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DESIGN OF SMALL HYDRO ELECTRIC PROJECT USING TAILRACE EXTENSION SCHEME

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ABSTRACT— *World's electricity consumption is constantly rising. At the same time energy production rate does not seem to be fit for following this trend of growth. Electrical energy, produced by hydropower plants, usually reaches up to 30 and more per cent of national primary production rate and represents one of the stable foundations of electrical energy systems. It might be that, due to the increase of the electricity tariff in the last years small hydroelectric power plants become cost effective. Outlet water from any power plant if the sufficient water quantity and gravity flow is available a small hydro plant is put to get additional power. Power generation by this method is known as tail race extension scheme. By using a tailrace extension scheme we utilize tail water available after generation of power to ensure maximum utilization of available water and also we can increase the capacity of the existing plant without using additional water. For this we have to design a new system with which maximum possible efficiency can be obtained.*

This paper deals with the aspects of tailrace extension scheme and also includes design aspects of a small hydro electric project using the same at Poringalkuthu power station. The design study showed that construction of small-hydroelectric project was feasible in the project site.

INDEX TERMS—TAILRACE EXTENSION SCHEME, KAPLAN TURBINE, GENERATOR DESIGN, SHEP

I.INTRODUCTION

Hydro-electric power is a form of renewable energy resource, which comes from the flowing water and to generate electricity, water must be in motion. When the water is falling by the force of gravity, its potential energy converts into kinetic energy. This kinetic energy of the flowing water turns blades or vanes in hydraulic turbines. The form of energy is changed to mechanical energy. The turbine operates the rotating part of generating unit which converts the mechanical energy into electrical energy [1]. Hydropower was the first renewable source which was used to generate electricity over 100 years ago. Today, hydropower is an important source of Producing electrical energy; approximately 20% of the world electricity is supplied by hydroelectric power plants [5].

Energy is one of the most fundamental elements of our universe. It is the base for survival and indispensable for development activities to promote education, health, transportation and infrastructure for attaining a reasonable standard of living and is also a critical factor for economic development and employment [2]. At the same time energy production rate does not seem to be fit for following this trend of growth. Electrical energy, produced by hydropower plants, usually reaches up to 30 and more per cent of national primary production rate and represents one of the stable foundations of electrical energy systems.

In Kerala, electricity is generated mainly in hydro-electric power plants. Hydropower projects produces no end products in form of waste like coal power plant, hence project will contribute in bringing the environmental sustainability around the nearby area of project site. But availability of water is a main factor in electricity generation. Load-shedding imposed in the State was partly due to poor rainfall and low supply from the Central grid. So maximum utilization of water is to be ensured.

This paper describes about electricity generation using tailrace extension scheme and also the aspects of tailrace extension. The new hydro electric power station is designed based on the available hydraulic energy at the tailrace of the existing plant at Poringalkuthu power station. Also small hydro electric power plants can generate power up to 10 MW. Small hydroelectric power plants are low cost, small sized. The design of small hydro-electric power plant is done by taking into account a lot of design considerations.

II. TAILRACE EXTENSION SCHEME

In Kerala the available water is not stored and utilized properly in the case of electricity generation. Kerala's power requirement is around 3800MW. But state generates only 2230MW. We get around 900MW from central pool. By 2020, the state's power requirement will increase to 6000MW. The state is heading for a severe power crisis, unless drastic steps were taken to keep pace with the development. Therefore the state needs more small-scale hydro-electric projects to augments power production.

Small hydro-electric power or SHEP is both an efficient and reliable form of clean source of renewable energy. Tailrace is nothing but the path through which water is pumped out of the hydro power plant after power generation. Outlet water from any power plant if the sufficient water quantity and gravity flow is available a small hydro plant is put to get additional power. Power generation by this method is known as tail race extension hydroelectric project. By using a tailrace extension scheme we utilize tail water available after generation of power to ensure maximum utilization of available water. Using this method we can increase the capacity of plant without using additional water. For this we have to design a new system.

This method has a minimal environmental impact on the local ecosystem. It is an alternative source of energy generation. So there is a scope for harnessing the micro-hydro-electric power plant potentiality by identifying proper site and designing appropriate power generation systems. The advantages of small -hydro-electric power plant are:

1. It can deal more economically with varying peak load demand
2. It is able to start-up quickly and make rapid adjustments in output power.
3. It does not cause pollution of air or water.
4. It has low failure rate, low operating cost and is reliable.

5. It has the efficiency as same as the large hydro electric plant.
6. It ensures Maximum utilization of available water.
7. This scheme Increases the total capacity of the plant without using additional water.
8. Load Demand can be met easily with the available water quantity.

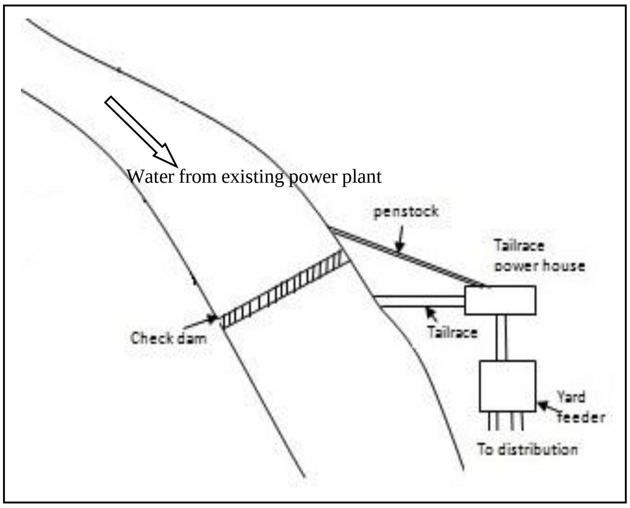

Figure 1. General layout of the new power plant

III.DESIGN CONSIDERATIONS AND CHALLENGES

Design, construction and operation of Hydropower plants are complex tasks. A large number of details must be carefully considered, coordinated and executed in order that the projects achieve safe and economical operation. Design is a concept with the application of science, technology and invention to the realization of a machine so as to satisfy required performance and characteristics. That is it's specifications with optimum economy and efficiency. The major considerations to evolve a good design are: (a). Cost (b) Durability (c). Compliance with performance criteria as laid down in specifications [4].In most of the situations it becomes difficult to design a machine which meets all the performance indices and also satisfies the cost and durability criteria because these requirements are usually conflicting. It is impossible to design a machine which is cheap and is also durable at the same time. This is because a machine which is to have a long life span must use high quality materials and advanced manufacturing techniques which obviously make it costly.

The design of small hydro-electric power plant is done by taking into account a lot of design considerations such as site survey, measuring of head and water flow rate, civil work components(eg: penstock), selection of hydraulic turbine type and dimensions and specifications of electrical power generator.

A. Head measurement:

The gross head (*Hg*) is the vertical distance between the water surface level at the intake and at the tailrace for the reaction turbines such as Francis and Kaplan turbines and the nozzle level for the impulse turbines such as Pelton, Turgo and cross-flow turbines. Once the gross head is known, the net head (Hn*)* can be computed by simply subtracting the losses along its path, such as open channel loss, trash rack loss, intake or inlet to penstock loss, gate or valve loss and penstock friction loss [1].

B. Flow rate measurement

To measure the water flow rate or discharge several methods are available. The velocity-area method is a conventional method for medium to large rivers, involving the measurement of the cross-sectional area of the river and the mean velocity of the water through it. It is a useful approach for determining the stream flow with a minimum effort. The river should have a uniform width and the area well defined [1][3].

C. Turbine Power output:

The turbine power output can be calculated by the equation given below [7]:

$$\text{Power output, } P=\eta.\rho.g.Q.H$$

Where η = hydraulic efficiency of the turbine; ρ = density of water (1000 kg/m^3); g = acceleration due to gravity (9.81 m/s^2); Q = volume flow rate passing through the turbine (m^3/s); H = effective pressure head of water across the turbine (m).

D .Tailrace:

After passing through the turbine, the water returns to the river through a short canal called tailrace. Impulse turbines can have relatively high exit velocities, so the tailrace should be designed to ensure that the power house would not be undermined. Protection with rock riprap or concrete aprons should be provided between the power house and the stream. The design should also ensure that during relatively high flows the water tailrace does not rise so far that it interferes with the turbine runner. With a reaction turbine the level of the water in the tailrace influences the operation of the turbine and more specifically the onset of cavitation. The level above the tailrace also determines the available net head and in low head systems may have a decisive influence on the economic results [6].

E. Gates and valves:

In low head schemes with integral intake and power house, the best way to increase the head without risking up stream flooding, is the sector gate. A hydraulic system or an electric motor opens the gate, so that the water passes underneath. In case of maintenance or repair, a gate is used to avoid the runways speed on a shut down turbine. A sliding gate of cast iron, steel, plastic or timbers is suited to the intake small and micro-hydro systems. The loss of head produced by the water flowing through an open valve or gate depends on the type and manufacture of the valve [3].

F. Penstock:

Penstocks or pipes are used to conveying water from the intake to the power house. They can be installed over or under the ground, depending on factors such as the nature of the ground itself, the penstock materials, the ambient temperature and the environmental requirements. The pipe should be rigid enough to be handled without danger of deformation in the field. The wall thickness of the penstock depends on the pipe materials, its tensile strength, pipe diameter and the operating pressure [1].

G. Rotational and run away speed:

The rotational speed of a turbine is a function of its power and net head. In the small and micro-hydro schemes, standard generators should be installed when possible, so in the turbine selection, it must be borne in mind that the turbine, either coupled directly or through a speed increaser or gear box to reach the synchronous speed. Each runner profile is characterized by a maximum runaway speed. This is the speed, which the unit can theoretically attain when the turbine power is at its maximum and the electrical load has become disconnected. Depending on the type of turbine, it can attain 2→3 times the nominal speed. The cost of generator and gear box may be increased when the runway speed is higher, since they must be designed to withstand it. [8].

H. Power house:

Due to the presence of large and heavy equipment units, the power house stability must completely secured. Settlements cannot be accepted in the power house. If the power house is founded on rock, the excavation work will eliminate the superficial weathered layer, leaving a sound rock foundation. If the power house is to be located on fluvial terraces near the river banks which do not offer a good foundation then the ground must be reconditioned. The equipments of the power house are turbine, electrical generator and drive systems [3].

I. Considerations at the site:

The main consideration at the site was to maintain the flow rate at the Athirapilly waterfalls. In figure. (1) The water supply to the new power station is from the check dam constructed. If water is stored for the proposed system by using the check dam, the waterfalls will vanish. So the water stored at the check dam should be released at a minimum rate per second to keep the waterfalls. Thus the design was done by considering the minimum flow rate of water which should be released per sec. properly designed SHEP's causes minimum environmental disruption to the river or stream and can coexist with the native ecology. Thus we designed SHEP to ensure the same.

Another challenge of the design was that the construction of the new check dam should not cause any adverse effect to the species resides there at the site. In order to overcome this challenge we designed the check dam with efficient storage capacity and don't cause any ill effect to the surrounding area and the surviving species. The head was also chosen in order to get the maximum efficiency for the proposed system. The design should also ensure that during relatively high flows the water tailrace does not rise so far that it interferes with the turbine runner.

IV.SELECTION OF TURBINE

1. General Guidelines:

The choice of the turbine type depending mainly on the site head and flow rate. The turbine power and speed were directly proportional with the site head, but there were specific points for maximum turbine power and speed with the variation of the site water flow rate. The head losses in the penstock could range from 5 to 10 percent of the gross head, depending on the length of the penstock, quantity of water flow rate and its velocity.

The turbine efficiency could range from 80 to 95 percent depending on the turbine type, and the generator efficiency about 90 percent. Once the turbine power, specific speed and net head are known, the turbine type, the turbine fundamental dimensions and the height or elevation above the tailrace water surface that the turbine should be installed to avoid cavitation phenomenon, can be calculated. In case of Kaplan or Francis turbine type, the head loss due to cavitation, the net head and the turbine power must be recalculated. In general, the Pelton turbines cover the high pressure domain down to 50 *m* for small-hydro. The Francis types of turbine cover the largest range of head below the Pelton turbine domain with some over-lapping and down to 10 *m* head for small-hydro. The lowest domain of head below 10 *m* is covered by Kaplan type of turbine with fixed or movable blades. For low heads and up to 50 *m*, also the cross-flow impulse turbine can be used. Once the turbine type is known, the fundamental dimensions of the turbine can be easily estimated. There are two basic modes of operation for hydro power turbines: Impulse and reaction. Impulse turbines are driven by a jet of water and they are suitable for high heads and low flow rates. Reaction turbines run filled with water and use both angular and linear momentum of the flowing water to run the rotor and they are used for medium and low heads and high flow rate. [3][6].Once the turbine type is known, the fundamental dimensions of the turbine can be easily estimated. With all turbines, a vertical or horizontal configuration is possible. The orientation becomes a function of the turbine selection and of the power plant structural and equipment costs for a specific layout. As an example, the Francis vertical unit will require a deeper excavation and higher power plant structure. A horizontal machine will increase the width of the power plant structure yet decrease the excavation and overall height of the unit. It becomes apparent that generator orientation and setting are governed by compatibility with turbine selection and an analysis of overall plant costs [10].

Head	**Turbine**	**Type**	**Efficiency**	**Output**
High	Pelton	Axial-Flow Impulse	90 %	Large
Medium	Francis	Inward-radial reaction	90 %	Large
Medium	Turbo-Impulse	Axial-Flow Impulse	90 %	Medium & Small
Low	Kaplan	Axial-Flow Reaction	85 %	Large

Table 1. Different heads and corresponding turbines [9]

2. Turbine specifications for the new SHEP:

According to the general guidelines and the above table, table1, we selected a full horizontal Kaplan turbine for the proposed system. The turbine is a axial reaction type with a net head of 7m. The power output obtained was 1.32MW with an economic efficiency of 85%. Rated rotational speed was calculated as 600rpm and that of runaway speed was $13.28S^{-1}$.

The design was properly carried out. The no. of runner blades for the new turbine is 4, no.of guide vanes are 24 and the runner is of 1.5m dia.

The turbine is designed by keeping a minimum water flow rate of 11.54m^3/sec which is the flow rate at Athirapilly waterfalls. Also, the maximum flow rate kept as 24.06m^3/sec. This quantity of water (24.06m^3/sec) is obtained from the tailrace of the existing power plant when two 8MW machines and one 16MW machine are operated. This quantity of water is constant.

V.SELECTION OF GENERATOR

a. General guidelines:

There are basically two types of alternating current generator: synchronous and asynchronous or induction generators. The choice of the type to be used depends on the characteristics of the grid to which the generator will be connected and also on the generator's operational requirements. Synchronous generators are used in the case of standalone schemes isolated networks.

In case of weak grids where the unit may have significant influence on the network synchronous generator are used. For grid connected schemes both types of generator can be used. In case grid is weak; Induction generators be used if there are two units, one of the unit can be synchronous so that in case of grid failure; supply could still be maintained. Unit size is limited to 250 kW. In case of stronger grids induction generators up to a 2001 kW or even higher can be used. In case of isolated units, small capacity Induction generators with variable capacitor bank may be used up to a capacity of about 20 kW especially if there is no or insignificant Induction motor load i.e. less than about 20%. Before making a decision on the type of generator to be used, it is important to take the following points into consideration:

- A synchronous generator can regulate the grid voltage and supply reactive power to the network. It can therefore be connected to any type of network.
- An induction generator has a simpler operation, requiring only the use of a tachometer to couple it to the grid as the machine is coupled to the grid there is a transient voltage drop, and once coupled to the grid the generator absorbs reactive power from it. Where the power factor needs to be improved, a capacitor bank will be necessary. The efficiency of an asynchronous generator is generally lower than that of a synchronous one [10].

The hydraulic turbines should determine the turbine speed for maximum efficiency corresponding to an even number of generator poles. Generator dimensions and weights vary inversely with the speed. For a fixed value of power a decrease in speed will increase the physical size and cost of generators. Low head turbine can be connected either directly to the generator or through to a speed increaser. 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. 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 3 MW capacities [9][10].

KVA and power factor is fixed by consideration of 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 involve.

b. Generator specifications for the new SHEP:

According to the rules, the generator for the proposed system was selected and designed for the maximum possible efficiency. Salient poles synchronous generators are recommended being more stable for grid connected SHEP. Generator terminal voltage should be as high as economically feasible. So, the generator is designed with a terminal voltage of 3.3KV.The power factor is taken as 0.9lag. The frequency is normally 50Hz in India. As the speed of the generator is 600rpm, the no. of poles is obtained as 10 from the equation,

$$N_s = 120f/P$$

Where, N_s is the synchronous speed in rpm; f is the frequency in Hz; P is the no. of poles.

VI.CONCLUSION

Designing of a generator and turbine using this scheme aims at the maximum utilization of the water than wasting it or allow it to flow free to the sea. A full horizontal Kaplan turbine is selected for the small hydro electric power plant with a speed of 600rpm. A horizontal machine will increase the width of the power plant structure yet decrease the excavation and overall height of the unit. The turbine is designed by keeping a minimum water flow rate of $11.54m^3$/sec which is the flow rate at Athirapilly waterfalls. The no. of runner blades is 4 and that of guide vanes is 24. The hub and the runner were designed with an economic efficiency of 85%. The head is 7m.

The generator for the proposed system was selected and designed for the maximum possible efficiency. Salient poles synchronous generators are recommended being more stable for grid connected SHEP. Generator terminal voltage should be as high as economically feasible. So, the generator is designed with a terminal voltage of 3.3KV.The power factor is taken as 0.9lag.

It is concluded that there is a big scope to develop a machine having smaller power rating. The developing design can overcome the load shedding problem especially in the non- monsoon period. Hence the capacity of the power station increase and thus the efficiency increases. For a small hydro power plant, the space of the hub is little and it is enough to fit a proper mechanism with which to adjust the blades.

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