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A COMPLETE STUDY OF MICRO-HYDRO POWER PLANTS

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Abstract: Hydropower plays a crucial role within the development of the country because it provides power at cheaper rate being perpetual and renewable sources of energy. In hydroelectric power station, the energy of water is employed for generating electricity. It is a well-known incontrovertible fact that the rain falling upon earth’s surface features a P.E. relative to oceans toward it flows. Most of the tiny hydro power plants are supported Run of River scheme, implying that they are doing not have any water storage capability. The power is generated only enough water is out there from the river. When the stream flow reduces below the planning flow value, the generation will reduce because the water doesn't flow through the intake structure into the turbine. Small hydro plants may stand alone system in isolated areas but could also be grid connected. The paper presents the study of potential selection of turbine and generator for micro hydro power plants.

IndexTerms **- Potential; Turbine; Generator; Control; Protection; hydropower**

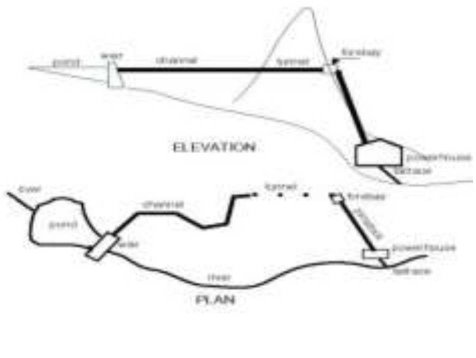
1. INTRODUCTION

Hydro power projects are classified as large and small hydro projects based on their sizes. Different countries have different size criteria to classify small hydro power project capacity ranging from 10MW to 50 MW. In India, hydro power plants of 25MW or below capacity are classified as small hydro, which have further been classified into micro (100kW or below), mini (101kW-2MW) and small hydro (2-25MW) segments. As of 31 March 2020, India's installed utility-scale hydroelectric capacity was 46,000 MW, or 12.3% of its total utility power generation capacity. Additional smaller hydroelectric power units with a total capacity of 4,683 MW (1.3% of its total utility power generation capacity) have been installed. During fiscal year 2020, the amount of hydro electricity generated across India was about 155 billion kilowatt hours. Being the third largest producer as well as consumer of electricity in the world, the country's national electric grid had an installed generation capacity of approximately 370 gigawatts.

India is extremely rich with hydropower potential and thought of together of the pioneering countries in establishing hydroelectric power plants. In terms of usable potential India stands fifth in world but only 19.9% has been developed or used for development. [1]

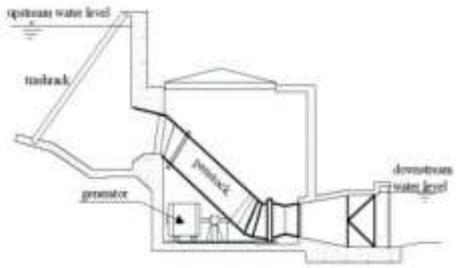
The large majority of small hydro plants are “run-of-river” schemes, meaning that they need no or relatively small water storage capability. The turbine only produces the target of a hydropower scheme is to convert the P.E. of a mass of water, flowing during a stream with a particular fall to the turbine (termed the "head"), into electric energy at the lower end of the scheme, where the powerhouse is found. The facility output from the scheme is proportional to the flow and to the top.

Schemes are generally classified according to the “Head”:-

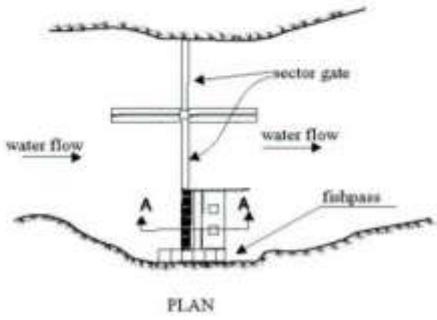


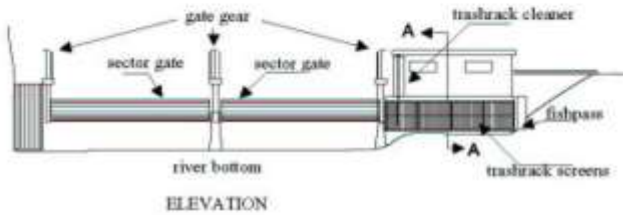
• Medium head: 30 - 100 m

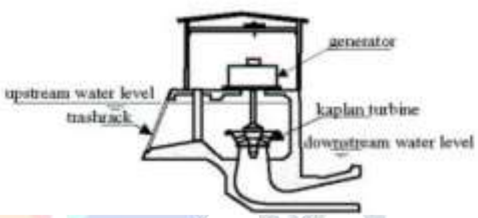
• High head: 100-m and above



Low head: 2 - 30 m







These ranges are not rigid but are merely means of categorizing sites.
Schemes can also be defined as:-
• Run-of-river schemes
• Schemes with the powerhouse located at the base of a dam
• Schemes integrated on a canal or in a water supply pipe power when the water is available and provided by the river.
Electricity production from hydropower has been, and still is today, the primary renewable source wont to generate electricity. In 2001, approximately 365 TWh of hydro energy was produced within the ecu Union from an overall capacity of 118 GW. Small hydro plants accounted for 8.4% of installed capacity (9.9 GW) and produced 39 TWh (about 11% of Hydropower generation). Given a more favorable regulatory environment, the ecu Commission objective of 22000 MW by 2020 should be achievable which small hydro would be the second largest contributor behind wind generation.
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- High efficiency (70-90%) by a wide margin the best of all the technologies of energy.
- High factor of capacity (specifically > 50%).
- High predictability level, fluctuating with annual patterns of rainfall.
- Slow rate of progress; the power of output fluctuates just steadily from day to day (but not from minute to minute).
- A good connection with demand i.e. there is maximum output in winter.
- It is robust and long-lasting technology; systems can promptly be designed to last for 50 years or even more than this.

2. SELECTION OF TURBINE

Type of turbine is selected from techno economic considerations of generating equipment, powerhouse cost and relative advantages of power generation. Head variation, load variations, efficiency, turbine setting and specific speed etc. play important role in selection of type of turbine with horizontal/vertical configuration.

S. No.	Type of Turbine	Specific Speed	Head Application (m) Min.	Max.
1	2	3	4	5
1.	**Impulse**			
i.	Pelton wheel	12-30	100	500
ii.	Turgo Impulse (inclined pelton)	20-70	40	200
iii.	Cross flow	20-100	1	200
2.	**Reaction (Francis, mixed flow)**	80-400		
i.	Francis horizontal, vertical		10	250
ii.	Francis open flume		2	25
3.	**Reaction (Axial flow)**	340-1000		
i.	Vertical fixed blade Propeller		2	25
ii.	Vertical adjustable blade and adjustable gates propeller (Kaplan)		16	40
iii.	Tubular with adjustable blades and adjustable gates (Horizontal Kaplan)		2	25
	Bulb (Horizontal Propeller)		2	25
iv.	Rim (Horizontal Propeller)			

3. CLASSIFICATION OF HYDROTURBINE

The selection of right type of turbine for a given site conditions is one of the most important aspect of any SHP development. The maximum annual conversion of energy at the lowest investment cost at utmost reliability is often the gospel criteria. The load requirement and its projected growth over a period of time also have to be taken into account for deciding the size and number of units in the case of decentralized power stations.[3]
Before considering the selection of turbine it is essential to know the various types of turbines available for SHP development.

Types of Turbines for SHP

- There are mainly two types of turbines:
- Impulse type (H= 300m to 1700m)
- Reaction type (H= (2 to 70) & (30 to 450))

•Impulse type

Impulse type of turbine work on energy conversion by impulse principle; i.e. a jet of water striking on peripherally located buckets on a runner wheel. They are open type and the runner is at atmospheric pressure. They are always installed above the maximum Tail Water Level (TWL). The Impulse turbines could be single jet, double jet or multi jet.

•The Impulse turbines are of 3 types:

- Pelton turbine.
- Turgo Impulse.
- Cross Flow turbine

•Reaction type

In the reaction type, the turbine works on energy conversion by change in pressure and kinetic energy throughout its path over the runner. These are encased turbines and are installed above or below maximum TWL as per site requirement. The reaction turbines are either mixed flow or axial flow types. The mixed flow reaction turbines are known as Francis turbines while axial flow turbines are further subdivided into Propeller, Semi-Kaplan & Kaplan type. The Axial Flow turbines can be conventional type with Spiral casing, tubular type or bulb type. The turbines could be horizontal, vertical and occasionally inclined axial as well.

4. Selection of Turbines

The selection of the type of turbine for a given head and capacity does not have a unique solution. Quite often, more than one solution is feasible which is clear from the turbine selection chart shown in Fig. 2. It requires considerable expertise to trade-off the merits and demerits and finally arrive at the best solution. However, following points should be carefully considered for the final choice.

•High & Medium Head Machines

Impulses type turbine is the ideal choice for high head schemes. Pelton turbine is the undisputed choice for standard machines having head beyond 200 meters. This is due to its simple construction features having flat operating characteristics, resulting in much better efficiency on part load operations

For head range between 20 m and 200 m one has an option of using pelton, turgo impulse or Francis machine. Turgo Impulse turbine has all the good features of a Pelton turbine and is more economical than Pelton due to its higher specific speed.

The basic difference between the Pelton and Turgo impulse type machine is that the jet of a Pelton Wheel strikes the splitter edge of the bucket bifurcates and discharges at either side. While in the Turgo impulse turbine, the jet is set at an angle with respect to the face of the runner ere in the paper.

The jet strikes the bucket on the front side; water passes through the curved passages and is discharged on the other site. The runner diameter to jet diameter ratio for Turgo impulse turbine is less than that of Pelton as the jet diameter is much larger, resulting in smaller size of the runner thereby increasing the speed of the machine. The specific speed of the Turgo Impulse type turbine is more than of the Pelton turbine. The simplicity of operation and easy maintenance are the common features of both the machines.

There is a tendency to go for high speed Francis turbine to achieve overall economy, but it is not preferred for Small Hydel sets wherever Turgo impulse turbine has an overlapping range. It is basically due to the fact that Francis turbine has complicated features like a number of guide vanes, stuffing box has fine clearance between the runner and wearing rings, fine clearance between the movable vane face and housings. The approach to the runner and inner areas of Francis turbine is also relatively difficult due to enclosed type of construction. The runner is accessible by opening a few bolts, as the casing is split- half type. The bearings are outside the casings and are easily accessible for maintenance. The stalling of the machine due to clogging of runner is also frequent because the passage between two adjacent vanes of the runner is small where boulders of less than 10mm size (trash rack size) can also be cough firm.

The peak efficiency of Francis turbine is higher than that of Turgo impulse type machine, but the efficiency of the Francis turbine is poor at part at part load operation, as compared to Turgo impulse. The efficiencies of various types of turbines are compared by the world renowned author Emil Mosonyi, in his famous book titled Water Power Development which may be referred for details.

A Francis turbine can seldom be operated below 50% - 40% of loads due to cavitations and noise problems where as Turgo Impulse or Pelton does not have such limitations.

The governing of a Francis turbine is more cumbersome due to speed and pressure rise problems whereas there are no such problems in Turgo Impulse where jet strikes the runner at atmospheric pressure. Francis turbines some times need a surge tank when the length of penstock to head ratio (L/H) is more than 5 whereas a Turgo Impulse or Pelton has no such requirement.

The governing of Turgo Impulse machine is much easier with a deflector governing system. The price of a Turgo impulse machine as compared to a Francis machine of equal rating is lower because of its simple construction. For remote hilly areas, the emphasis for selection should be more on easy maintenance of the machine, as it is difficult to get locally trained people. The load also varies frequently in the hilly areas. A machine, capable of running more efficiently at part loads will be a better choice. Though both types of machines are available, from the experience gained, it is suggested that Turgo impulse machine will be a much better choice for hilly regions.

Cross flows turbines are used normally for output upto 100 KW or more for the low and medium head range 3 m to 100 m. However, the efficiency of Cross Flow turbine is much lower than of other types which restrict its use in higher capacity machines.

•**Low Head Machine**

The type of machine to be adopted for low head application has been debated for quite a long time. In India it is mostly agreed at all levels that for runner dia upto 3 m horizontal tubular turbine is an ideal choice, due to easy maintenance and better efficency for low head installations. For runner dia above 3m Bulb type offers the most economic solution.

A standard range of tubular turbines, covering the head range from 2 meters to 25 meters and output range from 5kW to 8000kW is available in market. The turbine selection chart (Performance curve) for Tubular turbine is shown in Fig. 4

The tubular turbine is a slow speed machine and it may require a gear box for speed increase, in order to use a standard generator. The overall efficiency drop of 1 to 2% may be considered for the gear box.

There are four options available for tubular turbines, i.e. Kaplan, Semi-Kaplan, Propeller with adjustable guide vanes and Propeller type machines.

•**Kaplan Turbine**

This type of turbine is having adjustable runner blades and guide vanes. In order to accommodate the runner blades adjustable mechanism in the runner hub, the size of the runner should be large enough. The turbine is best suited where there is a wide variation in head and/or discharge and its efficiency over a wide range of partial loads is very good. Butterfly valve (BFV) for shut-off purpose is not required in this type of turbine, as the guide vanes themselves will close the turbine. Due to its complicated construction Kaplan turbine is not preferred for runner dia of less than 1000 mm. The cost of this type of turbine is quite high.

•Semi-Kaplan Turbine

This type of turbine is having fixed guide vanes and adjustable runner blades. The necessity of large dia-runners, usually above 1000 mm, to accommodate mechanism for adjustable runner blades remains the same as for Kaplan turbine. Butterfly valve is required for shut-off purpose. This type of turbine is less complicated than Kaplan turbine. The efficient range of operation is limited as compared to the Kaplan turbine. The cost of Butterfly valve is considerable with the result the overall cost of the machine sometimes may be as high as Kaplan turbine, which is more efficient over a wide range of operation than Semi-Kaplan turbine. This type of turbine may be considered for coupling with Induction generators with level controls.

•Siphone type turbine

Siphon type of turbine is having fixed guide vanes and movable runner blades. It works on the principle of siphon action for starting and stopping turbines. Regulation of turbine is achieved by Governor by controlling runner blade opening and closing. This type of arrangement does not require intake and draft tube gate. A vacuum for starting and stopping turbine.

•Propeller turbine with adjustable Guide Vanes

This type of turbine is having fixed runner blades and adjustable guide vanes. The efficient range of operation is limited to 80% to 120% variation in head and 75% to 115% variation in discharge. The discharge through the turbine and generator output can be controlled by regulating the guide vanes. The machine is relatively simple in construction and can easily by maintain. Butterfly valve is not required or shut-off purpose as the wicket gates themselves will close. The overall cost of the machine is much less than Kaplan and Semi-Kaplan turbines. This type of machine is more suitable for Micro Mini Hydel stations with capacity of machine from 50 kW to 1000 kW where runner dia is less than 1000 mm.

•Propeller Turbine with Fixed Guide Vanes

This type of machine is having mixed runner blades and fixed guide vanes. The efficiency of the turbine is extremely very low at part load operations. The machine is simpler in construction and very easy to maintain. Butterfly Valve or Sluice valve is required for shut-off purpose. Wherever there is no large fluctuation in head and discharge and for regions with small population this type of machine is suitable. The turbine is used for very low output of say 5 kW to 50 kW for a head range 2 m to 20 m.

•Governor

The governor is used to control the speed of TG set. For grid connected systems it is controlling the load on machine. Before selection or governor, it is essential to know the various types of governor. There are mainly two types of governors for SHP: Hydro Mechanical Governor and Electronic Governor

5. SELECTION OF GENERATOR

Generators are selected keeping the capital cost of the plant and the cost of Generation as paramount factors.

•Synchronous Generators

As the name suggests the Synchronous generator runs at Synchronous speed corresponding to the system frequency and number of poles of the machine. An Excitation system to give DC Excitation to the field is required for this type.

Synchronous Generators can operate independently or in parallel with similar other sets or with grid. Special synchronizing equipment are however required for synchronizing the generator. They are costlier than induction generators.

The Synchronous Generator has ability to supply reactive KVAR to the Grid and can therefore regulate the power factor. This is another important advantage of having a Synchronous Generators.

•Induction Generators

The Induction Generator operates only at super synchronous speed-a speed well above synchronous speed corresponding to the supply frequency. The generator voltage, frequency and speed are all dictated by the electrical system with which is connected. Hence AVR for the generator and speed governor for the turbine are both redundant. The synchronizing equipment is not required to synchronize the induction generator with the grid. The generator can be simply switched ON with the grid at the proper speed. The Induction generator draws its excitation current from the grid eliminating separate excitation equipment. However, this imposes additional burden on the grid to supply excitation current thereby causing stability problems unless the grid is at least 10 to 15 times stronger than the induction generator connected with it.

Another important point to be considered is compatibility of voltage dips of the grid with the pull out torque of the generator which should be substantially high of the order of well over 200 % - 225 %.

The generation voltage preferred is 415 v for decentralized power station upto 1000 KW and 3.3/6.6/11 KV for above 1000 KW for grid-connected power stations. The criteria are the overall economy of the entire electrical system consisting of the generator, switchgear, transformer, protection system etc.[4]

6. CONTROL & PROTECTION EQUIPMENT:

Excitation Control System:

The generator excitation control system is required to maintain the terminal voltage of generator with in operating range.

Before selection of the excitation system it is essential to know various types of excitation systems. There are mainly three types of excitation systems.

(1)Static Excitation system

(2)Brushless excitation with overhung Ac excitor along with rotating diodes.

(3)Self Excited &Self-Regulated System (SESR)

A. Static Excitation system:

It feeds directly DC current to field of generator for controlling the generator terminal voltage. For rectifying AC to DC voltage here we use thyristor based DC rectifier circuit. Power for excitation and feedback voltage is derived from generator terminals with the help of PTs and Excitation power transformer. This type of system can regulate the voltage in range of 10% of rated terminal voltage. By using this system, power factor of generator can be controlled easily by incorporating an Automatic Power Factor Regulator (APFR). Power factor control is essential for such type of SHP which are connected with grid. Static Excitation System is not having any moving parts therefore it is almost maintenance free.

B. Brushless Excitation System:

This type of system consists of an AC excitor along with a rotating diode bridge. The AC excitor field is controlled by automatic voltage regulator. Power and feedback for AVR is derived from generator terminals. The main excitor field is controlled by AC excitor. The AC excitor field is controlled by AVR. AVR can be interfaced with APDR & APFR is automatically.

C. Self-Excited & Self-Regulated Excitation System:

For small outputs upto 250KW self-excited and self-regulated (SESR) type excitation system employing CT and choke are also used mostly for decentralized power station in remote hilly areas. This type of excitation system is used for the generators which has slip rings and carbon brushes. In this case V/F is automatically maintained constant as it is an open loop system.

CONTROL PHILOSOPHY FOR SHP

The control scheme of SHP is depended upon the size of the SHP as well as the type of operation i.e. Automatic Operation or Manual operation whether Black start required or not. In control scheme there are starting sequence, normal stopping sequence, emergency stopping sequence etc. All SHP control panels are provided with the above facilities.

There are mainly three types of panels:

•Manually operated / semi-automatic

•Fully automatic

•Remotely operated

For category (i) relay logic is sufficient for operation of auxiliary system for starting and stopping of the machine. For categories (ii) & (iii) SCADA/PLC is also required along with relay logic. In fully automatic control system all the equipment are started automatically in a sequential manner after getting start command for the operator. All parameters such as Governor OPU pressures, cooling water flow, cooling water pressure, temperature of various equipment etc. are all taken care of by SCADA/ PLC.

SCADA/PLC is microprocessor based system operated on digital technology. It can sense digital, pulse, RTD, Analog, Thermocouple and other types of input. Similarly it can give digital, analog, pulse type of output signal. Hence we can provided maintenance schedule & layout of power plant with respect to mechanical & electrical operation.

In such type of SHPs Electronic Governor is required as interface of SCADA/PLC for fully automatic and remotely operated power house.[5]

PROTECTIVE DEVICES

In SHP the protective devices are used to prevent the TG set from various faults. The selection of devices depends upon the sizes of SHP. Some protective devices are given below:

- Over current & earth fault protective relay (51).
- Over voltage and under voltage relay (59) & (27)
- Negative phase sequence relay (46)
- Reverse Power relay (32)
- Generator differential relay (87G)
- Generator transformer differential relay (87 GT)
- Generator excitation failures relay (40)
- Over/under frequency relay (81)
- Frequency trend relay (df/dt)
- Stator earth fault relay (64)
- PT fuse failure relay.
- Over speed protection mechanical
- Over speed protection electrical.
- Cooling water flow protection (flow switch)
- Oil level protection (Float switch)
- Oil/ water pressure protection (pressure switch)
- Bearing, generator winding, OPUs temperature detection / protection (temperature scanner)
- Battery /battery charger protection such as U/V, O/V/ E/F, Diode failure etc.

All the above protective devices will give tripping command to master trip relay whenever fault occurs and accordingly as per control scheme TG set will be switched off. After attending the fault TG set can restarted.

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