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Design Consideration and Selection of Hydro Power Plant Turbine

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ABSTRACT

The harnessing of energy available in falling water to provide mechanical power has been one of man's greatest achievements which require considerable care and attention in planning. There are many key factors on which hydro turbine selection depends such as specific speed, head, power output and discharge available. On the basis of these criteria and further analysis, specific turbine for hydro power plant is selected using hill chart and standardized data.

Keywords:— *Hydro Power Plant (HPP), Small Hydro Plant (SHP), Specific speed, Power output.*

I. INTRODUCTION

Development of Hydro energy is one of the important researches as a sustainable renewable energy. The globally accepted classification for hydro is in terms of power output varying from country to country. Also since there are many types of hydro power plant (HPP) schemes which make its wide spectrum of application for power generation. Huge opportunity of growth and the efficient utilization is present in this sector. The biggest advantage of hydro power is that it is the only green & clean power which is renewable source of energy available round the clock. Hydro power contributes numerous economic benefits like low running cost and short gestation period enabling quicker returns on development. To obtain optimum power from HPP depends upon correct selection of turbine [1] in order to minimize problems related to construction, operation and its management [2]. Key areas for technical development include low head turbine designs and application of optimization techniques. Low head turbine designs are essential to extend its application for small hydro technology. Along with this optimization technique is applied for hydro power turbine development in various areas like Draft tube optimization, efficiency of runner, blade profile optimization. Technology simplification of existing small turbine designs would be valuable for its stand-alone use by applying management techniques considering the investment involved and generation cost with respect to thermal power plant [3].

II. SITE SELECTION & SYSTEM COMPONENTS

The best site will usually be the one that has the best cost-benefit ratio (the least cost per kWh of electricity produced). In selecting the best site several factors are to be considered like availability of water, site access, topography of the site, elevation (potential static head), distance from turbine, catchment area and volume of water required for the turbine operation. Since the power output of a hydro power plant is proportional to the product of the head and flow rate, the relative frequency that various head flow combinations occur must be considered in selecting the generating capacity to be installed at a particular site. Classification of hydro plants based on different site as per systems of water usage is given below:

i. River power plants, where the head is created by weirs or dams,

ii. Diversion schemes that basically utilize naturally available heads,

iii. Run of river plants with little or no control of discharge and

iv. Storage power plants with high dam and large reservoir for flow regulation.

A large variety of hydropower configurations is possible because each site is different. There are however certain components that are common in most projects. The construction of a hydropower unit essentially consists of water intake, penstock that leads the water to the turbine, control system, turbine and generator to convert the mechanical energy into electrical energy. Switchgear and relays to protect the generators from electrical faults. Generally plants have transformers to increase the generator voltage to match the transmission line voltage which is usually higher. The hydropower system also includes civil works like dams, weirs, canals etc.

III. Design Considerations

Each hydropower site has unique characteristics. Thus each hydroelectric project and powerhouse design is different and it must be tailored as per unique characteristics of the site requirements. Hydropower design covers many disciplines of engineering. Broadly these are mechanical, electrical, civil, environmental, scheduling, planning etc. Mechanical aspects involve selecting turbines, designing and manufacturing. This paper will discuss the mechanical aspects of hydraulic turbines design. Turbine selection and design is based on the potential energy of water available at a certain height which is converted into mechanical energy by using a turbine and generator. The falling water hits or exerts a pressure on the blades of the turbine. The power available is proportional to the head and the rate of discharge of the water.

$$P = \rho \times g \times Q \times H$$

$$P_{11} = P / D^2 \times \sqrt[3]{H}$$

$$N_{11} = N \times D / \sqrt{H}$$

$$Q_{11} = Q / D^2 \times \sqrt{H}$$

Where,
P = power available (kW)
N_{11}= Unit speed
N= Rotational speed
η = hydropower system efficiency
P_{11}= Unit Power
H = head of the water (m), &
Q = flow of the water (m^3/s)

For a given turbine size, the flow will actually be faster if the head is larger. In practice, water heads are used from less than one meter to several hundred meters ranging from small to large turbines. With low heads obviously a large flow must be available to get a substantial amount of power. However with high head even low flow will work. The capacity of small hydropower plants can vary between a few kW to MW. Capacity of hydropower unit depends on local geographic, climatologically conditions and the characteristics of the demand for power. Accordingly it determines the type of construction, machinery required and investments. Hydropower generation is highly site specific. This implies that proper attention must be given to site selection and local surveys. For big hydro schemes it would require elaborate feasibility studies that have to be done by specialized consultants. For small hydro units simple survey methods can be adequate.

Selection of Turbines

Turbine forms the heart of the hydroelectric project. Various types of turbines are available as per design consideration and site location. They can be of the reaction types like the Francis turbine and the Kaplan turbines where the turbine is completely submerged in the water or of the impulse type like the Pelton turbine where a jet of water hits the turbine blades. The cross flow turbine that is used for mini and micro units has the characteristics of both the types. Selecting the type, kind, configuration, size, and number of turbine units that best suit a project is dependent on design consideration and site location. A chart giving the operating range of different types of turbine as per availability of head, power output and discharge is elaborated in below (figure 1).

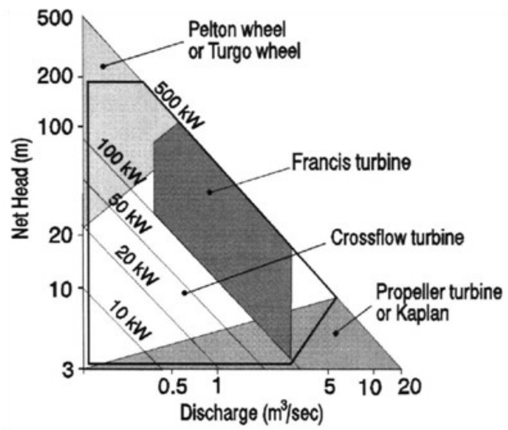

Figure 1: Operating range of turbines [4].

There can be different criteria for classifying hydro turbines like operating head, specific speed of turbine, type of flow and desired output. Commonly followed method for selection is based on a characteristic number known as Specific Speed. It is defined by equation:

$N_s = (N (\sqrt{P}/ (H))^{5/4}$

Where,
N_s = Specific Speed
P = Power, kW
Q = Flow, m3/s
N = Speed, rpm
H = Net Head, m

The specific speed value defines the approximate range of application for a specific turbine type. It also provides a means of comparing all types of turbines. The typical range of specific speeds is given below and shown in the figure 2.

Pelton turbines $N_s < 30$
Francis turbines $N_s = 35$ to 400
Axial flow $N_s > 100$

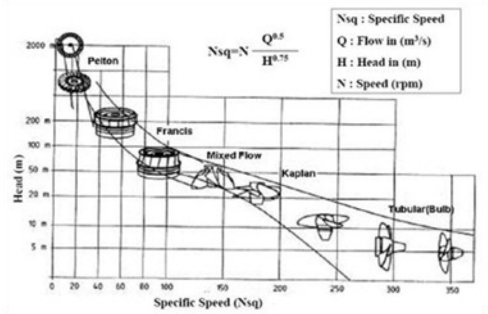

Figure 2: Range of specific speeds for turbines.

The consequences of selecting specific speed are efficiency, unit setting, runaway speed, machine size, weight and price. Once the turbine type is selected on basis of the specific speed the performance characteristics are determined from the models test data using the laws of similitude. The performance characteristics of a full-scale turbine can be predicted from the results of tests performed on a homologous scale model in the laboratory. Homologous turbines are geometrically similar turbines that have similar velocity vector diagrams and have geometrically similar streamlines. From a series of such tests, manufacturers develop a line of turbines that cover full range of specific speed in increments of design variations. These incremental design variations are chosen to provide an overlapping of performance so that nearly all combinations of head, flow and power required as per . Efficiency and flow as a function of hespecification can be accommodated exactly or with minimal deviation from homology. Prototype tests, model tests and computer analysis coupled with experimental test determines the turbine performance characteristicsad and operating speed are typically summarized on a turbine performance hill curve, similar to the one shown in the below figure 3.

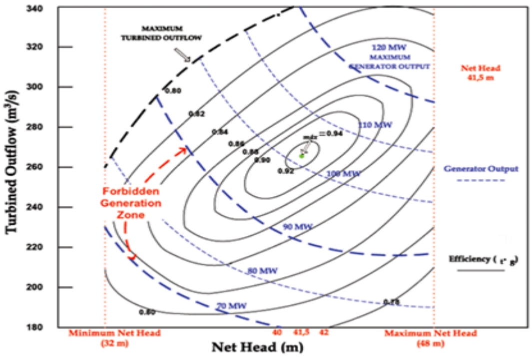

Figure 3: A typical Hill curve [5].

The rotational speed of the turbine is constant across the head range. Within the performance range of the turbine limits of operation exist. Based on the above studies a model is selected to suit the best efficiency operating point and the parameters of prototype turbine such as size, efficiencies, gate openings, safe operating range, runaway speed etc are determined. This is followed by the mechanical design of the prototype turbine based on the hydraulic design of the model. It involves the design of the turbine components like casing, runner, stay ring, guide vanes and its operating mechanism, head cover, discharge ring, draft tube, shaft, shaft seal and bearings. Design is further optimized based on the considerations using sophisticated software and computer programs. A three dimensional simulated cross section diagram of a hydraulic turbine is given in figure 4.

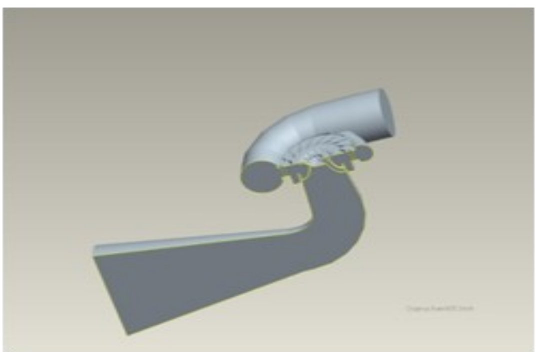

Figure 4: 3-D model of assembled Horizontal Francis Turbine [6].

IV. Conclusions

In order to develop an energy system which is economical, non-polluting, inflation free and environment friendly, great emphasis is placed throughout the world on quick development of micro, mini and small hydropower resources. Small and mini hydel potential can provide a solution for the energy problems in remote and hilly areas where the extension of grid system is comparatively uneconomical. Though the technologies for use in small scale hydro schemes are well established, improvements are possible to extend the range of the existing small hydro technologies notably to develop new low head turbines involving use new construction materials and to develop lower cost packaged systems. The standardization of products for low head turbines are also key areas for further technical development. Initiatives are needed in training, technical and non-technical areas to maintain competitiveness and maintain best practice within the industry.

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