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Dimensional Analysis for Determining Optimal Discharge and Penstock Diameter in Reaction Turbines: An Overview

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Abstract: The objective is to conduct a literature review to provide general insights for minimize the consumption of water while producing hydro electric power. The analysis presented in paper is based on the penstocks geometric and hydraulic characteristics, hydraulic head, and the desired power production. Minimizing water consumption for energy production may affect the availability of water for other purposes such as irrigation and navigation. Various dimensionless relationships between power production, flow discharge, and head losses were derived by authors. As mentioned in this analysis it was found that for minimizing water consumption, the ratio of head loss to gross head should remained not more than 15%. An example on reaction turbine of application is presented for determining optimal flow discharge and optimal penstock diameter for reaction turbine.

Keywords: Hydropower, penstock, optimal flow, gross head, dimensional analysis, gross head, turbine.

I. INTRODUCTION

Hydro electric powers projects are part of a multipurpose water resources development project. They help to support other important functions of the project. Hydropower achieves the benefits that rarely seen in other sources of energy. In fact, dams built not only for hydropower schemes, but also their associated reservoirs, provide human well-being benefits, such as securing water supply, flood control and irrigation for food production, and improved navigation. Hydropower can provide flexibility and reliability for energy production in integrated energy systems. The storage capability of hydropower systems plays a larger role in providing electric power of profitable quality.

Minimum water consumption while producing hydropower overuse of flows for energy production which results in shortage of flows for other purposes like irrigation or navigation. The present work was has to be improve when the author failed to get in literature a theoretical framework for the design of water turbines. Another author in 2011 provided a theory for determining the upper limit for hydropower gained by a turbine per unit width in an open rectangular channel. This is somehow different for both the turbine i.e. impulse and reaction turbines. The flow in the penstock is pressurized.

This paper is parted as dimensionless relationships between power production, flow discharge, and head losses. On another hand, these relationships are used to get general views on determining optimal flow discharge and optimal penstock diameter. At last, an example of application when designing impulse turbines is presented. The conclusion has summarized key results in the end of the paper.

II. LITERATURE REVIEW

A. Ling Zhu et al. 2014 [1] carried the derivation of various dimensionless relationships between power production, flow discharge and head losses which were used to get general insights on determining optimal flow discharge and optimal penstock diameter. It resulting that, for minimizing water consumption, the ratio of head loss to gross head should remained not more than 15%.

B. Arun Kumar et al. 2015 [4] previously available formulae for penstock design are being compared to review their suitability. He introduces a new method for optimum design of penstock based on minimizing the total head loss having friction losses and other losses. For few hydro electric power plant of varying capacity have results in reduction in annual cost as compared to other hydro power projects.

C. Singhal M. K. et al. 2015 [4] considering total head loss, friction losses all these have been formulated using Darcy Weisbach formula. These developed relations have been used for different 21 hydro electric power projects with varying capacity ranging from 25 kW to 60 MW to calculate optimum diameter. As determined from this new method, though the penstock diameter increased in the range, it resulted in the net saving in cost of earlier penstock cost which justifies the applicability of this new method for optimum design of penstock for hydro electric power projects.

D. MESA ASSOCIATES, INC Chittangaon, Tamilnadu et al. 2011 [2] gave and present the best practice for penstocks, tunnels, and surge tank. Explaining how innovations are there in technology, proper condition assessments, and improvements in operation and maintenance practices can contribute to maximizing overall plant performance and reliability. Author explained that the internal surface roughness of penstocks contributes to head loss and can be reduced to yield an increase in efficiency. Penstocks flows water from the intake to the generator and gives head loss to the system through hydraulic friction and geometric changes in the water flow such as bends, contractions, and expansions.

E. A. S. Leon at al. 2014 [1] author represents the dimensional analysis for determining optimal flow discharge and optimal penstock diameter in designing water turbines for hydro power projects. The aim was to provide general perception for minimizing water consumption while producing hydro electric power. It was found that for minimizing water consumption, the ration of head loss to gross head should remain below 15%.

F. Fatma Ayancik, Umut Aradag et al. 2013 [3] a collaborative design methodology is developed for the design and manufacturing of hydro turbine runners. The design of runner blade to get the desired head and efficiency depends on the correction of runner shape with trial-error, in-house MATLAB codes. The efficiency for the designed runner at the Best Efficiency Point is 92% while the hydraulic performance of turbine depends on the shape of the different parts. Runner geometry is complicated than the other part of turbine. To get accurate result and to reach hydraulic expectation, CFD analysis and advanced manufacturing tools are must needed.

G. Moko Antony et al. 2015 [6] author conducts a literature review about the specifications and design parameters required to design a penstock. After review of the field data that required for designing the component were derived from KENGEN SAGANA HYDRO POWER STATION because of poor performance of the existing penstock at the plant. The total head losses resulting from the ductile iron as the penstock material were calculated and its subsequent efficiency determined then compared to that of steel penstock and uPVC, it was noted that ductile iron is not as efficient as both steel and uPVC material. At this optimum penstock, power is noted a very reasonable increase and considering a new material has been used with more efficiency than initial, it's worth the cost. From head loss and the flow rate, available power could be estimated. Difference between the estimates produced by the two different friction head loss correlations were shown as a result of the differing sensitivity of each correlation to flow velocity.

H. Dipesh Thapa at al. 2016 [7] author observed that the loss coefficient for bifurcation has reduced. In long term this will added in the overall plant performance. Furthermore, with the help of Finite Element Analysis it is sure about the performance of the designed structure. The weak parts are identified during the design and change had made to make it acceptable. One of these areas is the design optimization of penstock manifold and bifurcation. With the proper design of penstock bifurcation, the head loss inducing in the mixed flow condition can minimised the outputs from both the units can be maximized. The flow and head loss were reviewed and the multiple arrangement were revised successively to achieve acceptable geometry.

I. Rishiraj P. Moni, Bijimol Joseph et al. 2018 [8] designed a sample anchor block and penstock pipe at several locations at different heads by analysing them, taking into consideration the water hammer effect. Design was done for Thottiyar hydroelectric project, Idukki district by providing minimum dimensions as per IS code but this failed the stability criteria. Increases in dimensions made the anchor block satisfy the stability criteria. The penstock design was done and proportional increase in thickness from upstream to downstream ranging from 12mm to 42mm respectively.

J. Peter F. Pelz et al. 2011 [2] on the basis of the energy equation author proved that the harvesting factor for a rectangular channel has the upper limit of one-half. Even for an ideal machine, one-half of in-hand hydraulic energy remains unused that washed down the tail water. Two independent dimensionless products that describe the tail water flow those are the dimensionless water depth or Froude number and dimensionless flow rate. The optimal tail water flow is critical, and the optimal flow rate is a function of the effective water depth.

K. Urmila Zope et al. 2014 [5] author gives a review on design of micro hydropower turbines by explaining the importance and necessity of such small scale projects. Utilizing of energy from falling water, such as a waterfall. Hydro power plant scheme are classified as Pico, micro, mini & small scale hydropower having power generation capacity of less 5kW, 100kW, 1000kW, and 6000kW respectively, focusing on review of different designs of micro hydro turbines. Also advanced technologies like Matlab used for analysis and design of the turbine parts by providing the finalized data to manufacture. Economy of turbine is explained and discusses review of work performed on generation of hydroelectric power by using various water turbines including already existing and also newly designed turbine.

III. CONCLUSION

Analysis is based on the geometric component and hydraulic characteristics of the penstock. The total hydraulic head and the desired power production are also dependent on the characteristics of penstock. This analysis resulted in various dimensionless relationships between power production, flow discharge, and head losses.

It was found that for minimizing water consumption, the ratio of head loss to gross head should maintained about 15%. Calculating diameter for given discharge and power, leads to the optimum parameters for penstock of turbine.

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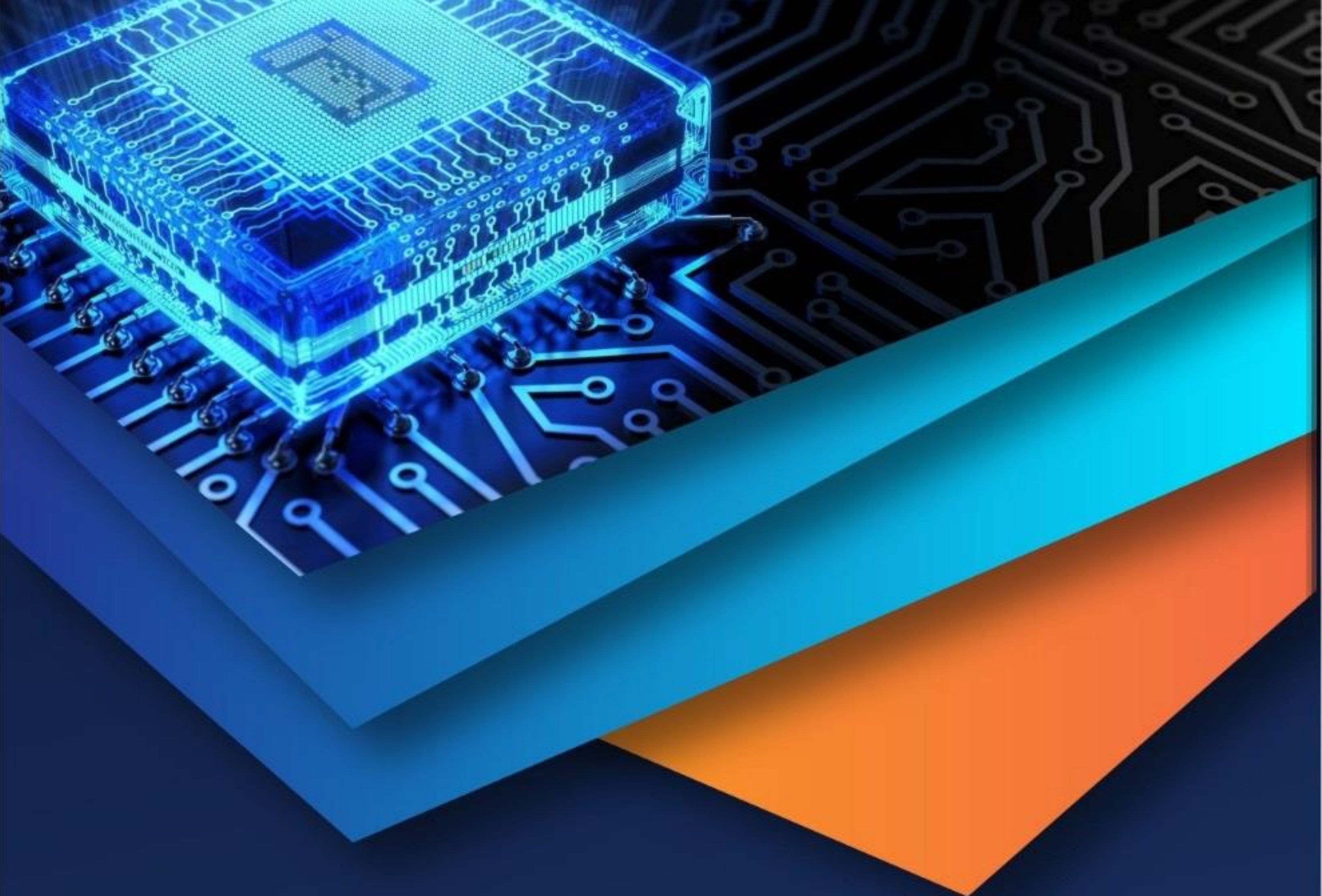

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