse and Definite Minimum Time – lag Characteristics

In general, a class 10P current transformer should be used for both directional and non-directional relays in system networks in which discrimination is obtained mainly by graded time settings, where close discrimination is of less importance, a class 15P transformer may be satisfactory.

Earth-fault Protective Relays with Inverse and Definite Minimum Time-Lag Characteristics

The requirement of current transformers used with earth fault protective schemes involving the use of three –line current transformer (with or without a neutral current transformer) and using relays with inverse and definite minimum time-lag characteristics (both non-directional and directional), are dependant upon the characteristics of the protective system itself. Application of current transformer may be as per manufacturers recommendation or as per IS 4201.

4.21.2.2 Protective Voltage Transformers

Terminology

1. **Protective Voltage Transformers:** - Single-phase protection voltage transformer intended to supply protective devices (relay or trip coils). These transformers are required to have sufficient accuracy to operate protective system at voltages that occur under fault condition.
2. **Accuracy Class Designation:** - The accuracy class for protective voltage transformer except those used for producing residual voltage is designated by the highest permissible percentage voltage error for the accuracy class concerned

from 5 percent of rated voltage to a voltage corresponding to the rated voltage factor. This expression is followed by letter P. reference to the voltage error upto voltage factor is for protective.

3. **Standard Accuracy Classes:** - this is designated by the highest permissible percentage voltage error at rated voltages prescribed for the frequency class concerned.

The standard accuracy classes for protective voltage transformer are '3P' and '6P'.

Rated Burden: - The rated burden of a voltage transformer is usually expressed as the apparent power in volt amperes absorbed at rated secondary voltage. The burden is composed of the individual burdens of the associated voltage coils of the instruments, relays, trip coils to which the voltage transformer is connected. The total burden is computed by adding them together after referring the individual value to a common base i.e. rated secondary voltage.

Normally the standard VA rating nearest to be burden computed should be used. It is undesirable to specify VA rating much higher than the computed value, as to do so might result inaccuracies and the transformer uneconomical in cost or of unduly large dimensions. When the value of the nearest standard VA rating is less than the computed value, the use of such VA rating should be made in consultation with the manufacturers.

Accuracy of a voltage transformer is guaranteed for burden variation between 25% to 100% of rated burden.

Limits of Voltage Error & Phase Displacement

Protective voltage transformer should comply with the following requirements at any voltage between 5% and 110% of rated voltage and with burden of 25% and 100% of rated burden at p. f. of 0.8 lagging.

Acc. Class	Percentage Voltage ratio Voltage	Phase Displacement
3 P	$\pm 3.0 \%$	± 120 minutes
6 P	$\pm 6.0 \%$	± 300 minutes

Voltage Transformer Intended to Produce Residual Voltage

- a) Rated secondary voltage of winding connected in broken delta to produce a residual voltage are employed to detect earth faults or directional element

4.21.2.3 Application of Measuring Voltage Transformers

A measuring voltage transformer need maintain its accuracy from 80 to 120 % of rated voltage. It is not required to maintain its accuracy within specified limit during the fault conditions.

4.21.3 Protective Relay – Induction type

If a protective device acts directly on the holding latch of a switch or a circuit breaker, it is known as 'Release Device'. If it opens or close an auxiliary circuit as shown in fig. 4.11.3.1 it is called a relay. Release devices are used in manually operated switches and breakers, while relays are used in solenoid-operated breakers.

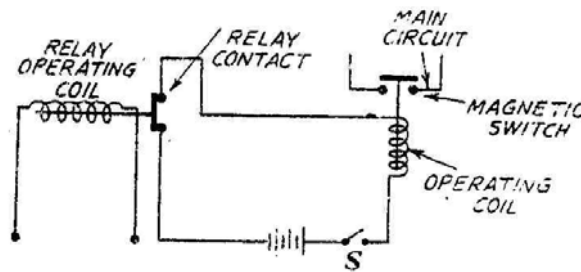


Fig. 4.56

Relays are classified according to their function such as current relay, voltage relay, frequency relay, phase unbalance relay, directional power relay, and also according to their time characteristics such as instantaneous relay, definite time relay, inverse time-current with definite minimum time-lag etc. A few of the more important types of relays are discussed in the succeeding paragraphs.

Instantaneous Overcurrent Relay

It consists of a solenoid, a plunger, and a set of contacts. The solenoid, generally operated by current transformer, attracts the plunger when current through it exceeds the specified value, which results in operation of the relay. Theoretically, there is no time-lag in operation but in actual practice, there is a time lag of about 240 milli-seconds which decrease as the fault current increases. Discrimination between successive relays of this type is possible with current ratio of 3 : 1.

Their principal application is in transformer feeders as the impedance of transformers permits good selectivity.

The instantaneous relays are unsuitable for circuits with high transients currents.

Definite Time Relay

This relay consists of a solenoid and a plunger with adjustable time delay feature in the form of an oil dashpot or an air escapement chamber. Such a relay operates after a specified time irrespective of the magnitude of the fault current. Selectivity amongst such relays is obtained, if there is a difference of 0.5 sec. In the time settings of the two successive relays.

The definite time relays are used in:

- i) Radial or loop circuits having a few sections.
- ii) As back-up protection for other forms of protection, and
- iii) On systems with wide variations of fault current due to source impedance.

4.21.3.1 Relay Application

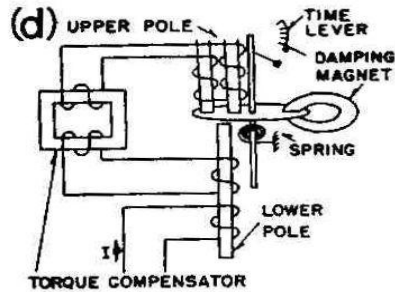
Application of relays requires evaluation of mainly following factors.

- i) The requirements of the power service and desired functioning of the system during fault conditions to produce this result.
- ii) The currents, voltages, temperatures, pressures, or other indicators at time of fault which provide the fundamental basis of discrimination.
- iii) The characteristics of available or standard relay elements.
- iv) The schemes in which they are used.

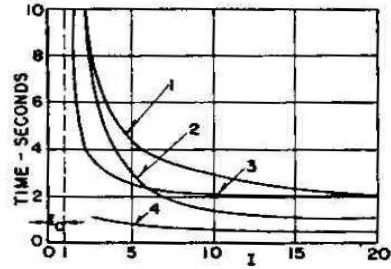
Electro magnet relays (induction disc type) only are discussed here.

4.21.3.2 Basic Relay Elements, Overcurrent Relay

Commonly used relay elements for overcurrent and directional by electromagnet induction disc are shown in figure 4.11.3.2 and 4.11.3.3 Instantaneous protection relay element is shown in figure 4.11.3.4.



Induction disk inverse-time overcurrent element—AC-Current is supplied to the lower pole, and by inductive coupling to the upper pole, directly, or through a torque compensator (saturating transformer). The upper pole induces currents in the disk. Torque is produced by the reaction between these currents and flux from the lower pole. Adjust current setting by coil tap and time setting by contact travel.

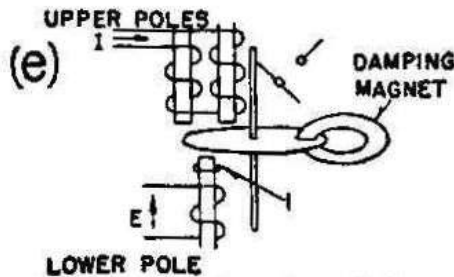


Operates for I greater than I_0 .

Times shown are maximum. Relays adjustable for times down to 0.1 or 0.05 times those shown.

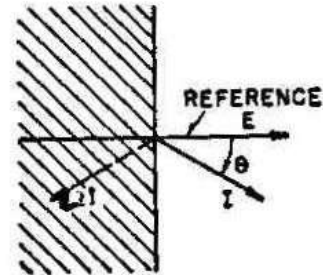
- 1 Inverse
- 2 Very inverse
- 3 Definite minimum time

Fig. 4.57-Induction disk inverse time overcurrent relay



Induction disk directional element. Current induced in the disk by the upper pole reacts on flux from the lower pole to produce torque.

- 1 Lag loop to bring lower pole flux in phase with upper pole current at unity power factor of E and I .



Vector diagram of E and I .

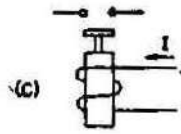
Contacts close for I in unshaded region, open in shaded region. Torque expression

$$T = K\bar{E}\bar{I} \cos \theta$$

where K is a constant, θ is the power factor angle.

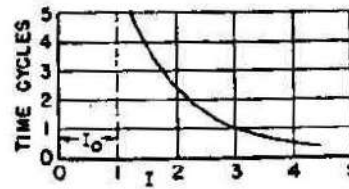
Fig. 4.58-Induction disc directional element

Schematic (a)



Solenoid, "Instantaneous," (d) AC or DC, adjust by taps on coil or by initial plunger position.

Operating Characteristics^(c)



Operates for $I > I_0^{(b)}$.

Fig. 4.59-Instantaneous element in relay

Inverse and Definite Time Overcurrent Relay (Induction disc type)

The following types of overcurrent relays normally used for the protection of power systems.

- 1) The inverse definite minimum time relay (IDMT relay)
- 2) A combined IDMT relay and high set instantaneous relay
- 3) A very inverse definite minimum time relay
- 4) A directional overcurrent relay
- 5) A definite time over-current relay

These are generally shown in figure 4.11.3.1 & 4.11.3.2, 4.11.3.3 and 4.11.3.4.

4.21.3.3 Terminology

The following definitions are commonly used.

Time Multiplier Setting

In the case of electromagnetic relays, a means of adjusting the movable back-stop which controls the travel of the disc and thereby varies the time in which the relay will close its contacts for given values of fault current. In the case of transistorized relays a potentiometer in the relay timing circuit is proposed.

Plug Setting Bridge

A device providing a range of current settings at which the relay will start to operate.

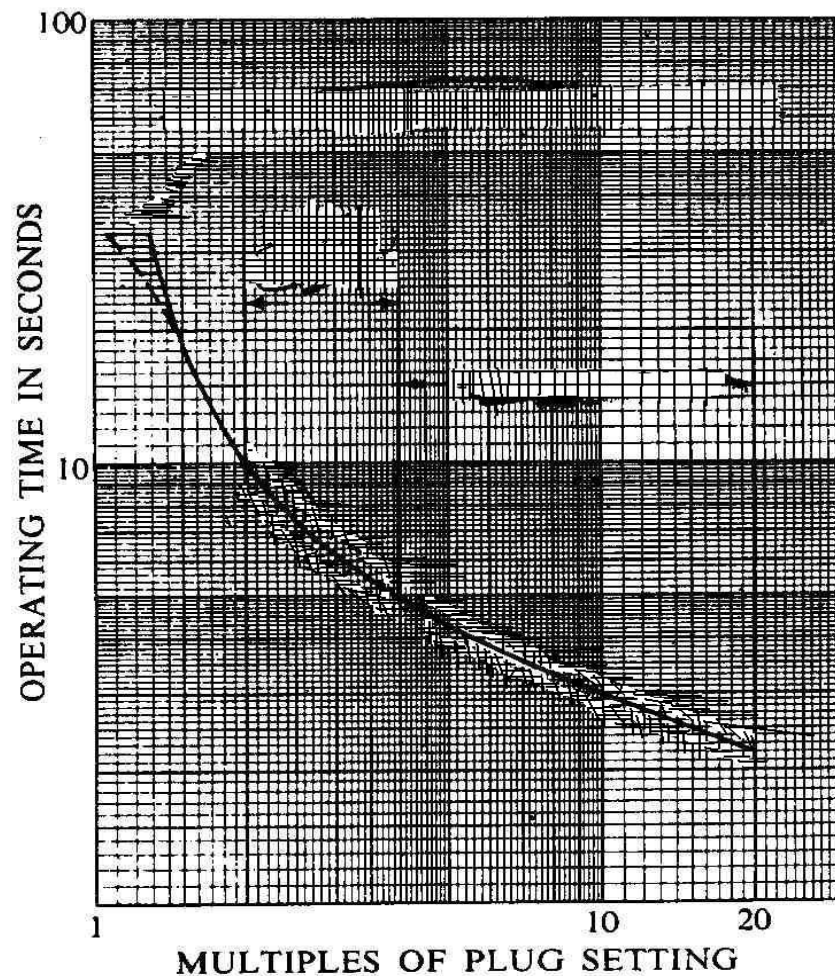


Fig 4.60 Typical curve for definite minimum time relay

Pick-up Errors

Errors in the current value at which the disc starts to move and at which its contacts close, expressed as a multiple of the plug setting.

4.21.3.4 Application of Induction Relay

Induction Relays are used extensively for protection against overloads, short circuits, and earth faults on the distribution/transmission lines and in industrial plants.

Relays with extremely inverse time-current characteristics are especially suitable for the protection of transformers, cables etc., as it is possible to achieve accurate discrimination with fuse and auto-reclosers in their case, which can seldom be made selective with standard IDMTL relays. This is because of their ability to ride through starting currents and surges, providing at the same time fast operation under fault

conditions. They are, thus, more suitable for installations with large in-rush currents after an outage.

Relays with very inverse time-current characteristics are used on feeders and long sub-transmission lines. Relays with inverse time current characteristics are widely used in distribution networks and industrial plant systems. Their relatively flat time-current characteristic permits them to achieve reasonably fast operation over a wide range of short circuit currents.

Selectivity of operation is achieved by:

- a) Grading the magnitude of the fault current
This is done with the help of the plug-setting bridge.
- b) Grading the time of operation
This is done with the help of time-setting multiplier
- c) Combination of (a) and (b)

4.21.3.5 Method of Calculating Relay Setting

Example

A relay is required to operate on a maximum fault current of 6000 amperes and the normal full load current is 300 amperes. Plug setting multiplier (Psm) and time setting multiplier (Tsm) is to be set. Relay is set to operate at 33% above the normal full load current.

Plug setting bridge is set at 400 amperes (300×1.33)

$$\text{Plug setting multiplier (PSM)} = \frac{6000}{400} = 15$$

$$\text{Time multiplier setting (TMS)} = \frac{T}{T_m}$$

Where T is required time of operation and T_m is the time obtained from relay characteristics curve using plug setting multiplier (PSM) equivalent of maximum fault current (15). $T_m = 2.5$ seconds (fig. 4.11.3.4). T is the time required for proper discrimination with other protection devices and it is 1.0 seconds then $\text{TMS} = \frac{1.0}{2.5} = 0.4$

4.21.4 Magnetic and Thermal Overload Relays

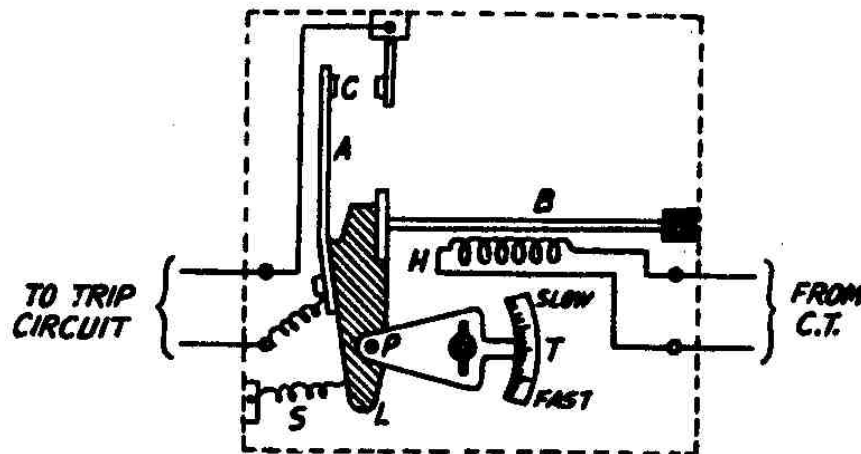
Magnetic and thermal overload relays are used to provide protection to motor and other sub circuits against overloads.

4.21.4.1 Magnetic over-load relay: In it, a plunger or armature is attracted by the magnet coil when current through it exceeds the specified value resulting in operation of the relay. To ensure its non-operation under conditions of transient overloads, time delay feature is provided with the help of oil dash-pots.

4.21.4.2 Thermal overload relay: provide the best means of overload protection to motors, as the heating characteristics of the two are similar. They are of two types:

- i) Bimetal type, and
- ii) Thermistor type,

i) Bi –metal Overload Relay. The essential element in such a relay is a bi-metal strip, which is heated directly or indirectly by the load current. The bi-metal strip bends when current through it exceeds the specified value resulting in operation of the relay. Time delay is adjustable by a tension of spring. The relay re-closes when the element cools down. The re-setting of relay can be automatic or manual. The latter method is to be preferred where automatic re-starting of the device can be dangerous.



- A = contact arm
- B = bimetallic strip
- C = contactor
- H = heater
- L = lever
- P = fulcrum
- S = spring
- T = time adjustment indicator

Fig. 4.11.4.1 Bimetal Type Overload Relay

- ii) Thermistor Relay. In this type of relay, the thermal element is a thermistor (T_{h1}) which forms one arm of a sensitive balance Wheatstone bridge. A temperature

compensated thermistor (T_{h2}) and two resistance (R_4 and R_5) form the other arms, as shown in fig.4.11.4.2 The change in resistance of the heat sink thermistor gives a signal across the output terminals of the bridge circuit, which is utilized to operate terminals of the bridge circuit which is utilized to operate the relay.

Where thermal relays are also operated from current transformers.

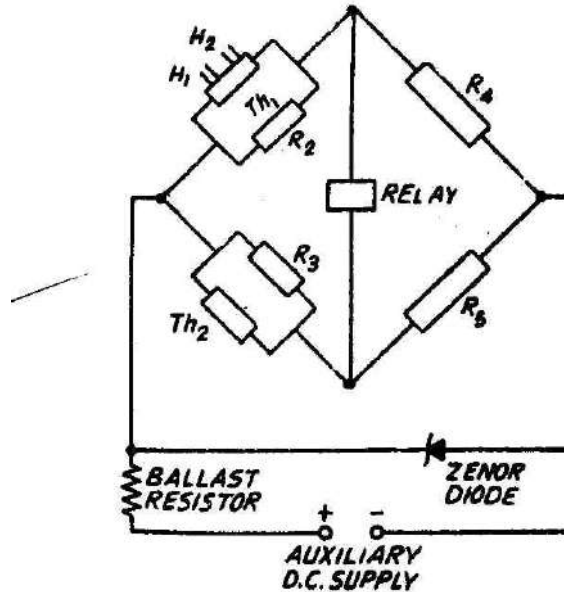


Fig. 4.61 Thermistor Overload Relay

4.21.5 Static Relays

Electromagnetic relays are in general built up from disc, induction cup, hinged armature relays etc. In the same way static relays are built up from basic circuits using transistors, resistors, diodes, capacitors and other discrete electronic devices. Among them following are important.

- i) Timers
- ii) Level detectors
- iii) Polarity detectors
- iv) Phase comparators
- v) Integrators

Low voltage d.c. requirement requires a good regulated power supply unit (Dc – Dc converter).

4.21.6 Power Transformer Protection

4.21.6.1 Nature of transformer faults: A power transformer is subject to the following faults:-

- o Overloads and external short circuits
- o Terminal faults
- o Winding faults
- o Incipient faults

All faults condition produce mechanical and thermal stresses within the transformer windings and in connecting bus bars.

Overloads can be sustained for long periods, being limited only by the permitted temperature rise in the windings and cooling medium. Excessive overloading will result in deterioration of insulation and subsequent failure. It is usual to monitor the winding and oil temperature conditions and an alarm is initiated when the permitted temperature limits are exceeded. This allows full advantage to be taken of the transformer overload capacity.

4.21.6.2 Protection System: The protection systems applied to a power transformer are :-

- o Gas and oil surge (Buchholz)
- o Overcurrent and earth fault (unrestricted)
- o Earth fault (restricted)
- o Differential

The usual practice on small transformers is to provide overcurrent and instantaneous earth fault protection only. On very small distribution transformers HV fuses are the only protection provided. Above 500 kVA all transformers fitted with conservators are provided with gas and oil surge protection. Differential protection is applied on all units above 20 MVA rating.

4.21.6.3 Incipient Faults: Faults while are not significant in the beginning but which slowly develop into serious faults are known as incipient faults. The oil is vaporized in the vicinity of break down such as a broken joint and or an earthfault, heavy short circuits increase the oil temperature to vaporizing point creating an oil surge due to pressure rise in the tank forcing oil through the connecting pipe into the conservator. Device use to provide gas and oil surge protection is known as Buchholz relay.

4.21.6.4 Overcurrent and earthfault (unrestricted): Plain overcurrent and earth fault protection utilizing IDMTL relays is used primarily to protect the transformer against the effects of external short circuits and excess overloads. The current settings of the protection must be above the permitted sustained overload allowance and below the minimum short-circuit current. The ideal characteristics is the extremely inverse relay as it closely approximates to the thermal curve of the transformer (figure 4.11.6.4 shows typical connection.

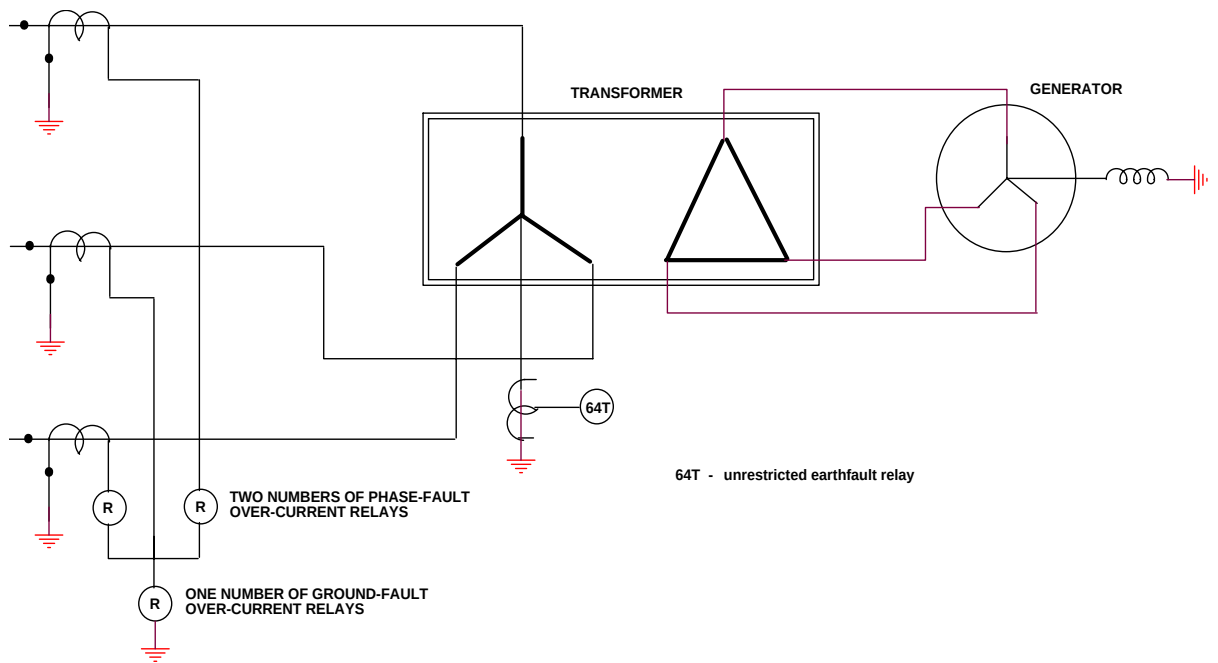


Fig. 4.62 Over-current and earth fault protection of a transformer

4.21.6.5 Differential System: Modern differential system of protection provide in a single scheme the most complete coverage for winding and terminal faults. The system operates on the well-known Merz-Price circulating current principle in which the current transformers at each output terminal are balanced against each other. Current magnitude at input (LV side) and output (HV side) are compared. An internal fault creates an unbalance which results in operation.

Application of this scheme to transformers is constrained by the magnetizing and inrush current as well as by Y Δ transformations.

Percentage differential relay generally employed for transformer protection comprises of two restraint coils and one operating coil per phase. The contact closing torque produced by the operating coil is opposed by restraint coil torque. Therefore, during through fault conditions the setting of the relay is increased and relay operating due to spill current is prevented. During internal faults the torque produced by the restraint coil is ineffective and relay close its contact when setting current flows the rough the operating coil.

The spill current level for the relay to just operate expressed as a percentage of through fault current causing it is defined as percentage bias of the relay.

$$\% \text{ Bias} = \frac{\text{Spill current for relay operation}}{\text{Through fault current causing it}} \times 100$$

Connection of percentage differential relay showing internal fault (e.g.) is shown in figure 4.11.6.5.

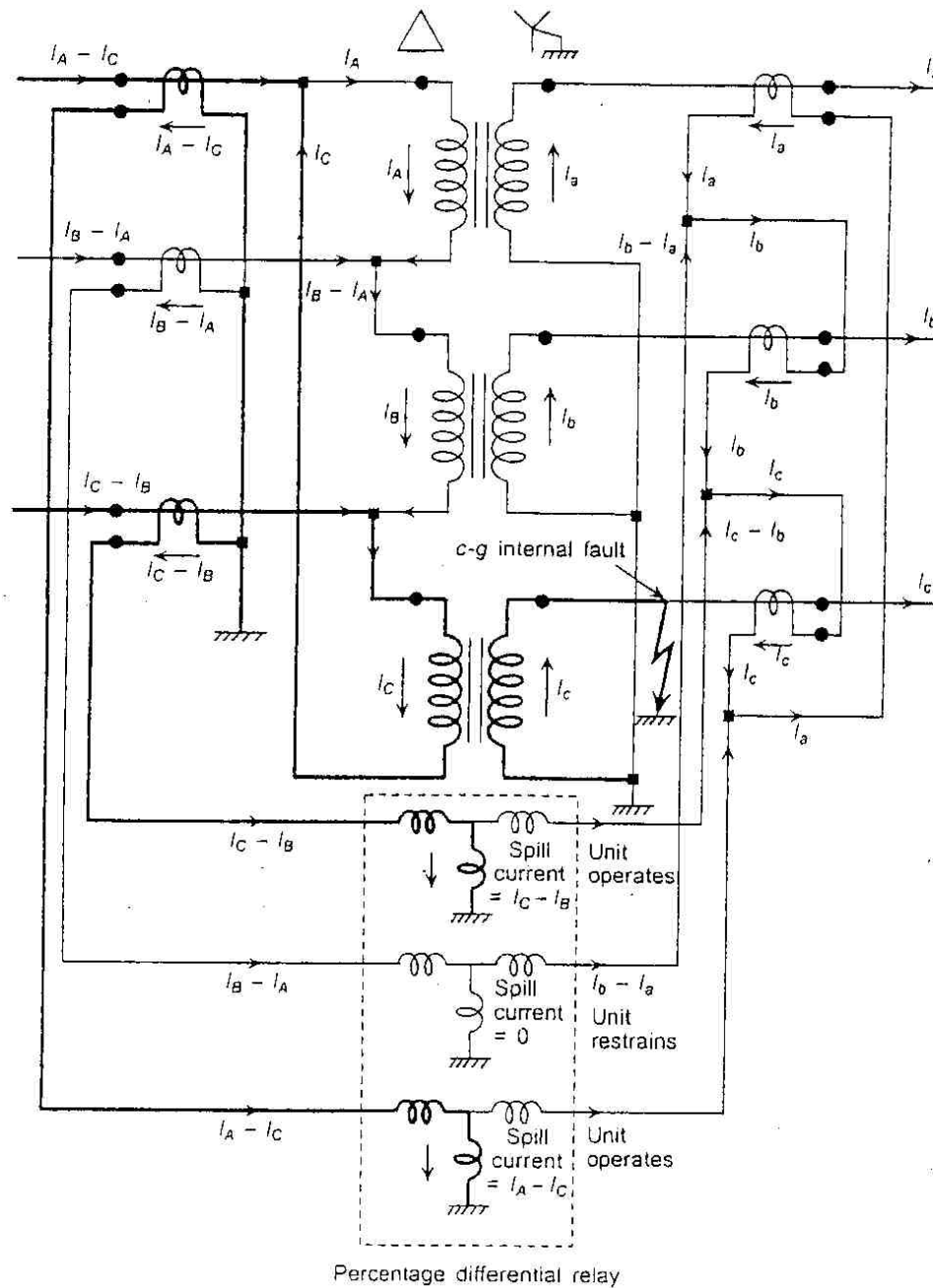


Fig. 4.63 Phase c to ground (c-g) internal fault

4.21.6.6 Illustrative Numerical problem of differential relay application

An Illustrative Numerical Problem

Problem For a 45 MVA, 11 kV/66 kV, star-delta transformer, design the percentage differential scheme. What is the minimum recommended percentage bias?

Solution As shown in the worksheet of Table 4.5, we find that the pilot wire currents are 6.817 A from the star side CTs while they are 3.936 A from the delta side CTs. Thus, we need intermediate CTs to correct this mismatch as shown in Figure 4.23. Such CTs are known as *interposing CTs* and are usually autotransformer types. The turns ratio of the interposing CTs is, therefore, found out to be $6.817/3.936 = 1.731 : 1$.

Table 4.5 Worksheet for % differential relay calculations

Step	11 kV star side	66 kV delta side
1 Full-load line current, I_{FL}	$\frac{45 \times 10^6}{\sqrt{3} \times 11 \times 10^3}$ = 2361.88 A	$\frac{45 \times 10^6}{\sqrt{3} \times 66 \times 10^3}$ = 393.64 A
2 To allow for 25% overload, choosing ($I_{FL} \times 1.25$) as primary current	2361.88×1.25 A = 2952.35 A	393.64×1.25 A = 492.05 A
3 CT ratios (5 A relay)	Choosing a CT of 3000 : 5 i.e. CT ratio = 600	Choosing a CT of 500 : 5 i.e. CT ratio = 100
4 CT secondary currents	CT secondary current = $\frac{2361.88}{600} = 3.936$ A	CT secondary current = $\frac{393.64}{100} = 3.936$ A
5 Pilot wire currents	(CT secondaries are in Δ) Current in the pilot wires = $\sqrt{3} \times 3.936$ A = 6.817 A	(CT secondaries are in Y) Current in the pilot wires = 3.936 A
6 Turns ratio of the interposing CT ($6.817/3.936$) : 1 = 1.731 : 1	Current after the interposing CT = $\frac{6.817}{1.731} = 3.938$ A	Current in the pilot wires = 3.936 A

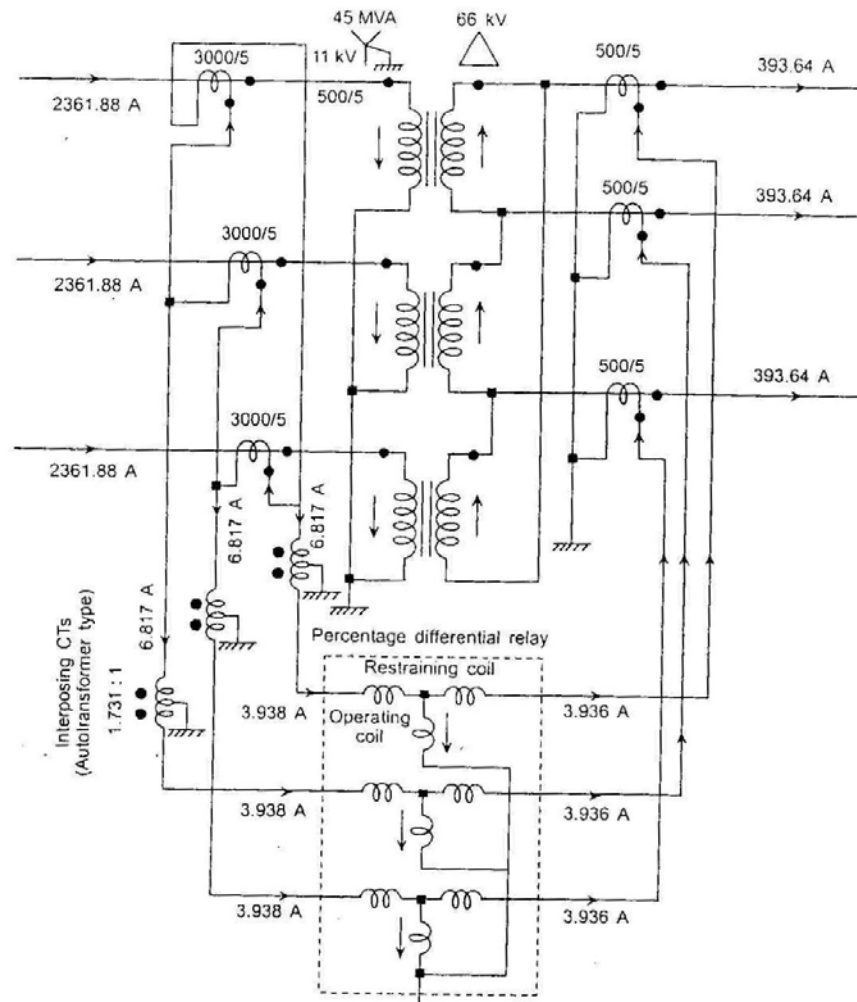


Fig. 4.64 Numerical problem on percentage differential protection of transformer

Assuming a slope of 40%, spill current required for tripping is

$$0.4 \left(\frac{3.936 + 3.938}{2} \right) = 1.57 \text{ A}$$

Actual spill current = $3.938 - 3.936 = 0.002 \text{ A}$. therefore, the scheme remains stable on full load or external fault.

4.22 GENERATION CONTROL

There are many functions to be performed in a hydropower station. Here, the term turbine governor is used to cover speed control of the turbines themselves, plant automation is used to cover such operations as auto start, auto synchronization, remote control start up or water level control, and data acquisition and retrieval is used to cover

such operations as relaying plant operating status, instantaneous system efficiency, or monthly plant factor, to the operators and managers.

The main function of control in a hydropower plant may be categorized into the following:

4.22.1 Turbine Control

This is the speed/load control of turbine in which the governor adjusts the flow of water through the turbine to balance the input power with the load. In case of small plants in the range of micro hydel (100 kW unit size), load control is also used, where excess load is diverted to dummy load to maintain constant speed. With an isolated system; the governor controls the frequency. In interconnected system, the governor may be used to regulate the unit load and may contribute to the system frequency control. Figure 4.12.1 shows the different types of control applicable to turbines.

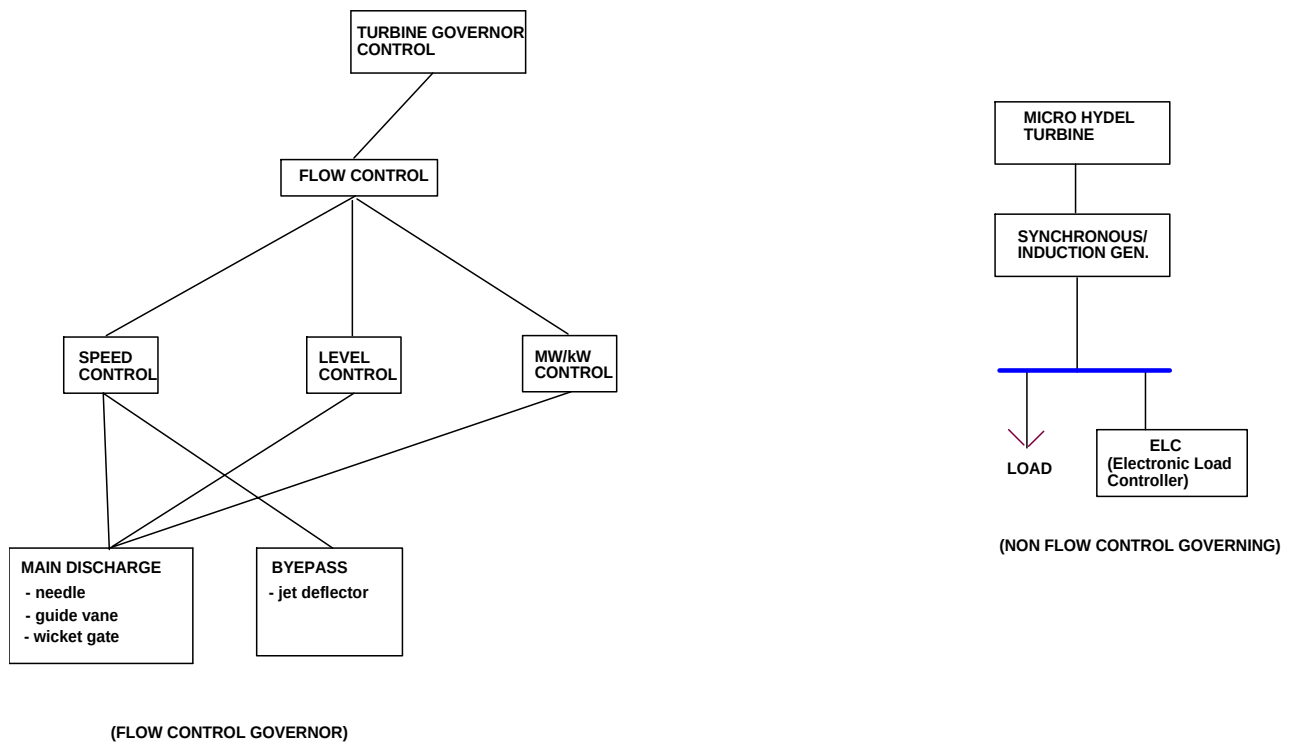


Fig. 4.65 Schematic Overview of Turbine Control

4.22.2 Generator Control

This is the excitation control of synchronous generator. The excitation is an integral part of a synchronous generator, which is used to regulate the operation of the generator. The main functions of excitation system of a synchronous generator are:

1. Voltage control in case of isolated operation and synchronizing

2. Reactive power or power factor control in case of interconnected operation.

4.22.3. Plant Control

Plant control deals with the operation of the plant. It includes sequential operations like start up of the machine, excitation control, synchronization, loading of unit under specified operating conditions, normal and emergency shutdown, etc. The mode of control may be manual or automatic and may be controlled locally or from remote location. Plant control usually includes monitoring and display of the plant conditions.

Method of control is given in table 4.12.1.

Table 4.12.1 – Summary of control hierarchy for hydroelectric power plants

Control category	Subcategory	Remarks
Location	Local	Control is local at the controlled equipment or within sight of the equipment
	Centralized	Control is remote from the controlled equipment, but within the plant
	Offsite	Control location is remote from the project
Mode	Manual	Each operation needs a separate and discrete initiation; could be applicable to any of the three locations
	Automatic	Several operations are precipitated by a single initiation; could be applicable to any of the three locations
Operation (supervision)	Attended	Operator is available at all times to initiate control action
	Unattended	Operation staff is not normally available at the project site

The control system receives input signals from main equipment such as the turbine or the generator, and from various other accessory equipment, such as the governor, exciter, and automatic synchronizer. Status inputs are obtained from control switches and level and function switches indicative of pressure, position, etc. throughout the plant. The proper combination of these inputs to the control system logic will provide outputs to the governor, the exciter, and other equipment to start or shutdown the unit. Any abnormalities in the inputs must prevent the unit's startup, or if already on-line, provide an alarm or initiate its shutdown.

4.23 SCADA

4.23.1 Introduction

The term SCADA stands for Supervisory Control and Data Acquisition. A SCADA system is a common process automation system which is used to gather data from sensors and instruments located at remote sites and to transmit and display this data at a central site for either control or monitoring purposes. The collected data is usually viewed on one or more SCADA Host computers located at the central or master site. A real world SCADA system can monitor and control hundreds to hundreds of thousands of I/O points. A typical water SCADA application would be to monitor water levels at various water sources like reservoirs and tanks and when the water level exceeds a preset threshold, it activates the system of pumps to move water to tanks with low levels. The analog signals that SCADA systems monitor and control are levels, temperatures, pressures, flow rate, electrical signals and motor speed. Typical digital signals to monitor and control are level switches, pressure switches, generator status, relays, metering and motors.

4.23.2 Schematic Overview

Supervisory control from an offsite station of a group of power stations is also provided sometimes. Schematic overview of power plant automation with supervisory control and data acquisition (SCADA) system is shown in fig. 4.12.2.

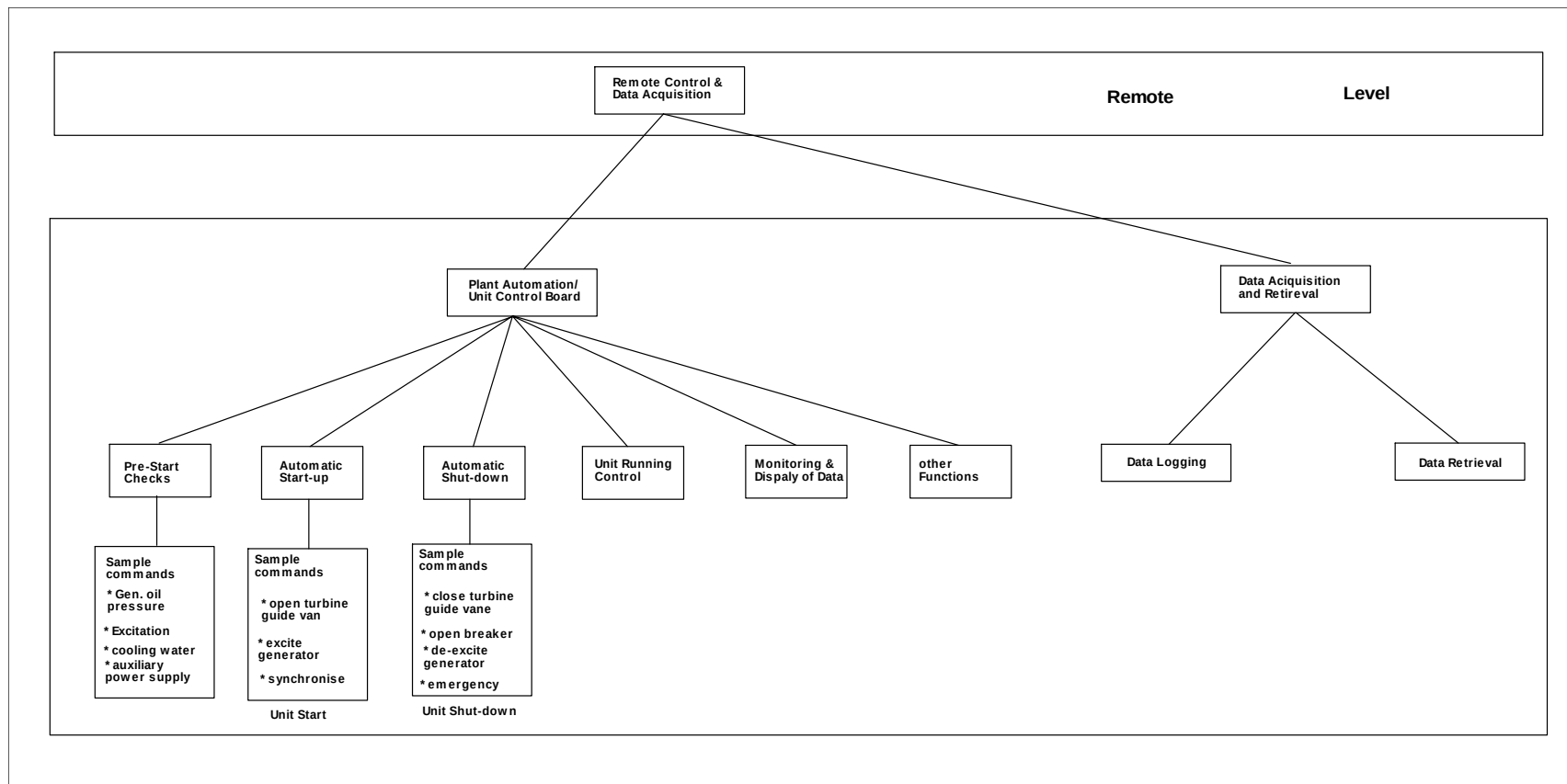


Fig. 4.46 Schematic overview of power plant automation with supervisory control and data acquisition (SCADA) system