DESIGNING OF A SMALL HYDRO POWER PLANT IN UTTARAKHAND & ESTIMATE ITS CARBON EMISSION REDUCTION POTENTIAL

A thesis submitted in fulfillment of the requirements for the Degree of

Master of Technology

(Energy Systems)

By

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Under the guidance of

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(H.O.D Energy Systems)

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April, 2011

CERTIFICATE

This is to certify that the work contained in this thesis titled "**Designing of a Small Hydro Power Plant in Uttarakhand & Estimate Its Carbon Emission Reduction Potential**" has been carried out by **Arnab Das** under my/our supervision and has not been submitted elsewhere for a degree.

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Dr. Kamal Bansal

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Date:

Abstract

Hydro power is non-polluting, renewable energy sources found across the globe. It is the use of water power flowing from a certain height to run the turbines and hence producing electricity. There are mainly two types of hydro power plants like

1) **Small Hydro Power Plant up to 25 MW**

2) **Large Hydro Power Plant above 25 MW**

There are other types of classification of hydro power plants according to their head available. But in this text we will be concentrating on the capacity installed. In Uttarakhand, the present hydro power potential is approximately 26215 MW out of which 3355.02 MW is of SHPs. So harnessing these potential will lead to at least the electrification of rural parts of U.P. where grid facility is not available or not economical to reach.

SHPs are beneficial from the following point of view

1) High Plant Load Factor can be maintained
2) SHP mainly being developed in the rural areas, it contributes to the development of local people
3) In certain projects, water treatment plants are added so as to supply pure drinking water to the locals
4) The biggest advantage of SHPs are that practically there is no R&R required due to absence of building large dams and hence very little or no environmental impact
5) It helps in local employment

CDM benefits are again another advantage of renewable energy sources. They help in reducing carbon dioxide from the atmosphere as well as helps in financing the project. So, in this thesis designing as well as carbon dioxide reducing potential of a SHP in Uttarakhand has been taken into account

Objective

To design the major parts of a typical small hydro power plant in the state of Uttarakhand and calculate its carbon emission reduction potential. The following are the parameters for the small hydro power (Kaldigad) site identified.

1.	**Location**			
(i)	State	:	Uttaranchal	
(ii)	District	:	Uttarkashi	
(iii)	Tehsil	:	Bhatwari	
(iv)	Village	:	Sangam Chatti	
(vi)	Reference of topo sheet	:	53 J/5	
		:	Weir site	PH site
	Geographical coordinator Latitude	:	30^0-50' 27'' N	30' 49' 38'' N
	Longitude		78^0 28'39'' E	78^0 27' 6'' E
(vii)	Altitude	:	1781 m above mean sea level	1506 m

Acknowledgement

I would like to thank **Dr. Kamal Bansal (H.O.D Energy Systems)**(internal guide), **Mr. Manav Sharma of Regency Group** (Ponta Sahib), **Mr. Manoj Keserwani** of **Uttarakhand Jal Vidyut Nigam Limited, Mr. A.K. Tyagi** of **Uttarakhand Renewable energy development agency (UREDA)** for their valuable information and immense help. Without their support my thesis would not have been completed on time. My special thanks to **Mr. Y. N. Apparao (M.D.)** of **Teesta Urja Pvt. Limited** who helped me in bits and pieces throughout my project. I would also like to thank **M/s Century Transformer Pvt. Limited of Kolkata** who supplied me with the technical specification of the required transformer upon my request.

CHAPTER I

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Nomenclature

S.H.P	:	Small Hydro Power
D.P.R	:	Detailed Project Report
U.R.E.D.A.	:	Uttarakhand Renewable Energy Development Agency
Cumecs	:	Cubic meter per seconds
V.C.B.	:	Vacuum Circuit Breaker
S.L.D.	:	Single Line Diagram
KV	:	Kilovolt
KW	:	Kilowatt
KWh	:	Kilowatt-Hour
Amp	:	Ampere
V	:	settling velocity in [cm/sec]
g	:	acceleration due to gravity [cm/s^2]
S	:	specific gravity of the silt particle
S'	:	Specific gravity of water

d	:	particle size in	[cm]
Pr	:	power in metric horse power at full gate opening – (1 kW = 0.86 metric hp)	
Hr	:	rated head in	[m]
J	:	moment of inertia of the rotating components	[kg m^2]
Ω	:	angular velocity	[rad/s]
T_t	:	torque of turbine	[Nm]
T_L	:	torque due to load	[Nm]
P	:	Rated power in	[KW]
gH	:	specific hydraulic energy of the turbine,	[J/kg]
L	:	length of water column,	[m]
V	:	velocity of the water ,	[m/s]
I_m	:	maximum full-load current on line	
K_l	:	annual load factor of the line	
n	:	turbine rpm	[t/s]or [r.p.m]
n'	:	turbine specific speed	[t/s] or [r.p.m]

CHAPTER I

Introduction

Hydro power is non-polluting, renewable energy sources found across the globe. It is the use of water power flowing from a certain height to run the turbines and hence producing electricity. There are mainly two types of hydro power plants like

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CHAPTER II

Technical Parameters

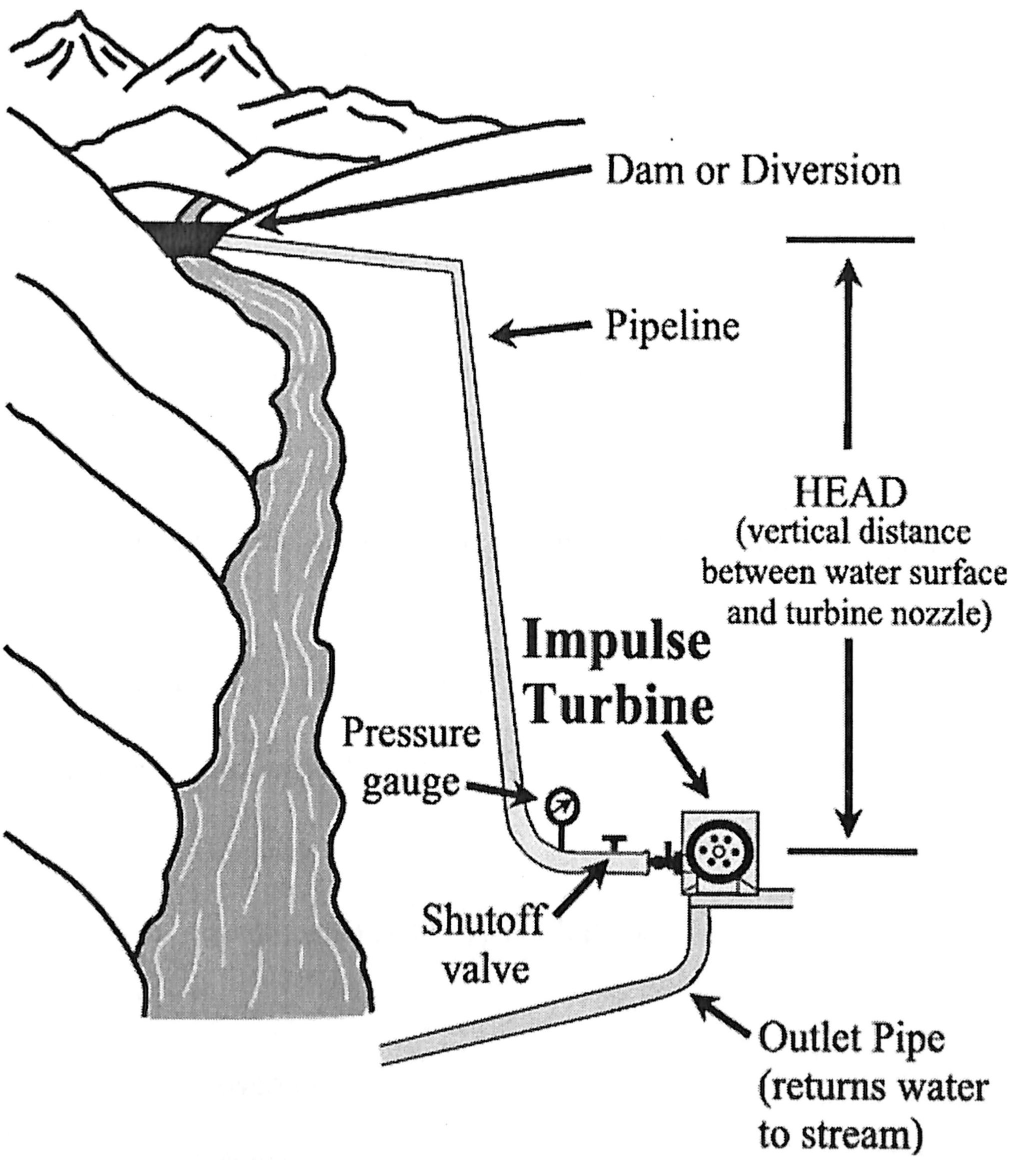


Fig 1 :*Basic Layout of a hydro electric power plant*

Planning a Small Hydro Power System

The planning of SHP consists of the following steps

1) Verifying Topography and geology of the selected site
2) Measurement of flow and head available
3) Site selection and basic layout
4) Selection of hydraulic turbine and generators/controls (as per design in DPR)
5) Economic evaluation and financing potential

The main part of this thesis is to design the important components of a hydro power plant like

1) Theoretical power calculation
2) Electro-mechanical equipment design
    a. Penstock
    b. Desilting tank (if any)/Trash Rack
    c. Turbine
    d. Governor
    e. Generator
    f. Transmission lines

Theoretical Power Calculation

The power calculation of a hydro power plant solely depends upon two factors like the *HEAD* available and the *FLOW* of water. Head is given in meters which are mentioned in **FIG.1** whereas flow is given in "m^3/s". Flow of water in streams, lakes, rivers varies from season to season and hence the head becomes the major parameter for power calculation. The power equation is given as:

$$Kw = Q \times \rho \times g \times H \times \square$$

Where,

Q	= flow (m3/s)
ρ	= density of water (kg / m3)
g	= acceleration due to gravity (9.81 m/s2)
H	= available head in meters (m)
□	= efficiency of the turbine-gen set

Water Flow Measurement

For developing a hydro power plant it is always needed to study the pattern of stream flow, precipitation pattern, and climatic condition of the particular site for over a period. Because of the time limit the data has been obtained from UREDA, Regency Group and Uttarakhand Jal Vidyut Nigam Limited (U.J.V.N.L.).

Measurement of discharge is done by:

Velocity-Area Method: It is the most conventional method of measuring the discharge for large, medium rivers where the cross sectional area of the river and mean velocity is measured

A certain point in the river should be selected which is straight and flow is smooth. The width at this point should be uniform. As the water level varies the top level of water known as "*stage of the river*" rises and falls. The rise and fall is observed every day with a board marked with meters. Now a days electronic registers are used which automatically senses the up and down of stage and records in registers.

<u>Measuring The Cross Sectional Area</u>: The natural watercourse should be divided into number of trapezoids. The sides are then measured as illustrated in FIG.2

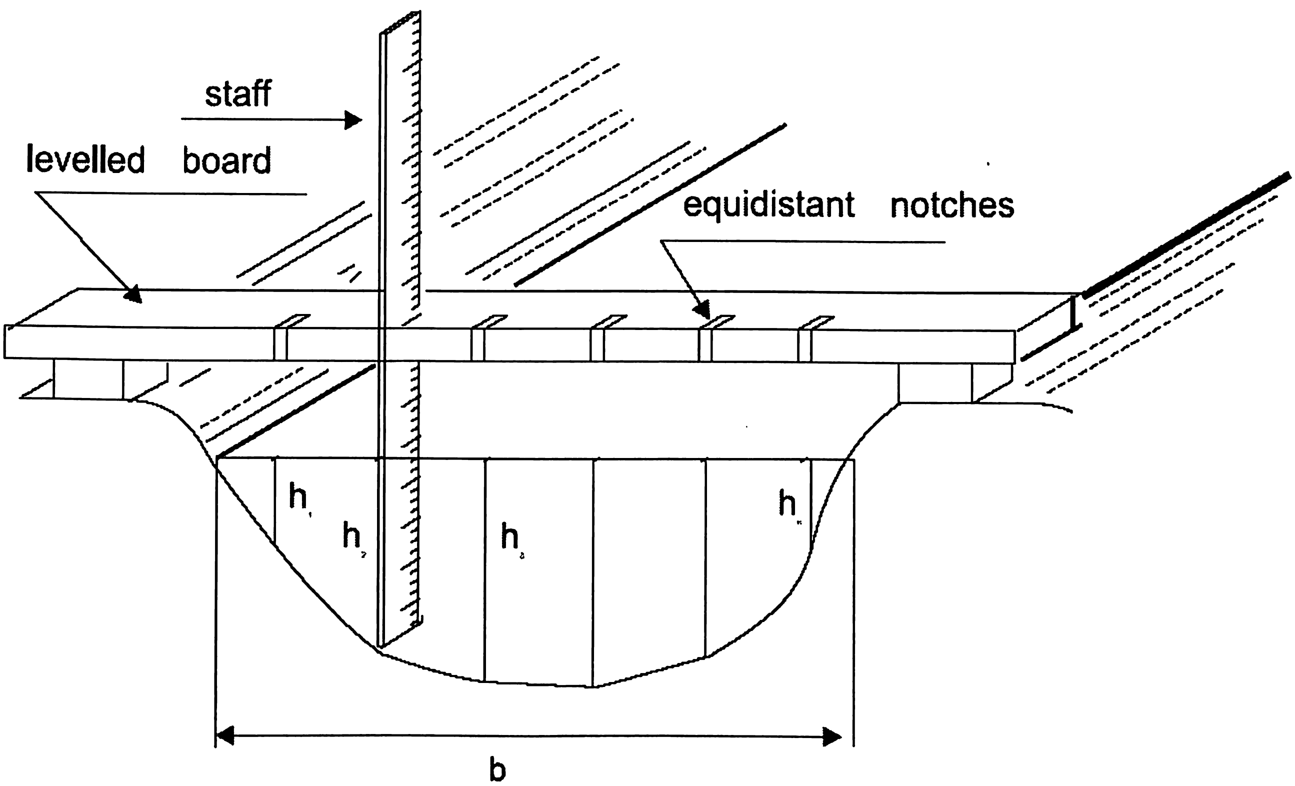


FIG2: measuring the discharge

Month and Period		Discharge in cumecs for 10-day daily average
Jan	I	3.07
	II	3.01
	III	3.01
Feb	I	3.01
	II	3.01
	III	3.58
March	I	3.58
	II	3.70
	III	4.00
April	I	4.12
	II	4.12
	III	4.12
May	I	4.12
	II	4.12
	III	4.12
Jun	I	4.12
	II	4.12
	III	4.12
July	I	4.12
	II	4.12
	III	4.12
Aug	I	4.12
	II	4.12
	II	4.12

Sept	I	4.12
	II	4.12
	III	4.12
Oct	I	4.00
	II	4.00
	III	3.70
Nov	I	3.70
	II	3.22
	III	3.22
Dec	I	3.22
	II	3.07
	III	3.07

Table 1: Discharge Data

Maximum flood discharge has been calculated on the basis of Dickens' formula modified

C = 2.342 log 0.61T * log 1185/P+4

Where,

T = time period, taken as 100 years

P = a + 6/A

A = Total catchment area is sq.km = 111.46 sq.km.

a = Snowbound catchment area = 33.81 sq. km.

Substituting the above values in equation C = 10.5

The probable maximum flood discharge = **C (A)** $^{3/4}$ = 360 cumecs

If C is taken as 14 which is applicable for hills in the Himalayas, probable maximum flood works out to 480 cumecs. To be on the safer side, the flood discharge for design of waterway is taken as 480 cumecs.

Trash Rack

A trench weir or trash rack is a trapezoidal trench (trough) built across the stream below the stream bed level. The trench is given a bed slope of not less than 1 in 25 towards the intake so that sufficient velocity is generated to carry away the silt / shingle that fall into it. The bed slope also gradually increases the cross sectional area of the trench to cater to more and more water entering into it from the stream through the trash rack. The top of the weir is covered with trash rack to ensure that boulders and bigger stones do not fall into the trench and clog it. The rack itself is designed to withstand the load of the rolling boulders. The rack is made removable so that it can be removed periodically after rains or flash floods to clear the trench of any deposits if required. The crest level of the diversion weir is kept slightly below the stream bed to facilitate maximum withdrawal of stream flow during lean periods.

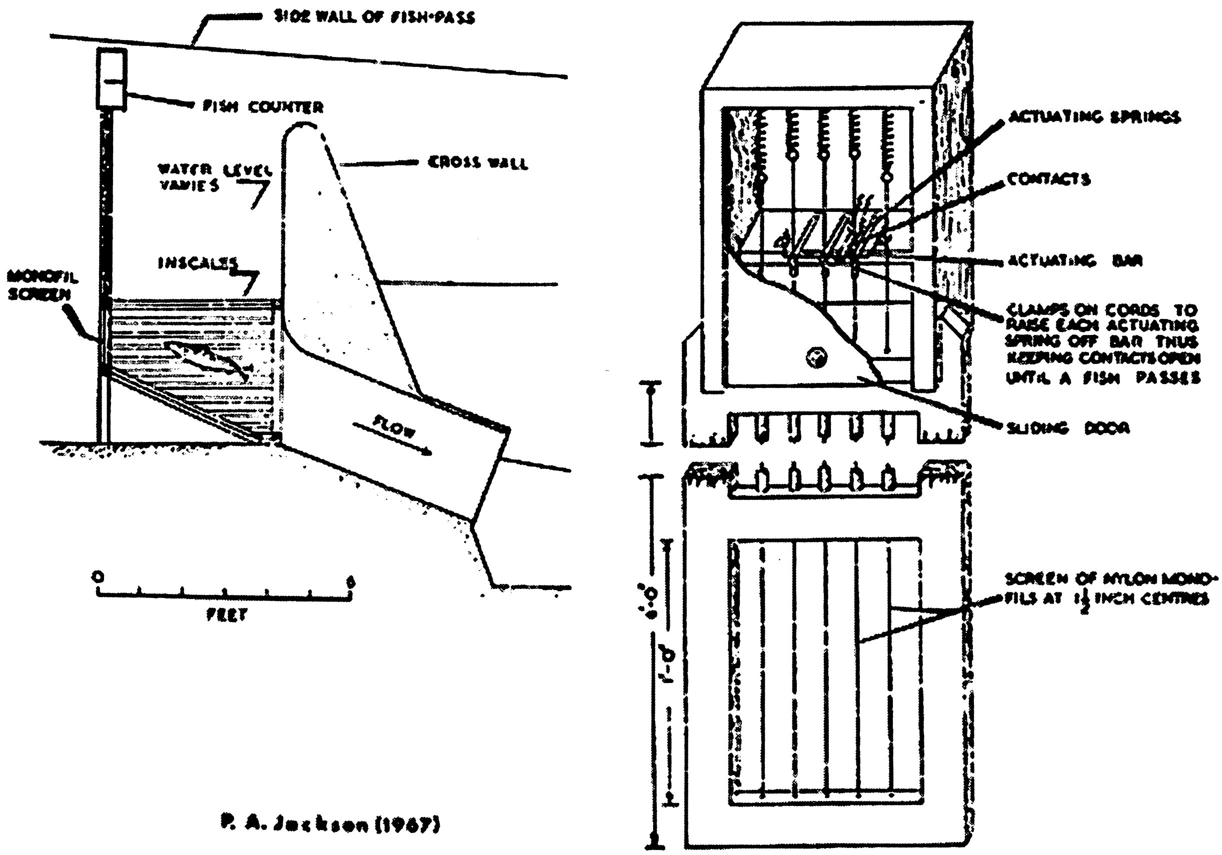


FIG 3: Trash rack (www.fao.org)

Fig 4: (Image Courtesy: http://www.infobarscreens.com/trash-rack.htm)

The rack is periodically maintained to remove the collected logs, stumps, or debris. The removal is done either mechanically or electronically.

DESILTING TANK

Water in hilly stream is silt free except during monsoons when it carries lot of silt. The particles smaller than the trash rack opening size enter the trench weir. Of these, heavier particles settle in the intake well and are flushed out through the shingle excluder at the intake. The silt particles, however, flow through the power duct and hence a desilting tank is provided at the end of power duct to trap the silt load of particle size more than the desirable particle size from turbine point of view. Just before the desilting tank a surplussing weir is provided to spill back to the river the flow in excess design discharge. An open channel power duct starts after the desilting tank. The power channel carriers relatively silt free water as the desilting chamber is designed to settle all silt particles bigger than permissible particle size. The desilting tank is located at a relatively flatter ground keeping in view the structural safety, economy in design and operation, easy accessibility and availability of natural drainage for escape of flushing discharge and for location of surplussing weir.

The basic features of a desilting tank are

1. Detention period required and provided.
2. Average linear velocity of flow at top and bottom.
3. Depth, width and length of tank
4. Inlet and outlet transition
5. Cleaning / flushing arrangement

The sediment particles of size more than **0.2 mm** are removed by the desilting tank by gravitational settling.

Velocity of the free flowing water through the lined channel should be in between 1m/s – 3 m/s as per IS:5331so that neither scouring nor silting occurs. The proposed channel shall be designed to have a velocity which is sufficient to carry away silt particles of size below 0.2 mm as per IS: 7916. The silt particles of bigger size are retained in the desilting tank.

Turbine Selection

There are different types of hydraulic turbines and there is some overlap between them, each type tends to have a distinct range of applications where it will be more economic and efficient. The turbine generator unit is the largest portion of the total cost of any small hydro plant.

Turbine Types

- Pelton
- Turgo
- Crossflow
- Propeller type

There are many factors which contribute to the selection of turbines. The factors being cost, efficiency, head available and power to be generated. So, selection of a particular turbine will be a toss between cost and efficiency. Here in this project it is recommended to go for pelton turbines but propellor turbines are also in R&D stage and are a better option for small hydro projects also.

	high head	medium head	low head
impulse turbines	Pelton Turgo	cross-flow multi-jet Pelton Turgo	cross-flow
reaction turbines		Francis	propeller Kaplan

Table 2: Different Turbines

Pelton wheel with one nozzle	0.005 <= **n'** <=0.025
Pelton wheel + 'n' nozzles	$0.005n^{0.5}$ <= **n'** <=$0.025n^{0.5}$
Francis	0.05 <= **n'** <= 0.33
Kaplan,Propeller	0.19 <= **n'** <= 1.55

Table 3: Range of specific speed for each turbine type

Turbine type	Head range in meters
Kaplan and Propeller	$2 < H_n < 40$
Francis	$25 < H_n < 350$
Pelton	$50 < H_n < 1'300$
Crossflow	$5 < H_n < 200$
Turgo	$50 < H_n < 250$

Table 4: Range of heads for different turbines

Pelton Wheel

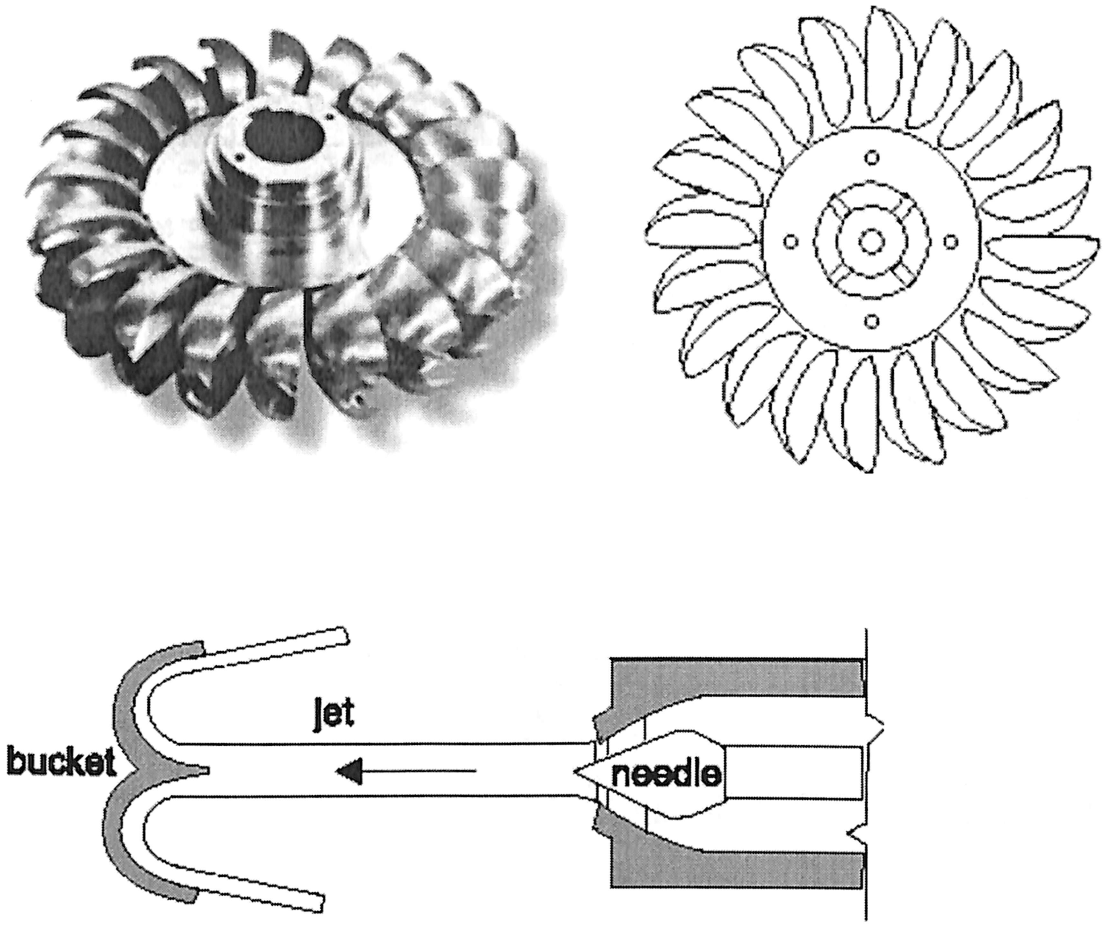


Fig 5: Pelton wheel / runner

Propeller Turbine

The propeller turbine has characteristics which make it useful for low head applications. Operating speed is comparatively high even at very low heads. The turbine looks very much like a marine propeller, with the blades twisted through an angle from hub to tip, and having a thin aero foil shape. The blade angle increases as head decreases. Propeller turbines are quite small in diameter for a given throughput of water. The preferred range is 10 feet to about 60 feet.

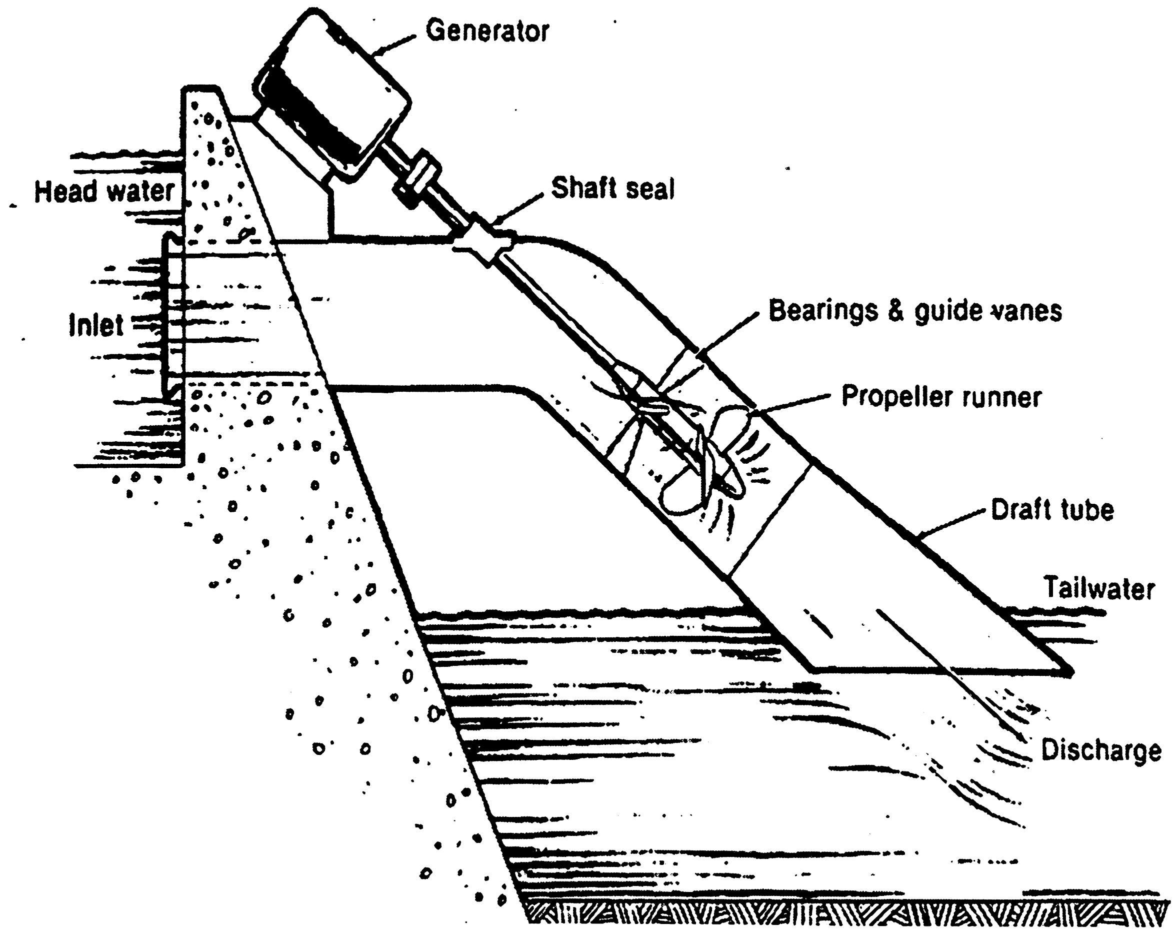


FIG 6: scheme showing arrangement of propeller turbine

On no load conditions, the speed of the water flowing through an impulse will be equal to the spouting velocity, which is the natural speed of water freely issuing from a jet, and is equal to:

$$V = (2gh)^{1/2}$$

Where

V - velocity

g = gravitational constant,

h = head

Turbines depend upon the deflection of the water jet or current in order to develop power. If the circumferential velocity at the edge of the turbine wheel were equal to the spouting velocity, no deflection would take place and no power could be developed. Actually, a little deflection does take place, just sufficient to keep the wheel running at a speed nearly equal to the spouting velocity. This is true for all turbines, which run at about twice full load speed under conditions of no load. Full jet deflection occurs at very nearly half of the no load speed. Thus, we have a condition that at any load between zero and full load, the turbine, left to it, would run at a speed proportional to load. The only way to control the speed is either to ensure that the load remains fixed, as in the case of electronic governors, or to vary the amount of water entering the turbine by means of a mechanical governor operating in the turbine valves.

Generator Selection

Principle of Operation

The operation of generator and motors are nearly the same. When a wire is moved past a magnetic field so as to cut it perpendicularly, a voltage is induced in the wire. There three components movement, magnetism and wire.

In generators either the magnetic field is moved over a stationary coil or coil is moved past a stationary magnetic field. Generators produce varying voltages which osculates between the zero voltage line/the mean values. In effect the current also moves back and forth. In three phase voltages there are three single phase voltages which are displaced 120 degree from each other.

All generators must move at constant speed for generating voltage at constant 50 Hz frequency.

$$N = 120 \times \frac{f}{p}$$

Where,

N = revolution per minute

f = frequency

p = no. of poles

Standard rpm for generators and the no. of poles

RPM	No. of Pole
2	3000
4	1500
6	1000
8	750
10	600
12	500

The 2 pole and 3000 rpm is too high for small hydro plants. Generally 8 to 10 pole generators are used. The cost of generators is inversely proportional to the speed as lower the speed the higher is the generator frame and hence high cost. Where there is low head and low speed then speed increasers are used (gear boxes).

Construction

Modern generators come in complete package that is it includes

1) Voltage regulator
2) Voltage adjusting rheostat
3) Field circuit breaker
4) Instrumentations for volts, hertz, amperes

All of the above are attached to the back of the generator in the instrumentation panels. Above 100 Kw generators the above components are purchased separately to attach them to a separate dashboard. The following are the frame types of a generator

1) Open protected
2) Drip proof
3) Total enclosed

The preferred generator terminal voltage according to the IEC 60034-1 is as follows:

3.3 kV	→	above 150 kW (or kVA)
6.6 kV	→	above 800 kW (or kVA)
11 kV	→	above 2500 kW (or kVA)

Synchronous Generator: A synchronous generator rotates at **synchronous** speed that is, the speed at which magnetic field created by the field coil rotates. Construction is same as any generator having rotor, stator, and exciter. An exciter helps in creating the magnetic field inside the generator. In synchronous generator the reactive power is given to the rotor and the armature produces the active power.

Excitation

Excitation system provides and regulates all the D.C. power required by the generator field windings and includes all power regulating control and protective elements. Standard excitation voltages defined in ANSIC50-12 are 62.5V, 125V, 250V, 375V, and 500V

Asynchronous Generator (Induction Generator): An induction motor can be used as a generator and mostly it is induction motor which is used as generator. By adding capacitors in parallel to the motor leads and running the motor just above the synchronous speed, the motor will start producing AC voltages. This difference in actual rpm and synchronous rpm is called the slip. With the help of prime mover or external mechanical force the rotor is turned which produces induced current in the stator which in turn charges the capacitors. Due to continuous change of poles of the magnet (rotor) the direction of the induced current also changes and hence the capacitor charges and discharges. As the rotor turns the EMF increases to the saturation level.

AVR (Automatic Voltage Regulator): The generator voltage tends to drop in proportion with load on it. This effect is offset in modern generators with help of voltage regulators. Voltage Mostly 2% up or down in voltage is allowed from no load to full load.

Over-speed: Generators should be rated 25% to 30% overspeed as the turbine runaway speed is nearly 1.8 to 2 times the operating speed.

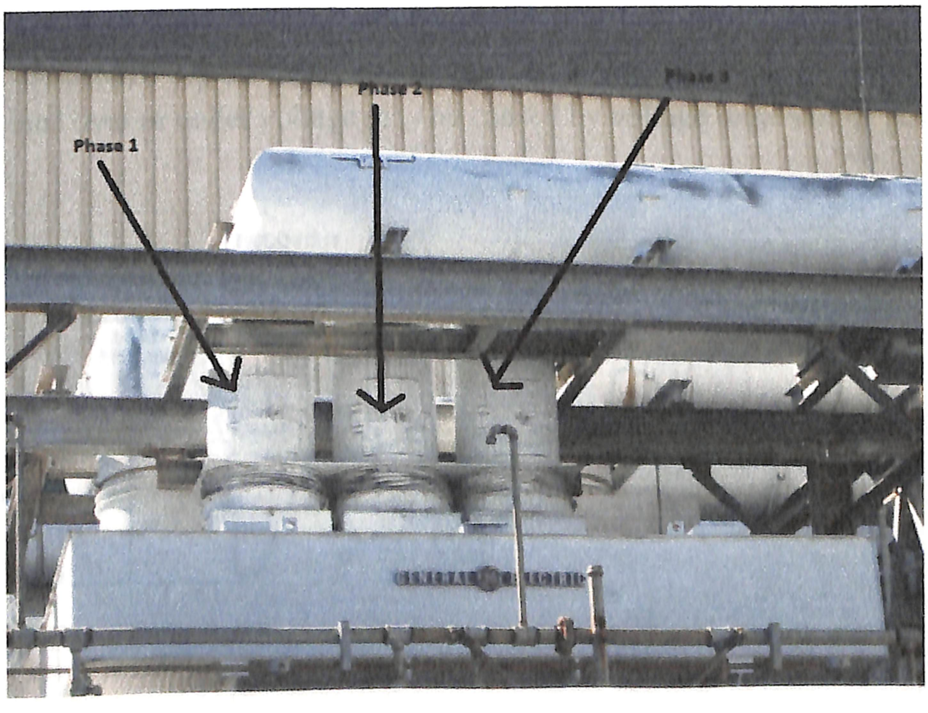
Sl. No.	Item	Synchronous Generator	Induction Generator
1.	Rotor Construction	Salient Pole	Squirrel Cage
2.	Excitation	Required	Not required
3.	Isolated operation	Possible	Not possible
4.	Stability	Maintained by exciter	Self
5.	Maintenance	More	Less
6.	Efficiency	High	Low
7.	Cost	High	Low
8.	Power Factor	Maintained by exciter	Maintained by connected load
9.	Voltage Variation	Possible	Not possible

Table 5: Merits and Demerits of synchronous over induction generator

Because of the advantages of synchronous generator over induction generator, former is selected as the generator to be used in this project.

Generator specification and calculation is given later in the calculation page

Generator Output terminals are generally put inside a hollow aluminum tube of 18 inch diameter as shown in the figure



Testing Of Generator

Factory and field test should be done before commissioning and following are the list of factory assembled tests

1) Resistance test of armature and field windings.
2) Dielectric test of armature and field windings.
3) Insulation resistance of armature and field windings.
4) No load saturation test
5) Short circuit saturation test
6) Mechanical balance of rotor
7) Temperature rise test

Following are the field test

1) Stator dielectric tests
2) Efficiency tests.
3) Heat-run tests.
4) Machine parameter tests.
5) Excitation test.
6) Over-speed tests

Generator and System Protection

The class and extent of generator protection depends on the ratings of the generator. It protects the genset against faults originating outside or inside.

Over and Under Voltage Protection

These relays are used to trip off the circuit breaker when voltage is below or over a set figure. Sustained over or under voltage may be caused by voltage regulator or governor failure.

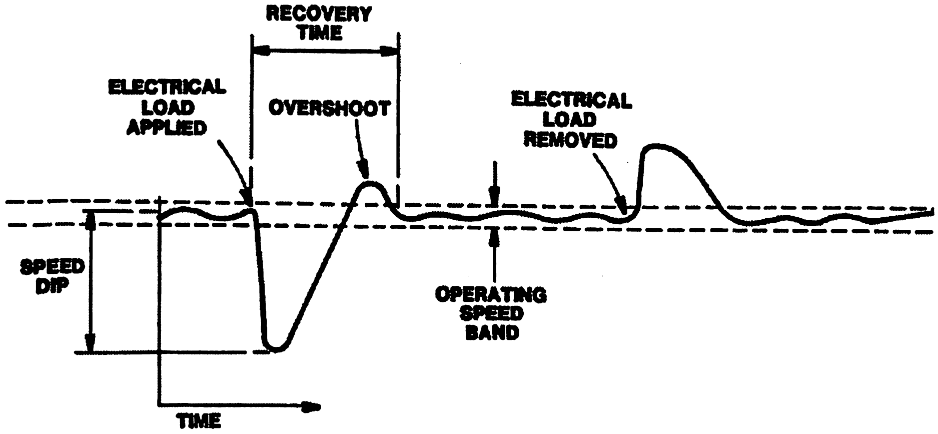


Fig 7: *Voltage Variation Caused By Switching Loads*

Field Breaker

Generators supplied with control panels are usually supplied with a field winding circuit breaker which protects the field winding from high voltage and currents. It is also used to trip the field circuit when the application of field current exceeds for five second. Excess field current occurs when voltage regulators attempt to maintain full voltage on the application of heavy loads.

Power Factor

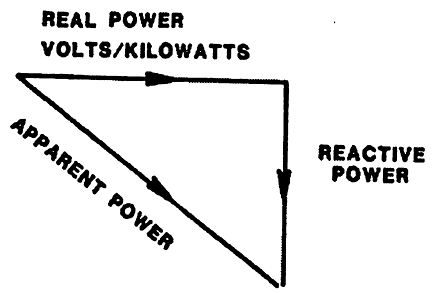


Fig 8: Power Triangle

Power Factor has to be considered when dealing with A.C. circuits and equipment, especially those containing iron core such as motors, transformers. This equipment needs extra current to magnetize the core. Therefore in addition to the current which converts to work done, there is an extra circulating current. This extra current is called reactive current and hence reactive power.

Power Factor $\cos\omega = \frac{\text{Active Power(KW)}}{\text{Apparent Power(KVA)}}$

For Example:

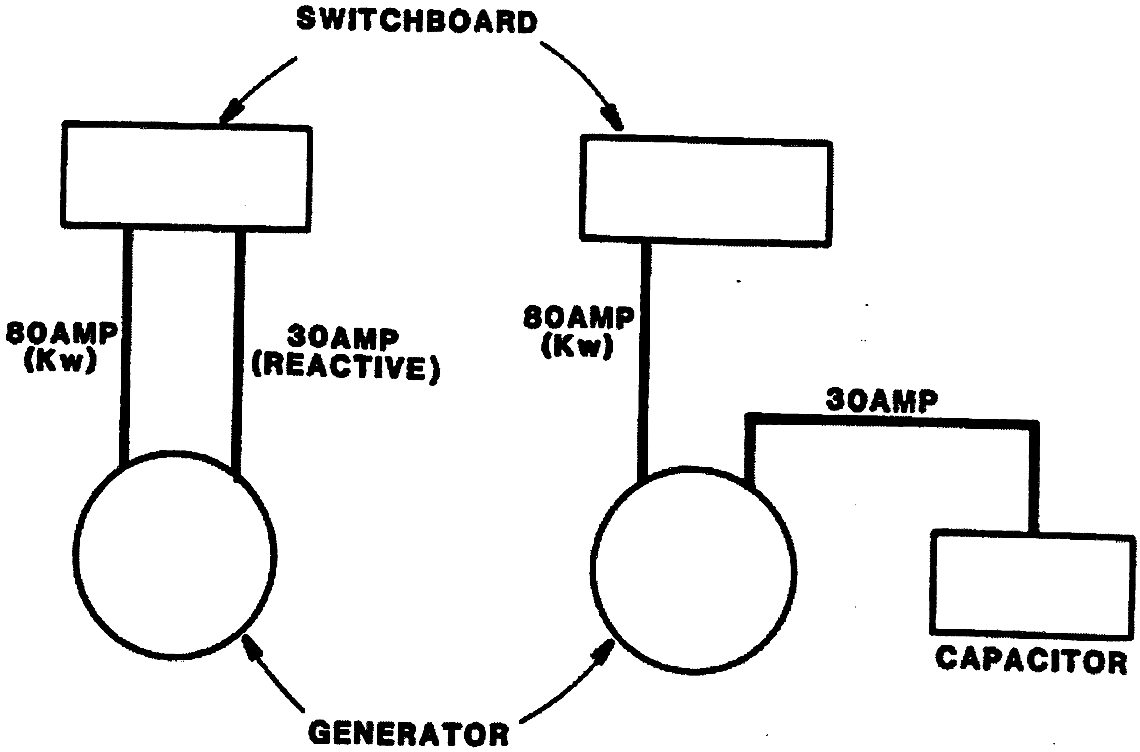


Fig 9 : image showing reactive power compensation

In this above example the motor on the left draws 80 amps which converts to work done plus 30 amps reactive current to magnetize the core. The reactive power is drwn from thje supply system. In the case of the right motor reactive power is supplied by the capacitor instead of the generator. Since power factor will be lagging in most A.C. systems, capacitors or leading power factor is used to counter it. T6he reactive power in low power factor systems results in poor utilization of generator capacity, cables and switchgears. Voltage regulation suffers, and overheating of generators and cables may result.

Electrical Transmission

Transmission of electrical energy at low or high voltage is usually necessary. As the hydro power plants are located far of places from the load, so cables and power transmission becomes a big factor. High voltage transmission reduces the current and hence the copper losses.

Cables and Its Capacity

Fig 10

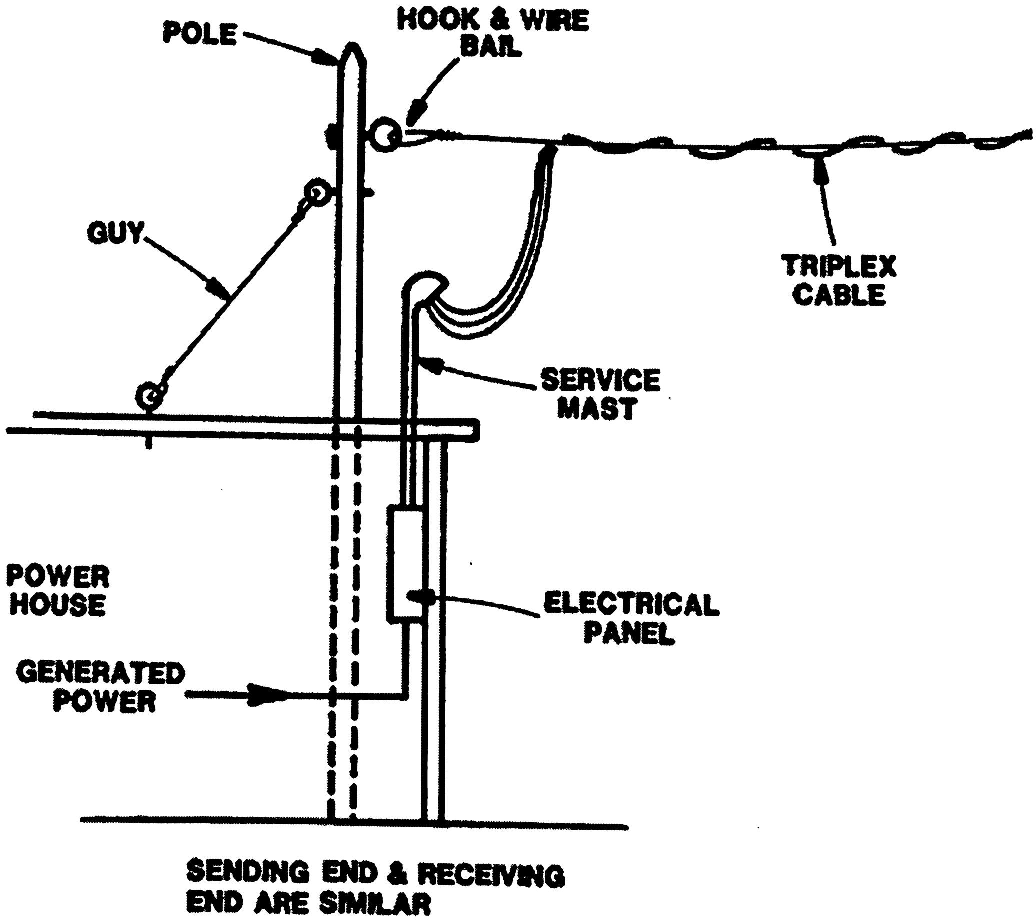


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Fig 10 : Wire & arrangement

Almost all the present day transmission line use aluminum conductor steel wire reinforced (ACSR). The steel core provides high tensile strength, while the aluminum wires carry the current.

Insulators

There are three types of insulators.

1) Pin Type
2) Suspension Type
3) Strain or tension type

Insulators will be normally pin type, rated for the defined voltage.

Conductor Sagging

All overhead lines must be sagged by a calculated amount in order to compensate for extremes in temperature. At low temp. The line contracts, raising the stress in the conductor. The sagging amount depends upon many factors like the conductor size, material, and temperature extremes stringing tension. Sag charts are prepared locally by the SEBs for quick reference.

Grounding

All neutrals, low or high voltage, must be reliable grounded. For example, the pole transformer, the arrestor and the insulated neutral conductor must be grounded by means of a rod inserted in the ground at the pole base.

Transformer

Transformers are necessary when lower AC voltages are required to step up/step down to the required voltage. For small hydro three basic type of transformer are used:

a) Oil filled, pole mounted outdoor

b) Oil filled pad mount

c) Dry type, indoor

Typical Connection Diagram

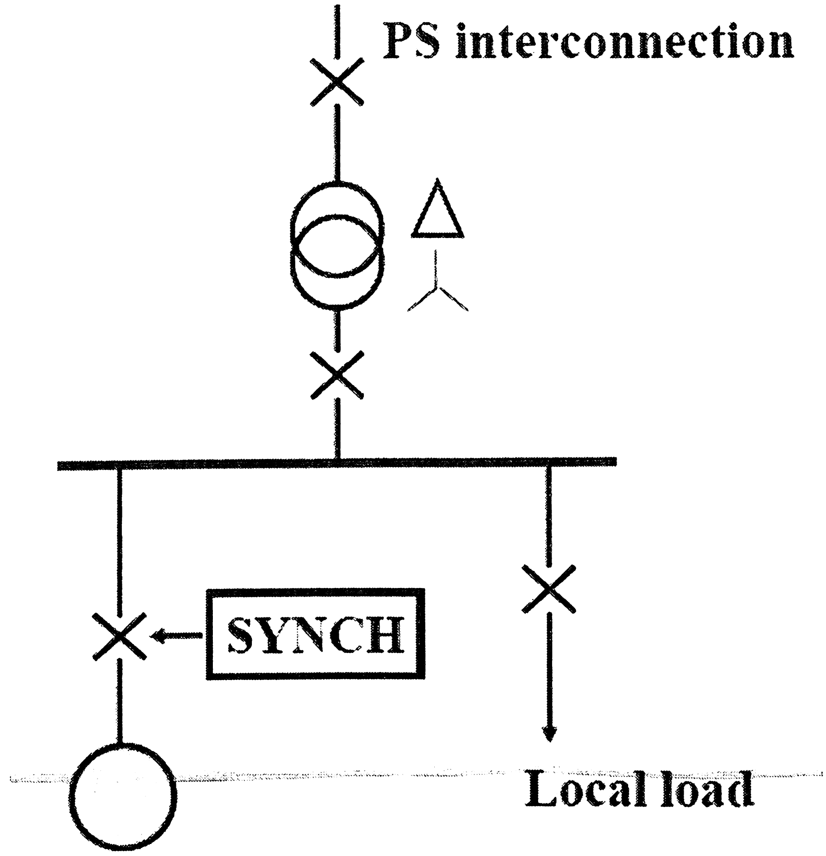


Fig 11: SLD for switchyard

Oil Filled Pole Mounted

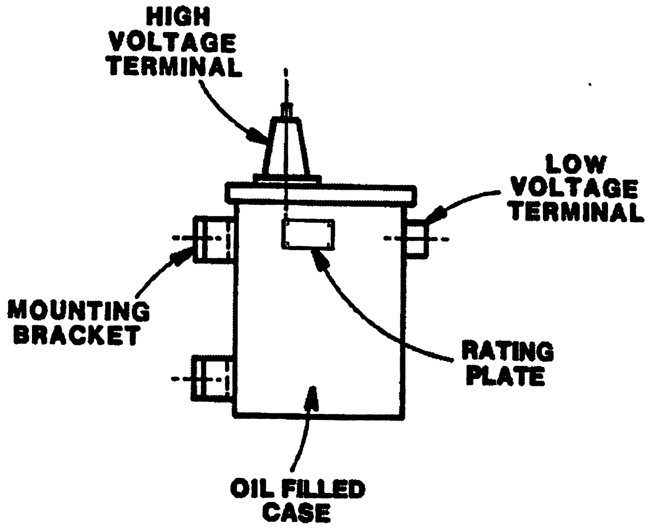
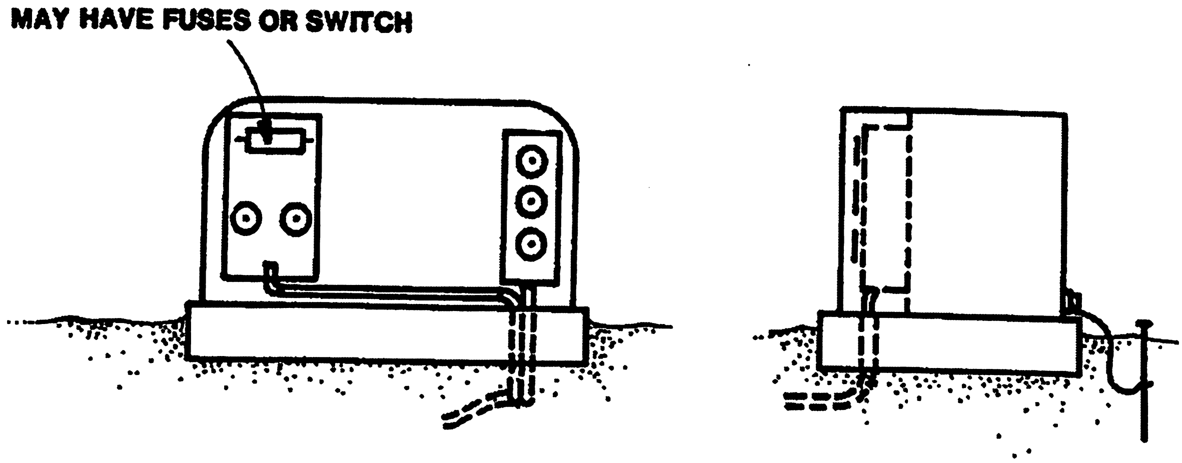
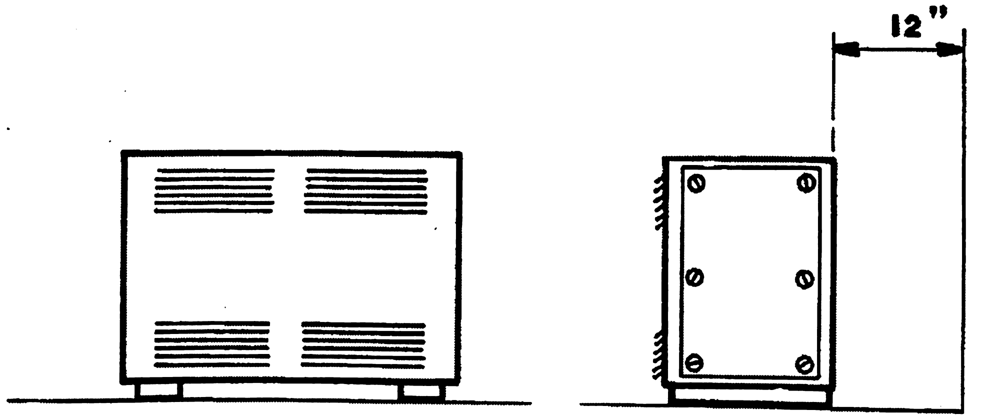


Fig 12: Transformer Components

Oil filled pad mount



Dry type, indoor



DRY-TYPE INDOOR TRANSFORMER

Fig 13: Different types of transformers

Regulation

The secondary of a transformer drops on load, owing to internal winding losses. This is called regulation and amounts to 1.5 %at unity power factor to 7% at 0.8 lagging power factor.

Tappings

Taps are provided to adjust voltage drop on feeders. Automatic tap changers are generally used. Tap positions are numbered from #1 to #5 where #1 being the greatest effective primary turns and the lowest secondary voltage.

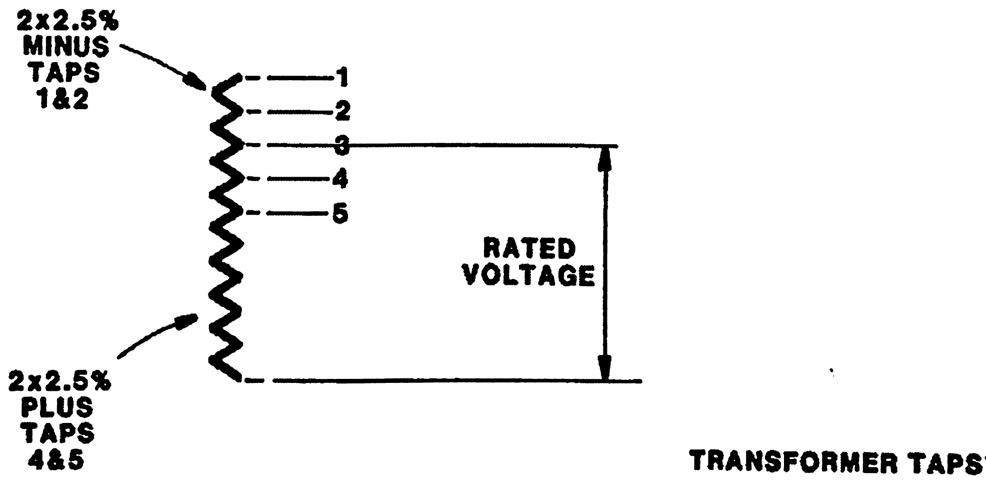


Fig 14: transformers Taps

Safety

If rotating parts are well guarded and maintenance is faithfully performed, the equipment should be safe, from a mechanical point of view. Keep the equipment and the floor clear of loose tools, parts, oil and water. Safety requirements for electrical components are covered in the Electricity Transmission section to follow.

Vibration

All rotating machines vibrate, and good design practice ensures that vibration is held to a practical minimum. Vibration is either linear, which is caused by unbalanced forces usually in more than one plane; or torsional, which is caused by forces making the shaft twist and untwist like a rotating pendulum. Linear balancing; provided on generators, couplings and sheaves, is done on balancing machines which allow for various conditions; this is called static and dynamic balancing. Turbines should be statically and dynamically balanced, and this requirement should be stated in the contract.

Torsional vibration in hydro units can be caused by vibratory forces generated in impulse turbines; and by hydraulic forces and cavitation in other types of turbines. The likelihood of torsional vibration can be calculated when all of the design details of a particular installation are known. The turbine builder should run a check on each machine.

Synchronizing

All A.C. systems must be synchronized prior to being connected together. The speed, voltage, and angular relationship between the voltage waves of the two generators must be equal. If these conditions are not correct at the moment of connection, heavy currents and severe mechanical shock will result. The running machine tries to jerk the incoming one into synchronism, and in severe cases, expensive noises will result. Worst case scenarios include sheared couplings, broken crankshafts and wrecked generators. Synchronizing by hand is a matter of judgment and experience. The possibility of damage is known to the operator, so that the necessity of synchronizing often becomes an occasion for apprehension.

Auto Synchronizing

Auto synchronizing utilizes a relay which measures the difference in speed (slip frequency) and the phase angle between the generator voltages. The relay is adjustable for slip frequency, circuit breaker closing time, and the frequency-matching impulse lengths which it applies to the governor speed. When conditions are correct, the relay will, depending on type, either:

(a) Indicate by means of a ready-to-close lamp that conditions are correct. The operator then closes the circuit breaker. This is called permissive paralleling; or

(b) Send a 'close signal' to the circuit breaker. This is called semi-automatic synchronizing.

Governor Selection

A governor is combination of mechanical devices which detects the speed variation in the turbine and the position of the spear through servomotor mechanism. There are two types of governing systems:

1) Mechanical system (used earlier / small units)

2) Electronic servomotor mechanism (latest / large units)

Speed variation occurs mainly due to sudden loading or load rejection on the generator.

Note: Induction generator does not need governor as the frequency is controlled by the grid to which it is connected.

Because of small unit & save cost, flywheel mechanism is adopted.

Flywheel Mechanism

The main purpose is to reduce or increase the flow of water to the turbine when situation demands. In case of deceleration or starting from the zero rotational speed, there has to be certain inertia which has been calculated later on this thesis.

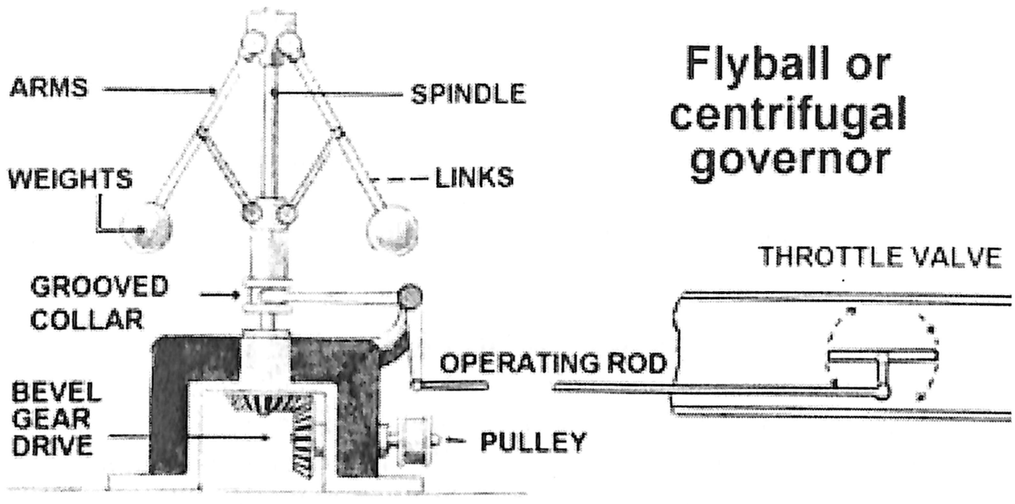


Fig 15:Governor (flywheel mechanism)

Working: When there is a sudden load rejection, generator starts rotating at high speed than previous state. As the speed increases, the turbine speed also increases which in turn rotates the flywheel. Due to fast movement and centrifugal force the fly-balls (*weights*) tend to move outward and the *grooved collar* moves up thereby pressing the operating rod and hence moving the spear inward. This reduces the flow of water into the turbine.

Selection of Switchyard Equipment

As, the name suggests these devices are used to trip or isolate an electrical circuit during fault condition. The efficiency of these devices depends upon the response time during fault conditions. Circuit Breakers are categorized according to their medium used to cool stretch the electrical arc permitting interruption. The most commonly used circuit breakers for SHPs upto 25 MW are

1) SF-6 – Sulfur Hexafluoride Breakers
2) Vacuum circuit breakers upto
3) Air circuit breaker upto 12 kV (Generator circuit breaker)

Sulfur Hexafluoride "*Arc Suppressing Agent*":- Pure sulfur hexafluoride gas is inert in nature and thermally stable. It has very good arc suppressing as well as insulating properties. Sulfur hexafluoride remains in a gaseous state upto a temperature of 90^0C at 15 kg/cm2 pressure its density is about five times of air. Apart from being a gas, it is non-inflammable, non-poisonous and odourless. When arcing takes place through the gas, some by-products are produced due to breakdown of the gas. These by-products are a hazard to the health of the maintenance personnel therefore should be properly taken care of. At a pressure of 3 atm the dielectric strength of sulfur hexafluoride is about 2.4 times that of air and compares very well with that of oil. Even when gas is exposed to electric arcs for fairly long periods, it has been found that decomposition effects are small and the dielectric strength is not affected. Gas circuit breaker generally employs SF-6 (sulfur hexafluoride) as an interrupting medium and sometimes as an insulating medium. Some older low-pressure SF6 breakers employed a pump to provide the high pressure SF6 gas for arc interruption.

Vacuum Circuit Breakers (V.C.Bs): Vacuum circuit breakers use a smaller cylinder covering the moving contacts under a high vacuum. When the contacts part, is a formed from contact erosion, the arc products are immediately forced to and deposited on a metallic shield surrounding the contacts. Without anything to sustain the arc, it is quickly extinguished.

Difference between SF_6 and vacuum circuit breaker

a) For SF6 Breakers there is one Red, Yellow and green lamp to indicate the SF6 pressure inside the breaker. Need to check the SF_6 gas pressure inside the Breaker every month to ensure that the SF_6 gas is still O.K. For Vacuum Breaker no need to do it because the Vacuum breaker is completely sealed.

b) If SF_6 breaker gas pressure is less, it can be filled.

c) For maintenance cost there should be one stand by a cylinder of SF_6 gas inside substation for filling. But for Vacuum Breaker nothing is needed

d) Vacuum circuit breaker does have limited operational life.

Following tests are to be performed on a circuit breaker before employing it:

Type Test

i) Dielectric tests (1.2/50 micro second lightning impulse withstand) and 1 minute power frequency voltage with stand (dry & wet) test
ii) Radio interface voltage (r.i.v.) tests
iii) Temperature rise tests
iv) Measurement of the resistance of the main circuit
v) Short-time withstand current and peak withstand current tests
vi) Short circuit making and breaking tests

Routine tests

i) Power frequency voltage withstand dry tests on the main circuit
ii) Voltage withstand tests on control and auxiliary circuits
iii) Measurement of the resistance of the main circuit
iv) Mechanical operating tests

Table 450.3(A) Maximum Rating or Setting of Overcurrent Protection for Transformers Over 600 Volts (as a Percentage of Transformer-Rated Current)

		Primary Protection over 600 Volts		Secondary Protection (See Note 2.)		
				Over 600 Volts		600 Volts or Less
Location Limitations	**Transformer Rated Impedance**	**Circuit Breaker (See Note 4.)**	**Fuse Rating**	**Circuit Breaker (See Note 4.)**	**Fuse Rating**	**Circuit Breaker or Fuse Rating**
Any location	Not more than 6%	600% (See Note 1.)	300% (See Note 1.)	300% (See Note 1.)	250% (See Note 1.)	125% (See Note 1.)
	More than 6% and not more than 10%	400% (See Note 1.)	300% (See Note 1.)	250% (See Note 1.)	225% (See Note 1.)	125% (See Note 1.)
Supervised locations only (See Note 3.)	Any	300% (See Note 1.)	250% (See Note 1.)	Not required	Not required	Not required
	Not more than 6%	600%	300%	300% (See Note 5.)	250% (See Note 5.)	250% (See Note 5.)
	More than 6% and not more than 10%	400%	300%	250% (See Note 5.)	225% (See Note 5.)	250% (See Note 5.)

Notes:

1. Where the required fuse rating or circuit breaker setting does not correspond to a standard rating or setting, a higher rating or setting that does not exceed the next higher standard rating or setting shall be permitted.
2. Where secondary overcurrent protection is required, the secondary overcurrent device shall be permitted to consist of not more than six circuit breakers or six sets of fuses grouped in one location. Where multiple overcurrent devices are utilized, the total of all the device ratings shall not exceed the allowed value of a single overcurrent device. If both circuit breakers and fuses are used as the overcurrent device, the total of the device ratings shall not exceed that allowed for fuses.
3. A supervised location is a location where conditions of maintenance and supervision ensure that only qualified persons monitor and service the transformer installation.
4. Electronically actuated fuses that may be set to open at a specific current shall be set in accordance with settings for circuit breakers.
5. A transformer equipped with a coordinated thermal overload protection by the manufacturer shall be permitted to have separate secondary protection omitted.

Fig 16: *National Electrical code for circuit breaker (overcurrent protection device)*

The figure shows the rated values for circuit breaker for primary and secondary side of the transformer > 600 V (National *Electrical Code 2008*)

Single Line Diagram with the Components

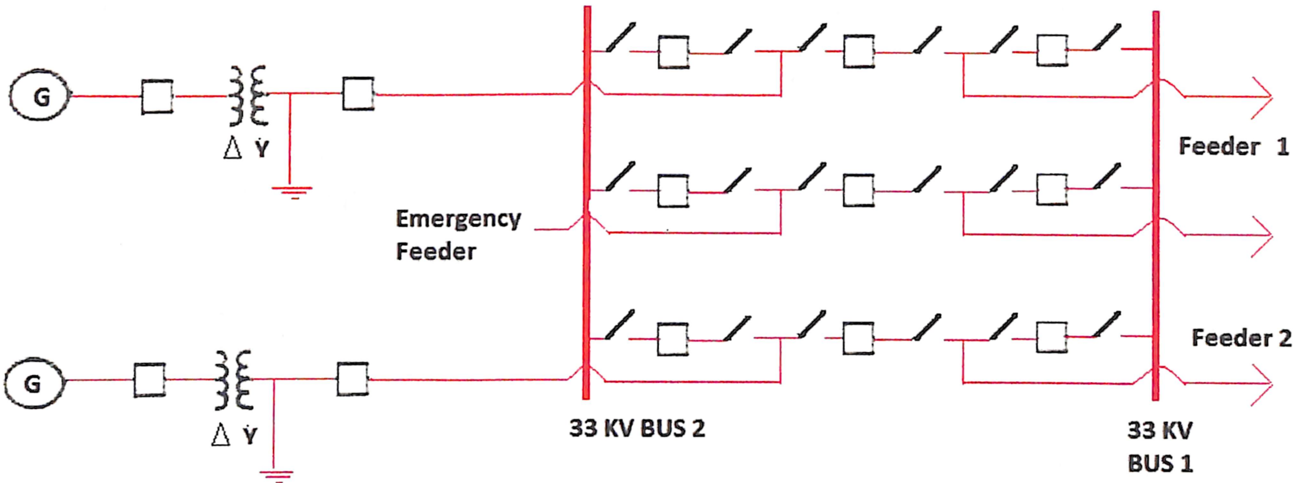


Fig 17: Single Line Diagram

Cable / Conductor Selection

The factors taken into account for selection of conductors are:

1) Conductivity
2) Tensile strength
3) Corona loss
4) Local condition
5) Cost

Skin Effect: If d.c. is passed in a conductor, the current density is uniform over the cross-section of the conductor. In a conductor carrying a.c. there is tendency of the current to crowd near the surface of the conductor. This phenomenon is known as ***skin effect***.

Explanation: Assume the conductors to be made up of a number of concentric cylinders. The magnetic flux linking a cylindrical element near the center of the conductor is greater than that linking another element near the surface conductor. This is due to the fact that the former element is surrounded by the internal as well as external flux, while the latter by external flux only. The inner element will possess a greater self-inductance and therefore, will offer a greater inductive reactance than the outer element. This difference in the conductive reactance gives a tendency to the current to crowd towards the surface or skin of the conductor. The current density is maximum at surface and minimum at the center of the conductor. The effect is virtually equivalent to a reduction of cross-sectional area of the conductor & therefore, the effective resistance of the conductor is increased.

At low frequencies, such as 50Hz, there is a small increase in the current density near surface of conductor, but high frequencies, such as with radio, practically the whole of the current flows on the surface of the conductor.

One of the main factors for designing a line is cost or economy of transmission. This is given by **KELVIN'S ECONOMY LAW**. According to the law there are two parts

1) The **fixed standing charges**: It consists of the interest on the capital cost of conductor, the allowance for the depreciation and the maintenance cost.
2) The **running cost**: It mainly consists of the cost of electrical energy wasted die to losses during operation.

Both the above mentioned factors depend upon the sizing of the conductor. So it's a call between ***cost and loss.***
There are many types of cable

1) Circular Oil filled cables: low viscosity oil is kept under pressure either within the cable sheath itself or within a containing pipe. The oil fills the voids in oil impregnated paper under all condition of varying load. There are three types of oil filled cables
    a) Self-contained circular type
    b) Self-contained flat type
    c) Pipe line cables

Load Factor K_l%	Form Factor K_f%
10	2.25
15	1.88
20	1.68
25	1.55
30	1.45
40	1.3
50	1.2
60	1.13
70	1.08
80	1.04
90	1.02
100	1.00

Table 6: Approximate Values of Form Factor for Various Load Factors

Sag & Tension: An adequate ground clearance of the conductors at maximum temperature and minimum load condition should be maintained. The conductor should not break under most severe condition of ice and wind loadings which are assumed. Also due to cold and hot climates adequate clearance should be there for expansion and contraction. This is the reason why sag is important.

Sag is calculated by the following formula:

$$\square = \frac{wl^2}{8H}$$

Where,

w	= weight per unit length of conductor
l	= conductor sag
H	= tension in the conductor at the point of maximum deflection.

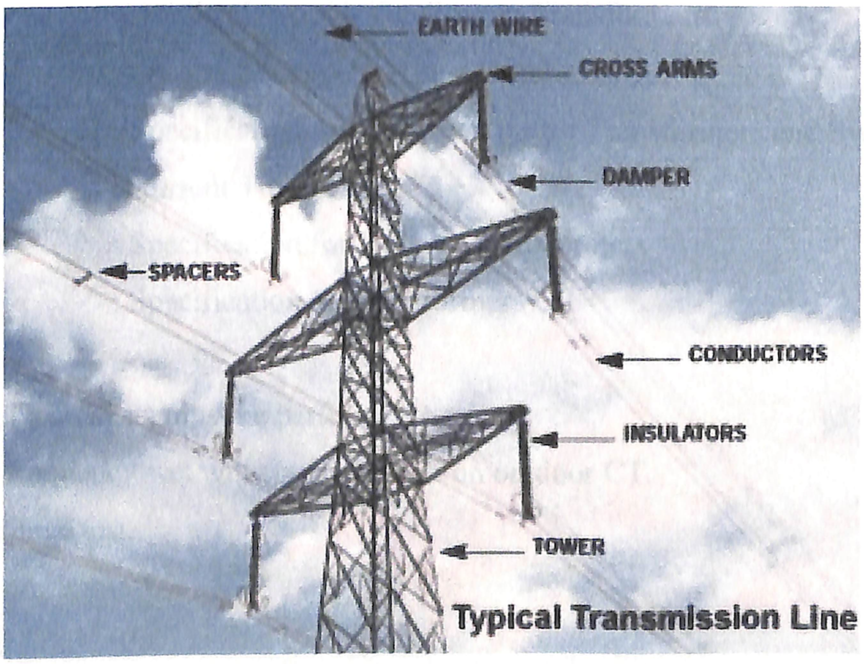
Minimum Ground Clearance

Voltage Level	Clearance
For low, medium and high voltages lines upto and including 11,000 volts, if bare	4.6 meters
For low, medium and high voltage lines upto and including 11,000 volts, if insulated	4.0 meters
For high voltage lines above 11,000 volts	5.2 meters

Table 7 : Ground Clearance as per Indian electricity supply Act

Proper ground clearance is given by **Indian electricity supply act** which is 17 feet (5.18m) for 33KV line and for every additional 33 KV thereof additional 1 foot (0.3048m).

For example, for 132 KV line, 132 = 33 + 3 x 33
= 5.18 + 3 x 0.3048
= 6.1m



$$E = 5.5\sqrt{\frac{L}{1.6} + \frac{KVA}{150}}$$

E = Economic voltage for power transmission

L = Distance of transmission line

KVA = Power to be transmitted

Selection of Current Transformer/Potential Transformer

C.Ts is mainly used to scale down the original higher range voltage & current into useable metering values. Mainly these are used for metering along with potential transformers.

Current transformers consists of the following

I. A laminated steel core
II. A secondary winding around the core
III. Insulating material

Specification for the current transformer and potential transformer should comply with the following standards:

IS:2705 (Part-I-IV)	: Specification for Current Transformers.
IS:4201	: Application guide for Current Transformers.
IS:2099	: Specification for HV porcelain bushings.
IS:335	: Specification for insulation oil for Transformers and Switchgears
IEC:185	: Current Transformers.
IS: 3156:1992	: Specification for Voltage Transformers
IS: 335:1983	: Specification of Transformers Oil

The following Type Tests must be performed onsite

(a) HV power frequency wet withstand volt test on outdoor CT.

(b) Impulse voltage test.

(c) Short time current test.

(d) Temperature rise test.

Technical Specification of 33 KV Outdoor Type Current Transformer

Type	: Dual Core Dual Ratio Outdoor Dead Tank Type with terminal connector suitable for ACSR "Dog "Conductor.
Applicable Standard	: IS: 2705-1992 (Part-1, 2, 3)
Basic Insulation Level	: HV: 70 KV (r.m.s.)/170 KV (Peak): LV: 3 KV (r.m.s.)
Ratio	: **400-200/1 A**
System Earthing	: Non-Effectively Earthed.
Short Circuit	
Withstand Capability	: 20 KA for 3 Sec.
Number of Cores	: 3 (three)
Accuracy Class	: I. Metering Core : 0.5
	II. Protection Core : 5P20
	III.Protection Core : PS
VA Burden	: 20 VA for Metering Core & 30 VA for Protection Core
Instrument Security	: Less than equal to 5 at lower ratio. Input for Metering Core
Min. V_k at lower ratio	: 600 Volts for PS class
Max. I_e at V_k at lower	: 30 mA ratio for PS class
Max. RCT at higher ratio	: 4 W at 75°C for PS class
Creepage Distance	: 900 mm
Suitability	: Should be suitable for upright mounting on Steel Structure in outdoor Switch yard Standard base structure.

CHAPTER III

Calculation for Different Components

==

1. Penstock diameter calculation

Maximum flood Discharge	=	480 cumecs
Design Discharge	=	4.12 cumecs
Penstock Length (L)	=	560m
Head (H) Gross	=	271.56m

Assumption: Limit the head loss to a certain percentage for maximum power and generally it is 4%.

Friction Loss by **Manning's Formula,**

$$\frac{h}{L} = 10.3\frac{n^2Q^2}{D^{5.333}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

$$\Rightarrow D = \left[10.3\frac{n^2Q^2L}{h}\right]^{0.1875}$$

If *h* is limited to 4% of the total head losses then D = diameter

$$\Rightarrow 2.83\left(\frac{n^2Q^2L}{H}\right)^{0.1875}$$

So, for this project

$$D = 2.83\left[\frac{4.12^2 \times 0.012^2 \times 560}{271.56}\right]^{0.1875}$$

$$= 1.049 \approx \mathbf{1.05}\boldsymbol{m}$$

2. Total Head Loss Calculation

Total Head Loss in penstock is calculated by Scooby's Formula

$$h_l = 0.34 \times \left(\frac{V^{1.9}}{D^{1.1}}\right) \times \left(\frac{L}{1000}\right) \ldots\ldots\ldots\ldots\ldots (2)$$

where,

h_l	=Total Head Loss
V	= Velocity
D	= Diameter of Penstock
L	= Total Length of Penstock

All units in above formula are in feet (ft.) or feet per second (ft. /s) .

Thickness of Penstock Liner

According to A.S.M.E. minimum thickness in mm = 2.5 times the diameter in meters +1.2 mm. practically the following equation is used to calculated the thickness of wall

$$t' = \frac{D + 508}{400}$$

$$= \frac{1050 + 508}{400}$$

$$= 3.895 \approx 4\, mm$$

Now adding corrosion allowance of 2mm, the minimum thickness t = 6 mm

The shell thickness of penstock at a location is designed for the pressure head of water at that section plus the water hammer pressure. Since the length of penstock is sufficiently large we can use many thicknesses of penstock pipe like 8 mm to 18 mm in the present project. However, the minimum thickness of penstock liner shall not be less than 5 mm corrosion allowance of 2 mm is to be added to thickness

Computing the head loss in penstock

$$\boldsymbol{Area\ (A) = \pi \times \frac{D^2}{4} \ldots\ldots\ldots\ldots (3)}$$

$$= \pi \times \frac{1.05^2}{4}$$

$$= 0.866\ \mathrm{m}^2$$

$$\approx \mathbf{0.87 m^2}$$

$$\boldsymbol{V = Velocity\ in\ pipe = \frac{Q}{A} \ldots\ldots\ldots (4)}$$

$$= \frac{4.12}{0.87}$$

$$= \mathbf{4.73\ m/s}$$

$$= \mathbf{15.61\ ft/s}$$

Note: 1m = 3.3 ft/s

From Scoby's formula

$$h = 0.34 \times \frac{15.61^{1.9}}{3.465^{1.1}} \times \frac{1848}{1000}$$

$$= 0.34 \times \frac{185.125}{3.924} \times \frac{1848}{1000}$$

$$= \mathbf{29.64}\ \boldsymbol{ft.}$$

$$= \mathbf{8.98}\ \boldsymbol{m}$$

Total Head Loss = 8.98 + 20%

= 10.78 ≈ 11m

Therefore, total head loss = 11m

So, net head = 271.56 – 11

= **260.56 m.**

3. Power Calculation

Proposed power generation capacity (**P**) = 4.12 x 260.56 x .85 x 9.81 x 1000

= 8951.44 KW

≈ 9000 KW

Power Generation ≈ **9 MW**

It is proposed to install (4.5 M.W. x 2) of two units.

Therefore the total head loss is 11m and hence the available head in meters is **260.56m.** Now the new power calculated is 9 MW. So, it is proposed to have **2 units of 4.5 MW** keeping 10% extra.

4. Width of trash Rack

$$\boldsymbol{B = \frac{Q}{\left[E \times EE \times C \times L \times (2ghE)^{\frac{1}{2}}\right]}} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Where,

Q = design discharge+5% flushing shingles at intake+15% for silt flushing+10% extra power generation

E = ratio of opening area to total area

= 0.5 assumed

EE = Ratio of clogged to opening area

= 0.5 assumed

C = Coefficient of discharge through opening

= 0.465 for slope 1 in 14

L = Length of trash rack (width of stream)

g = acceleration

E = specific energy at any section of stream

Where E is calculated as in formula 6 and settling velocity is calculated by Stoke's law given by equation 7

$$\boldsymbol{E = \left(\frac{Q}{C'L}\right)^{\frac{2}{3}} \ldots\ldots\ldots\ldots\ldots (6)}$$

Where,

C' = Coefficient of discharge for broad crested weir

= 1.53(average value)

Calculation for settling velocity of silts is given by

$$\boldsymbol{V = \frac{1}{8} \times \frac{S - S'}{V} \times gd^2 \ldots\ldots\ldots\ldots\ldots (7)}$$

Where,

V = settling velocity in cm/sec

g = acceleration due to gravity cm/s^2

S = specific gravity of the silt particle = 2.65

S' = Specific gravity of water (1)

d = particle size in cm (.02)

Therefore, V = 0.2844 cm/sec

= 0.00284 m/s

Now, from equation 6

$$E = \frac{(7.5)^{\frac{2}{3}}}{\left[(1.53)^{\frac{2}{3}} \times (15)^{\frac{2}{3}}\right]}$$

$$= 0.475$$

From eq. 4

$$B = \frac{7.5}{\left[(0.5) \times (0.5) \times (0.465) \times (15) \times (2 \times 9.81 \times 0.475)^{\frac{1}{2}}\right]}$$

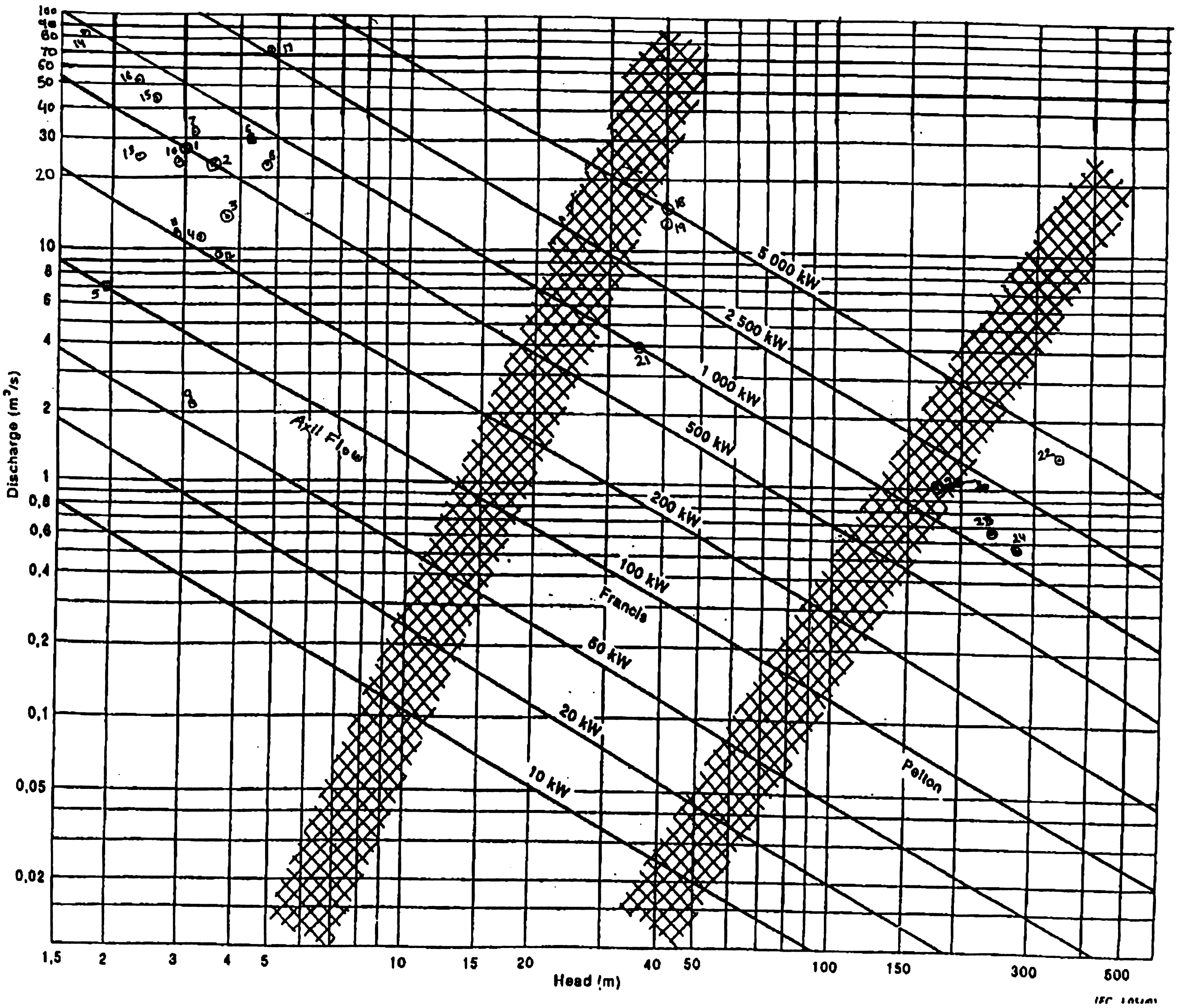
$$\boldsymbol{= 1.41\, m}$$

Practically instead of 1.41m, a trench weir of 2m wide is selected with length of 15m. Depth varies from 0.6 to 1.35m.Therefore as per calculation it is clear that the width of the trash rack is of **2 m**.

5. <u>Turbine Selection</u>

Turbine is selected by considering different parameters like cost, efficiency, and need. In this situation we have two options for turbines like PELTON and PROPELLOR type.

The below chart gives an idea for selection of turbines in different ranges of head and discharge.



Max. Flood Discharge =		480	cumecs
Length of water conductor =		470	m
	+	1500	m
	+	30	m
	Total	2000	m

Design Discharge(Q)	=	4.12	cumecs
Penstock Length (L)	=	560	m
Head (H) Gross	=	271.56	m
Head loss	=	11	m
Total Head Available	=	260.56	m
Power	=	9000	KW
Proposed Power	=	9	MW
Proposed Scheme	=	4.5×2	units
Penstock Dia.	=	1.05	m

Specific speed calculation

Turbine speed is given as a function of n' (specific speed).

Now, $$n = \frac{n' E^{\frac{3}{4}}}{\sqrt{Q}} \ldots\ldots\ldots..(8) \qquad (E = gH)$$

$$= \frac{n'(9.81 \times 260.56)^{\frac{3}{4}}}{\sqrt{4.12}}$$

$$= \frac{n'(359.5)}{2.03}$$

$$n = 177.1\, n' \ldots\ldots\ldots\ldots (a)$$

According to the table in literature review, if one nozzle pelton turbine is used then maximum specific speed would be 0.025 and hence from **eq.a** the revolution of turbine becomes $177.1 \times 0.025 = 4.42\frac{t}{s} = 265.2\, rpm$
But this rpm is too low for the generator and hence we use the formula for turbine with 2 nozzles. The maximum specific speed for 2 nozzles is $0.025n^{0.5}$

Hence, rotational speed of turbine becomes $n = 0.025 \times 2^{0.5} \times 177.1$
$= 6.26\frac{t}{s} = 375.6\, rpm$

Similarly, with 4 nozzle$n = 531.3\, rpm$

Now, keeping the economy in mind we have to go for 2 nozzle or 4 nozzle pelton wheel.

Therefore, rpm of turbine is 375.6 for 2 nozzle and 531.3 with 4 nozzles.

The calculation for **jet velocity, velocity of bucket, nozzle diameter, diameter of runner blades, and no. of buckets** are given

Calculation for jet velocity, velocity of bucket, Nozzle Diameter & diameter of pelton wheel & no. of buckets

1) **Jet Velocity** : $$V = (2 \times g \times h)^{\frac{1}{2}} \times Cv \dots\dots\dots (9)$$

$$= (2 \times 9.81 \times 260.56)^{\frac{1}{2}} \times 0.97$$

$$= 69.35 \frac{m}{s}$$

$$where, Cv = coeffcienct\ of\ losses$$

2) **Velocity of Bucket** (U) $= 0.46 \times V$**...........(10)**

$= 31.9$ m/s≈ $\mathbf{32\ m/s}$

3) Total **energy transferred** is calculated using the **Euler's equation** as shown

$$E = \frac{U}{g} \times (V - U) \times (1 - K\cos\theta) \dots\dots\dots (11)$$

Where,

U = 32 m/s

V = 69.35 m/s

$\theta = 165^0$ (conventional)

K = reduction of relative velocity = 0.85 (assumption)

$$= \frac{32}{9.81} \times (69.35 - 32) \times (1 - 0.85\cos(165))$$

$$= 120.35 \times (1 - 0.85\cos 165)$$

$$= \mathbf{221.86\ KJ}$$

4) **Nozzle Area:** $$A = \frac{Q}{V} \dots\dots\dots. (12)$$

$$= \frac{4.12}{69.35}$$

$$A = 0.06\ m^2$$

Therefore, Nozzle Diameter = $D_n = \sqrt{A \times \frac{4}{\pi}}$

$$= \sqrt{0.06 \times \frac{4}{3.14}}$$

$$= \mathbf{0.276\ m}$$

Therefore, **Dimensions of pelton wheel are**

$$D = \frac{0.68\sqrt{H}}{n} \ldots\ldots(13)$$

$$= \frac{0.68\sqrt{260.56}}{8.855} = 1.239 \approx 1.24\ \text{m}$$

$$B = 1.68\sqrt{\left(\frac{Q}{j}\right) \times \left(\frac{1}{\sqrt{H}}\right)} \ldots\ldots(14)$$

$$= 1.68\sqrt{\left(\frac{4.12}{4}\right) \times \left(\frac{1}{\sqrt{260.56}}\right)} = 0.425\ \text{m}$$

$$D' = 1.178\sqrt{\left(\frac{Q}{j}\right) \times \left(\frac{1}{\sqrt{gH}}\right)} \ldots\ldots\ldots(15)$$

$$= 1.178\sqrt{\left(\frac{4.12}{4}\right) \times \left(\frac{1}{\sqrt{9.81 \times 260.56}}\right)} = 0.17\ \text{m}$$

Dis defined as the diameter of the circle describing the buckets. Bis the bucket width. D'is the nozzle diameter. As a general rule, the ratio **D / B**shouldalways be greater than 2.7,else a new calculation with a lower rotational speed or more nozzles should to be carried out.

6. Generator Calculation

The generator specifications are

1) **Type** : **Synchronous**
2) **Terminal Voltage** : **11 KV**
3) **RPM (N)** : **500**
4) **Power Factor** : **0.8 (assumed)**
5) **KVA** : $\frac{4500}{0.8} = 5625$
6) **Poles(P)** : **12**

$$\text{No. of poles (P)} = 120 \times \frac{f}{N} \ldots\ldots\ldots (16)$$

7. Governor Equation

The basic equation of the rotating system is the following:

$$J.\frac{d\Omega}{dt} = (T_t - T_L) \ldots\ldots\ldots..(17)$$

Where:

J = moment of inertia of the rotating components [kg m^2]
Ω = angular velocity [rad/s]
T_t = torque of turbine [Nm]
T_L = torque due to load [Nm]

When $T_t = T_L$, $d\Omega/dt = 0$ and Ω = constant, operation is steady. When T_t greater or smaller than T_L&Ω is not constant then the governor will interfere so that the turbine output matches the generator load. But the control of the water flow introduces a new factor that is, the speed variations on the water column formed by the waterways.

The start-up time of the rotating system, **the time required to accelerate** the unit from zero rotational speed to operating speed is given by

$$t_m = j.\frac{\Omega^2}{P} = \frac{\Omega.R^2.n^2}{5086 \times P} \ldots\ldots\ldots.(18)$$

Where,

Rotating inertia	= weight of all rotating parts × square of radius of gyration	
P	= Rated power in KW	
n	= turbine speed	

The starting time for water from zero velocity to certain velocity V is given by

$$t_v = \sum L.\frac{V}{gH} \dots\dots\dots.. (19)$$

Where,

gH	= specific hydraulic energy of the turbine	[J/kg]
L	= length of water column	[m]
V	= velocity of the water	[m/s]

If $T_m/T_v > 4$, then it is good regulation. Practically the water starting time do not exceed 2.5 sec.

8. Transformer Selection

Phase	: Three
Frequency	: 50 Hz
MVA	: 6.0
Voltage	: 11/ 33 KV (step up)
Connection	: Dyn11

***** details of the transformer is given in annexure-1 Page 52***

9. Circuit Breaker Calculation

These are protective devices which isolate the circuit during any fault condition. Critical factor is the fault current. The following shows the selection procedure for circuit breakers.

Current Rating Calculation

Transformer Rating: 6000 kVA **(X)**

I Full load: $\mathbf{X \times \frac{1000}{\sqrt{3} \times VL}}$

$$= 6000 \times 1000/(\sqrt{3} \times 33000 \text{ (HV side)}$$

$$= 104.97\ amps$$

$$\approx 105\ amps$$

Where, X = Transformer rating in kVA

V_L = Line Voltage

Selection of circuit breaker is done according to N.E.C. (*National Electric Code*). So, according to figure 16 in literature review of this thesis we can see that circuit breaker for transformers over 600 V should be 250% of the full load current capacity for secondary or H.V. side in this case

Therefore, at 0.8 power factor I full load $= \frac{105}{0.8} = 131.25\ amps$

Circuit Breaker size should be $= 2.5 \times 131.25 = 328.125\ amps$

So, the circuit breaker should be at least 330 amps rated (according to NEC) (if 330 not available then next higher to be choosen)

10. Cable/Conductor Selection Calculation

Conductors are mainly selected by the ***KVA ratings***.

If there are n layers of strands of equal diameter in a circular formation with one central strand, the following general formulae are applicable:

Total no. of conductors in a strand of n layers **N = 1+3n (1+n)**

Overall diameter of stranded conductor with n layers **D = (1+2n) d**

Where *d* is the diameter of each strand. Thus, a 7-strand conductor has a central strand with 6 outer; the 19-strand conductor has a central strand with 6 strands in the first layer and 12 strands in the next layer.

Let us consider an example: **System voltage : 33 KV**

Maximum Load : 5625 KVA (gen. Rating)

Load Factor : 60%

Copper Conductor : 17.6 $\mu\Omega$-m^2/Km (Specific Resistance)

Rate of interest and depreciation: 10%

Cost of line per KM = Rs. 20000a+10000 (a = cross-sectional area)

Now,

I_m = maximum full-load current on line

K_l = annual load factor of the line $= \frac{avg.load\ over\ a\ period}{maximum\ load\ over\ the\ period}$

$$= \frac{no.of\ KWh \frac{generated}{year}}{maximum\ demand(KW) \times 8760\ hrs}$$

$= I_{avg} / I_m$

$K_f = \frac{root\ mean\ square\ current}{annual\ average\ current}$

$= I_{rms} / I_{avg}$

$I_{rms} = K_f \times I_{avg}$

Since, $I_{avg} = K_l \times I_m$

Therefore, $I_{rms} = K_l \times K_f \times I_m$

$$\sqrt{3}VI_m = 5500$$

$I_m = 98.42$ A ≈ **99** Amps (highest near value taken)

For a 60% load factor, $K_f = 1.13$ (from the table in literature review)

$$I_{rms} = K_l \times K_f \times I_m = 0.6 \times 1.13 \times 99 = 67.122 \approx 67.5 \text{ A}$$

$$\rho = 17.6\mu\Omega - \frac{m2}{Km} = \frac{(17.6\ \mu\Omega\text{–cm}^2 \times 10000)}{100000} = 1.76\ \mu\Omega - \text{cm}$$

Resistance of one conductor per Km $R = \rho \frac{l}{A}$

$$= \frac{1.76\ \times 10^{-6}\ \times\ 10^5}{a}$$

$$= \frac{0.176}{a}\Omega$$

Energy Loss in the line per year $= 3I^2_{rms} R \times t \times 10^{-3} = 3 \times 67.5^2 \times \frac{0.176}{a} \times 8760\ \times\ 10^{-3}$

$$= \frac{\mathbf{2.1074}}{\boldsymbol{a}} \times\ \mathbf{10^4}\boldsymbol{KWh}$$

Annual cost of energy wasted $= \frac{2.1074}{a} \times\ 10^4\ \times 0.15 = Rs.\frac{3.161}{a}\ \times 10^3$

Annual cost due to interest and depreciation = Rs. $0.1 \times 20000a$

= Rs. 2000a

By **Kelvin's law** for the most economical cross-section, the two annual charges should be equal.

Therefore, $2000a\ = \frac{3.161}{a} \times\ 10^3$

$a^2 = \frac{3.161}{2000}\ \times 1000 =\ 1.5805$ ➔ $a = 1.257\ cm^2 = 125.7\ mm^2 \approx 126\ mm^2$

So, the most economical size of the conductor = 126mm²

11. Carbon Reduction Potential

Basic formula for calculating CERs is

$$CERs = MW \times grid\ emission\ factor \times hrs.of\ operation \times no.of\ days \times plant\ load\ factor$$

So, in this project the following are the required data

MW	**= 9**
Grid emission factor	**= 0.8 (for North India)**
Hours of operation	**= 24 (assumed)**
No. of days	**= 365 (assumed)**
Plant load factor	**= 80% (assumed)**
Price per CERS	**= 10 Euros**
One Euro	**= Rs. 63.81** (*dated 10/4011*)

$$\boldsymbol{CERs = 9 \times 0.8 \times 24 \times 365 \times 0.8 = 50457.6}$$

Assuming 10 Euros/CER, the amount generated $= 50457.6 \times 10$

$= 504576\ Euros$

$= Rs. 504576 \times 63.81$

$= Rs. 32196994.56$

$$\boldsymbol{= Rupees\ 3\ crore\ 21\ lakhs\ (approx)/year}$$

CHAPTER IV

Results and Discussion

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The following are the results

Discharge	=4.12 cumecs
Total Head	=271.56 m
Penstock Diameter	=1.05 m
Thickness of penstock linear	=4 mm
Total Head Loss	=11m
Power	=9 MW
Width of Trench weir	=1.41 m
Dimensions of turbine	
- Diameter of the circle describing the buckets (D)	= 1.24 m
- Bucket width (B)	= 0.425 m
- Nozzle diameter (D')	= 0.17 m
Generator Specification	=6 MVA, Separately excited, 12 pole, 500 rpm, 11 K V
Transformer specification	=6 MVA, 11/33 Step Up, Dyn11
Circuit breaker specification	=
Conductors	=126 mm^2

CHAPTER V

Conclusion & Recommendation

As per my thesis, I would recommend our University to take up some small hydro power projects in the state of Uttarakhand as there is huge potential and numbers of villages are still in dark. There are also lots of CDM benefits along with some employment opportunities for poor. University has already taken up 100 KWp solar power project for the University premises and thus this step towards using renewable energy sources will take our University one step towards Green Future. My thesis work could be used as calculation and reference tool as major designing part has been covered and kept very simple so that it is understandable to anyone handling a hydro project

ANNEXURE - I

Century Transformers Pvt. Ltd.

Detail Technical Specification of 6000 KVA 11/ 33 KV Transformer.

Reference Standard: IS: 2026- 1977

Name of the Manufacturer: **Century transformers Pvt. Ltd.**

1. Service: outdoor
2. KVA rating:
   a) HV winding: 6000 KVA
   b) LV winding: 6000 KVA
3. Rated voltage:
   a) HV winding: 33000 Volts.
   b) LV winding: 11000 Volts.
4. Rated frequency: 50 CPS.
5. Number of phases: 3
6. Connection:
   a) HV : DELTA
   b) LV : STAR
7. Connection Symbol: Dyn11
8. Tappings: +10% to -10% @ 1.25% in 16 steps (by On Load Tap Changer)
9. Climate conditions considered:
   a) Maximum ambient air temperature: 50 deg. C.
   b) Maximum daily average temp. over a 24 hour in shade: 45 deg. C
   c) Maximum temperature attainable when exposed in sun: 60 deg. C.
   d) Minimum ambient temperature: 4 deg C.
   e) Maximum relative humidity: 100%
10. Type of cooling:Oil Natural Air Natural
11. Temperature Rise:
    a) Top Oil: 45 deg. C.
    b) Windings (measured by temp rise by resistance method): 55 deg. C.
12. Total loss at rated voltage at principal tapping and rated frequency (full load): 47.5KW.
13. Component losses:
    a) No load loss at rated frequency and rated voltage on principal tapping: 6.5KW (±5%)
    b) Load loss at rated current at principal tapping at 75 deg. C: 41KW (± 5%)
14. Impedance voltage at rated current for principal tapping: 7.15 %(± 10%)
15. Reactance at rated current and rated frequency: 7.1%
16. No load current at rated voltage and rated frequency: within 0.8% of the rated current.
17. Efficiency at 75 deg. C unity power factor.

	At unity P. F.	At 0.8 P.F.
At full load	99.21%	99.02%
At ¾ full load	99.34%	99.18%
At ½ full load	99.44%	99.30%

At ¼ full load	99.39%	99.25%

Century Transformers Pvt. Ltd.

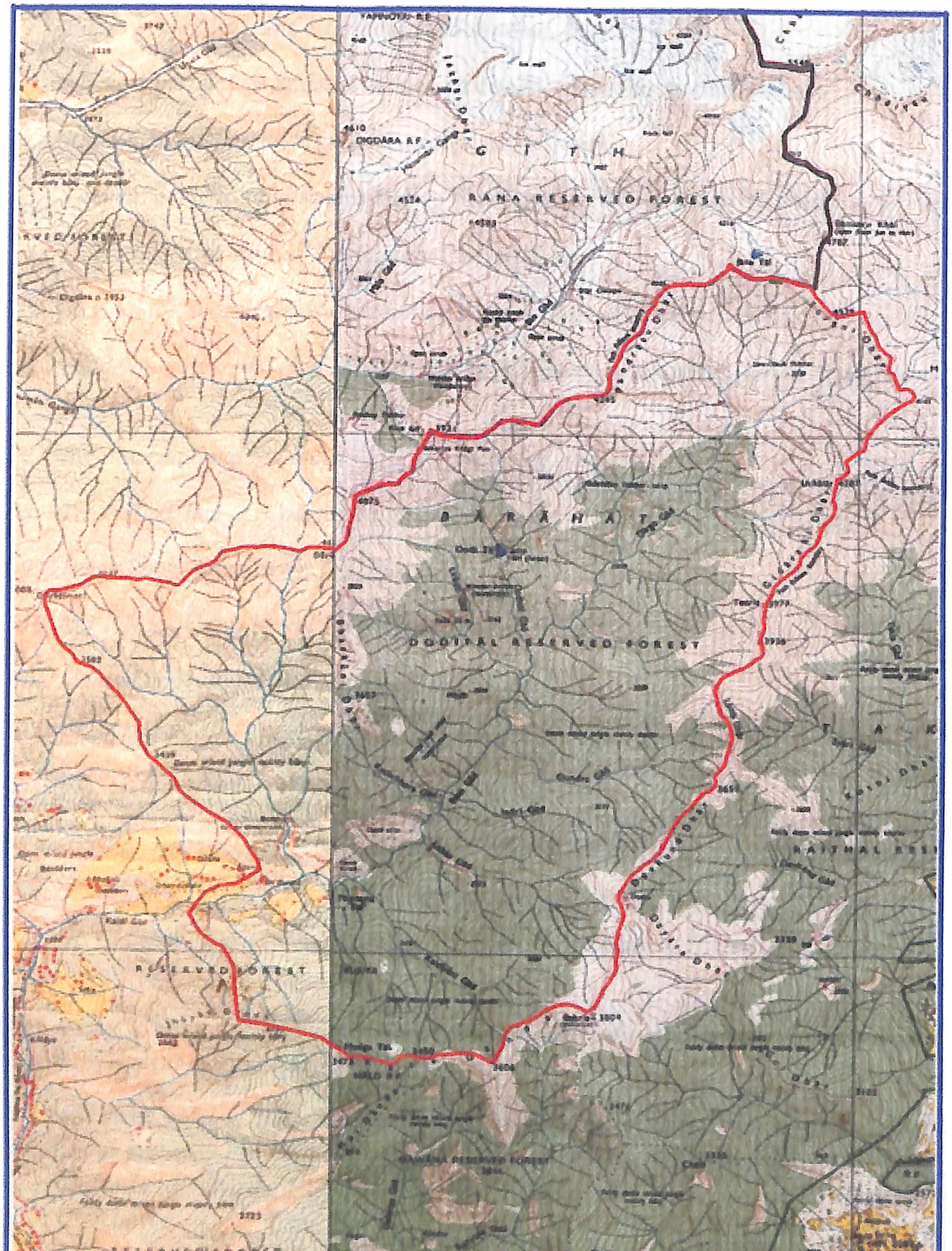
18. Regulation at full load at 75 deg. C.
    a) at unity power factor: 0.68%
    b) at 0.8 power factor: 4.8%
19. Equipment for ONAN cooling: Radiators with main tank.
20. Terminal arrangement :
    a) HV: Outdoor Bushings on the tank cover
    b) LV: Outdoor Bushings on the tank cover.
21. Approximate Masses:
    a) Core and windings: 6600kg.
    b) Tank fittings and accessories: 3000 kg.
    c) Oil : 3560kg
    d) Total mass: 13160 kg.
22. Approximate overall Dimensions (with radiators and other fittings):
    a) Length: 3100 mm
    b) Breadth: 2800 mm
    c) Height: 3100 mm.

List of fittings:

1. Inspection cover.
2. Rating and diagram plate.
3. Two earthing terminals.
4. Lifting Lugs.(with tank and top cover).
5. Drain valve 2.5" with plug- 2 no's
6. Filter valve 2.5" with plug.
7. Dehydrating Breather.
8. Oil level indicator.
9. Magnetic Oil Level Indicator
10. Conservator.
11. Oil temperature indicator
12. Winding temperature indicator
13. Air release plug.
14. Jacking lugs.
15. Rollers.
16. Skids.
17. Explosion vent.
18. Gas and oil actuated relay.
19. Marshelling Box

ANNEXURE II

Toposheet



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