International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Thermodynamics Performance Analysis of Hydropower Turbine

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Abstract
The rate of water consumption is considered as the turbine flow discharge that generates kWh of electricity. It is also considered an essential method for enhancing hydropower efficiency and capacity. IEC 60041 has proposed a method for measuring the turbine flow on the basis of the thermodynamics method. In this study, thermodynamic methods have been adopted for measuring the absolute flow discharge and rate of water consumption in a hydropower unit. Winter-Kennedy coefficient has been used for measuring the water consumption rate of the turbine. Results that have been obtained from this study could be used for optimizing the economical operation of different units.
The rate of water consumption in the hydropower units can be used for evaluating economic operations for these electrical substations. The hill chart curve of a turbine could be calculated and converted with the help of a model test. This will help in developing certain limitations to the system’s functionality.

Keywords: Hydropower, technology, turbine, thermodynamic, Hydroelectricity, efficiency measurement, Discharge

Introduction

Turbine efficiency is considered as one of the critical factors in the hydropower plants that measure the efficiency of a turbine for understanding the capability of that turbine. The method of thermodynamics is effective methods in which the spiral case inlet and draft tube outlet are calculated based on the first law of thermodynamics (Yu *et al*., 2022). This study focuses on the measurement of turbine efficiency for providing a solution to the absolute flow of turbines in hydropower plants. In the context of actual operation, energy delivered per unit of mass to the shaft of a turbine could be determined by the measurement of performance variables such as temperature, pressure, level, and velocity.

Power is essential for the development of a nation that is the most important tool needed for the country's economic growth. Hydropower technology is considered to be an attractive source that removes the pollution source that is associated with the burning of fuels. The concept of implementing hydropower technology is to use water sources as a primary form of energy generation. Hydropower plants capture the energy of moving water in order to generate electricity. The turbine present in the system converts the kinetic energy of water into electrical energy. Afterward, a generator converts mechanical energy into the form of electrical energy. By using firewood and fossils, hydropower energy could enhance electricity consumption in a better and cost-efficient method. The term hydropower refers to the generation of power shafting from the falling of water through a certain height. This generated power through the movement of the turbine is used for mechanical purposes and plays a significant role in the production of electricity. It is the most established renewable source of energy for getting positive results in commercial investment. However, this technology has a high significance in the current time and constitutes a cost-effective method for the development of rural regions. Renewable energy consumption is increasing due to pollution and other factors that ensure power generation within an industry. In a hydroelectric plant, there are four major components involved in the generation of energy. These components for generating power with hydropower plants consist of Dam, Turbine, Generator, and Transmission Lines. The efficiency of the turbine is measured at the beginning of the operation at regular intervals of time which includes various types of tests for the generation of electricity. The thermodynamic method is the direct and absolute way to measure the efficiency of a hydraulic turbine. This method uses the principle of conservation of energy which is the first law of thermodynamics applied for its operation. In this study, the thermodynamic performance of the hydro-turbine is analyzed for understanding better efficiency in the generation of electricity.

Literature Review

Application of Turbine in Thermodynamic Method

The efficiency measurement of the turbine uses field testing with various techniques that are used for the generation of electricity on the basis of head discharge measurement. This requires the assumption to evaluate the efficiency of the turbine and possess greater efficiency with the thermodynamic method. The thermodynamic method provides overall positive results regarding this operation and gives practical techniques for electricity production (Bagherian and Mehranzamir, 2020). It also consists of the hydrogenating unit that converts water potential into mechanical energy by the help of rotation of the shaft and turbine. Furthermore, it gets converted into electrical energy with the help of a generator. Turbines are mainly classified into two levels through the action of water on the rotating blades. The impulse and reaction turbines are majorly used in the practice of generating electricity. In the case of these turbines, different technical approaches are taken for successful operation. Water comes out from the nozzle and puts pressure on the surface, leading to hydraulic function (Tarodiyan et al. 2022). Cross turbines and Pelton turbines are considered in this category that emerges water in the form of free jets and sprinkles. Furthermore, water pressure puts a huge force on the runner blade faces those leads to a decrease in the speed of the turbine, which is considered the reaction turbine. This turbine testing operates with the running of submerged water with the help of the thermodynamic method. Its basic principle for the thermodynamic method is the conservation of energy which is also known as the first law of thermodynamics for finding the efficiency of the turbine (Jian and Qiuru, 2020). This refers to the method for evaluating the relationship between the energy trader and the flow of water through a certain height. However, sometimes it leads to hydraulic loss with the increase in temperature. The measurement value is calculated with the application of specific heat of the water. This gives significance to the effect measurement of the thermodynamic method that causes the heating of water in the specific unit. The efficiency of the turbine is the output and input ratio that supply the hydraulic power to the shaft of the turbine. It comprises the pressure, temperature, and speed measurement with the help of a thermodynamic process. The calculation of the efficiency of the turbine is obtained after the continuous operation with the use of the thermodynamic method. This testing also compares the efficiency of the current of the turbine with the opening and closing parameters.

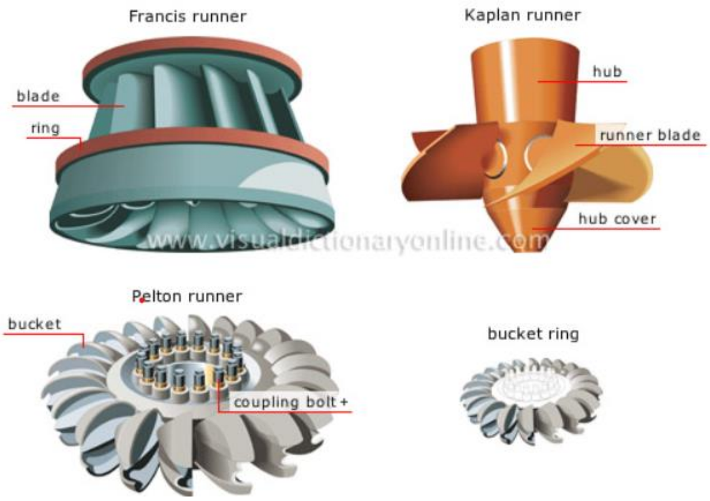

Figure 1: Various types of hydropower turbines
(Source: Jian and Qiuru, 2020)

Working of a Hydroelectricity turbine

The efficiency measurement for generation of Hydroelectricity uses the direct method in which water passes directly into different components of vessels without expansion. The sampling devices used for the measurement of efficiency are evaluated with unique sizes and with high pressure. This also uses the thermometer for each sampling in order to detect the sensing element during the water flow. It uses a transmitter for the measurement of static pressure at the turbine surface. Data acquisition systems are used to check the process of outputs of the sensor in the turbine. This thermodynamic measurement is efficient for Pelton turbines for the purpose of Hydroelectricity. Hydro turbines are used in electric generation that transfers the energy from moving flowing water to the shaft (Karre *et al.* 2022). This is the process of generation of electricity in which turbines are rotated to get the response according to the blade's action. The construction of the turbine is same; still, it differs from the working action alongside different sources of electricity.

A conventional dam is capable of holding water in a reservoir or a lake that is suitable for water collection during the working of a hydropower turbine. This water, when released from the dam, helps in spinning a turbine for the generation of electricity. This water then gets returned to the river through the downside of the dam. A pumped storage plant primarily uses two different reservoirs that have a higher elevation for producing power (Zakeri *et al*., 2022). The water gets released from the high reservoir into the tunnel for driving generators to the underground plant. These plants capture the energy of moving water for the purpose of generating electricity and converting it into mechanical energy. Afterward, a generator converts mechanical energy into electrical energy, thereby producing electricity at a larger scale. A hydroelectric plant primarily consists of four major components that help to develop the plant step-by-step. The first component is the Dam that raises the level of water in the river for creating falling water. This also controls the water flow and stores the energy formed into a reservoir. The second component is a turbine that rotates due to the force of falling water, thereby generating energy like a windmill.

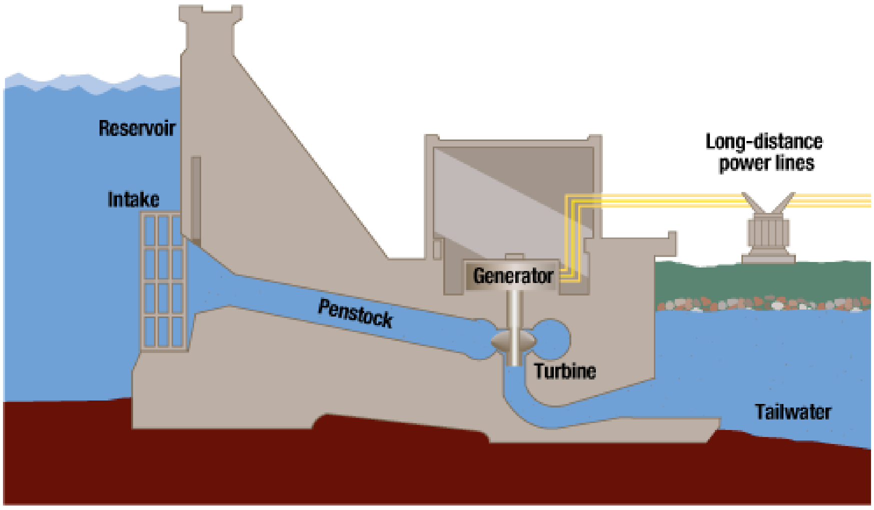

Figure 2: Conventional dam system
(Source: Tva.com. 2023)

This turbine helps to convert kinetic energy into mechanical energy, which later gets converted into electrical energy. The third component is a generator that gets connected to the turbine with the help of connecting shafts. A generator is responsible for converting mechanical energy into electrical energy, and this works similarly to other generators used in the operation of power plants. The final component is the transmission lines that conduct electricity from the plants to different businesses and residential areas. In this study, the Winter-Kennedy method has been used for estimating the relative flow rate by using pressure located at the radial section of the spiral casing (Tva.com. 2023). In the present time, there is a significant growth of renewable energy sources such as water, solar, and wind. Integration of electricity that is generated from these sources results in the grid fluctuations of the hydraulic turbines that help to balance the grid and undergoes the events of the hydraulic transient.

Methodology

This research paper uses a structured methodology for managing complex data and has also implemented the working process of a hydropower turbine for electricity generation. This method is done for the implication of the thermodynamic method in the research. The paper also uses the idea of positivism philosophy that is used to adhere to the knowledge from observation. It gives the overall performance of the turbine with the use of the thermodynamic method (Ahmadi *et al.* 2019). The qualitative approach is used in this research paper for the data collection and analyzing its various aspects. It gives the measurement value for evaluating the performance of a hydro turbine. The descriptive research design focuses on the information that describes the situation and condition of an issue such as fluctuations in temperature and pressure measurement. This is to give a sight on the various uses of turbines for the generation of electricity. Secondary resources used in this research paper are collected from Google Scholar, ProQuest, and so on. This research paper also uses the data processing method for the measurement of data and calculates the measurement of efficiency. It provides the use of modern technology for the immediate control and reading of accuracy. This study used a probability sampling technique for choosing smaller samples from a large dataset based on the probability theory. This is for highlighting the thermodynamic method's effect on the performance of the turbine. Data analysis has been done in this study to understand the technical aspects of a hydropower turbine and to implement the working of a hydropower turbine in electricity generation. The measurement of various parameters such as pressure, temperature, and others provide a distinct vision to find out the understanding level of the research.

Finding and Discussion

Outcomes of efficiency measurement through the thermodynamic method

It has been found that the sets of measurements for designing the power output and obtaining the maximum capacity highlights the importance of the thermodynamic methods in this research. These measurement sets are about 20%, 40%, 60%, 80%, and 100% with the repetition of thermodynamic efficiency. The highest output generated regarding hydraulic efficiency covers the whole range of power output from the turbine. The efficiency of the turbine increases with rage in turbine power by a significant amount. Furthermore, the increase in power declined the efficiency in which the maximum efficiency has been found to be around 92.13% which obtained the power rating of 47.76 megawatts (Iris, Ç. and Lam, J.S.L., 2019). This value does not increase for a further time due to variations in the temperature of the generator. The resulting efficiency gives a value around 4% lower than the other efficiency at the same level. The causes of lowering the value are regular erosion and the lack of maintenance of the hydropower turbine. The variation in the running blade and shaft moment are the main reasons for the deduction of the efficiency of the turbine. The curve shown above gives the lowering of efficiency in the first unit and after that it increases in a rapid manner. It helps to understand that surface erosion reflects terrible working conditions of the hydropower turbine that happens due to non-maintenance of the equipment. The growth of extra layers on the surface of the turbine ultimately reduces the performance of the turbine.

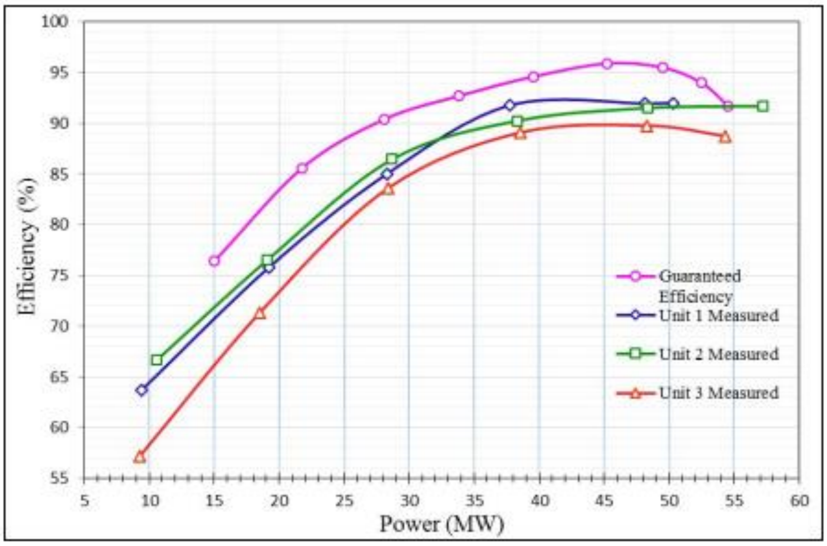

Figure 3: Curves between Hydraulic efficiency and power output

(Source: Iris, and Lam 2019**)**

From the above figure, the relation between the power and efficiency among the three units gives different values with unit 1 showing a considerable rise in the efficiency with the particular power value and unit 2 measuring a higher peak value. The change in percentage value for unit 3 represents the less rise value in comparison to guaranteed efficiency which has a higher value among all.

The presentation of scattering gives the Maximum temperature of difference value of 0.1066 degrees Celsius at a power output value of 9.26 MW (Hanus *et al.* 2019). There is a lowering of turbine efficiency with the increase in with the rise of boiled water. This reduction is done through the blades of the turbine which results in hampering its efficiency. The fact regarding this research overview is that temperature gets increased with the loss of value in power. Furthermore, the relation between the efficiency and temperature of water is directly proportional to each other. It refers that the efficiency of the turbine is directly affected through the water heating values that are the main method to evaluate the hydro-turbine power value.

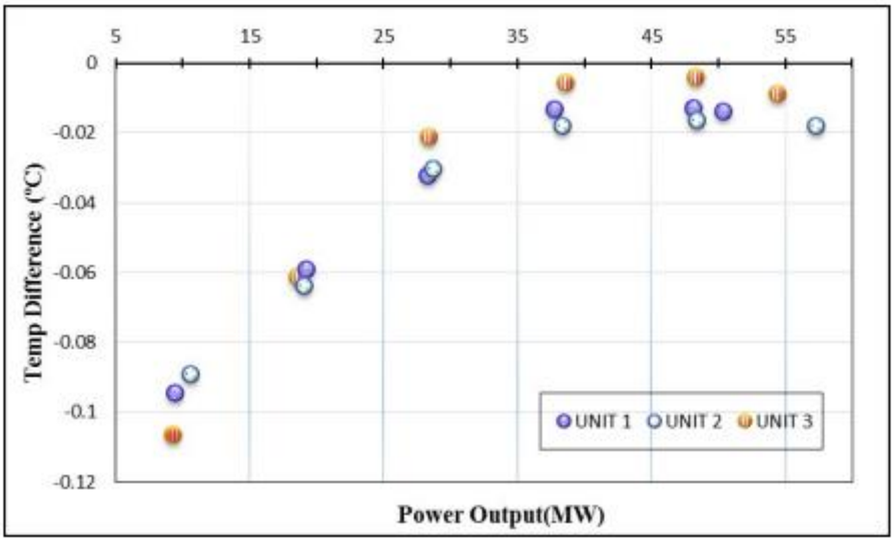

Figure 4: Scattering Representation of the temperature difference and power output

(Source: Hanus *et al.* 2019)

From the above figure, it depicts the temperature difference value in comparison to power output for all three units taken in the research. The regular increase between them gives an overview that depicts that there is an establishment of a directly proportional relationship among all.

Opening and Discharge of Turbine Efficiency

The result that comes out from the efficiency of the turbine relates to the raising of discharge value of 44.86 meter cubic per second. It further shows that there is a decrease in efficiency with the raised value of discharge.

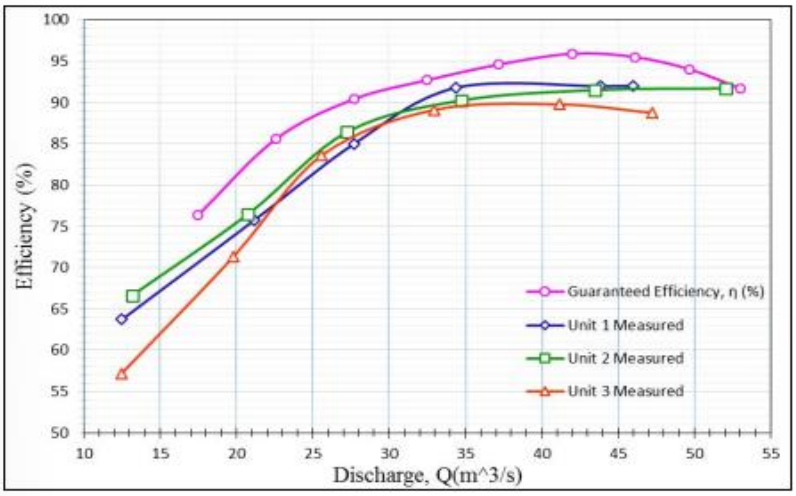

Figure 5: Curve efficiency comparison with Discharge

(Source: Kumar and Saini, 2022**)**

From the above figure, it is represented that unit 1 has a maximum efficiency of around 92.13% at the value of 43.87 meters cubic/sec. The performance curve between efficiency and discharge shows the various levels of the flow of water. It also shows that the increasing operating time and erosion cause a high discharge of water for obtaining the power output. This helps to optimize the output of power with the use of thermodynamic methods. Hydropower turbine performance gives a cost-effective design during the maintenance phase.

It has been observed that the efficiency of Hydropower turbines gives a leading value in the beginning and further decreases with an increase in power value. It also gives the design power output value and the highest capacity of measurement. The best efficiency value or new turbine gives higher results at lower power values (Karre et al 2023). Similarly, the capacity of the turbine provides an optimized result with less value. The degradation observed in the first unit is decreasing and increasing grossly. It states that the complete finishing of the surface imported from gives better resistance to erosion. This rapid growth slows down the overall performance of the turbine and decreases its capacity for operation. It causes a lot of leakage of water from discharge. Present in Hydropower turbines decreases efficiency and gives more discharge required for particular power output performance regarding the measurement and data analysis provides aid for the effective planning (Kumar and Saini, 2022). It could be observed that the data analysis has been done for enhancing the thermodynamic capability of the hydropower turbines. It also comes with the recommendation that hydropower plants need to take care of their turbines at regular intervals of time. Modification of the turbine could create damage caused by the erosion of the regular passing of water at a fixed interval of time. This leads to a decrease in the efficiency of turbines and it hampers the generation of electricity (Dudin et al. 2019). Regular monitoring and measuring are needed at the right interval of time which gives more energy as the output. The life of the turbine is enhanced through regular repair and rechecking for the purpose of greater efficiency (Bogatu *et al.*2019). The performance of the modern turbine is evaluated at the time of operation and also assures the guaranteed effects of the manufacturer to meet the desired level.

The flow of water inside the cylinder helps to implement the active forces on the inner blades of the nozzle and has been directed to the outlet to produce a reactive force. Every component present in the impeller turns alongside the water in a hydropower turbine, and their moment of inertia could be calculated with the help of integration (Dong *et al*., 2023). Theoretical analysis has been performed on the proposed design, and the torque-dependency and efficiency on water pressure have been obtained.

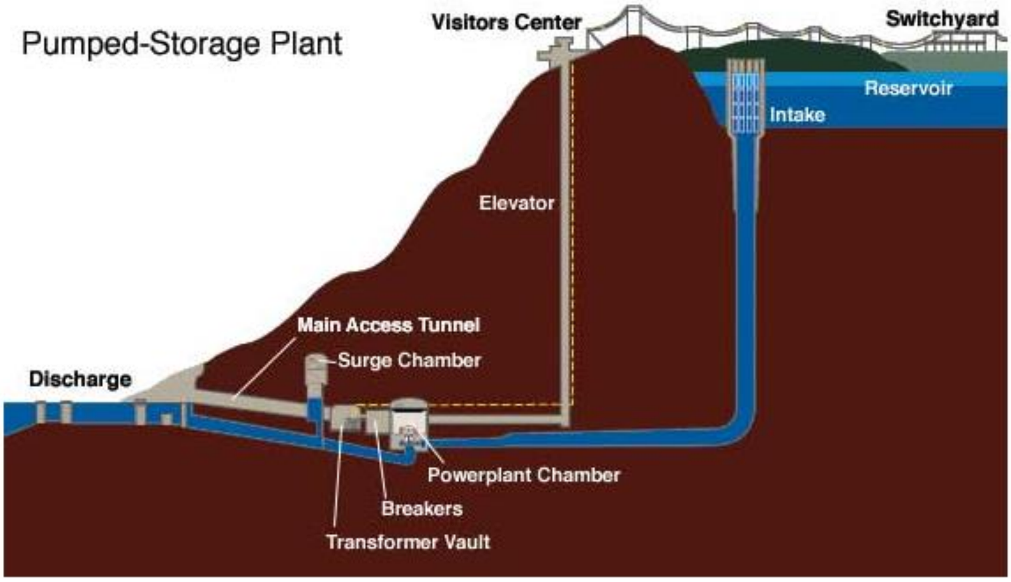

Figure 6: Pumped storage plant of a hydropower reservoir
(Source: Tva.com. 2023)

This ensures that energy losses are minimal and the energy values of hydro turbines can be obtained from the theoretical calculations. A constant amount of water is present for changing the component size of the hydro turbine, which could lead to an increase in their efficiency.

Conclusion

It has been concluded that hydropower turbines play an essential role in producing electricity through running water. The results of efficiency measurement regarding the proper use of turbine involve the thermodynamic method found to give higher satisfactory outcomes. This results in the establishment of thermodynamic method and head discharge technique. It also found that the rise of water regarding temperature is dependent upon each other. The analysis carried out for the turbine gave a successful result in efficiency measurement during the testing. The operating head found a low value that leads to a decline of the temperature difference in the measurement value of the turbine in relation to power output. This gives the working principle of turbines for the purpose of producing electricity. Hydropower turbines convert mechanical energy to electrical energy. The expectation regarding the measurement of efficiency for getting better results in the practice of production of electricity. It also focuses on the system that uses Hydropower technology in the form of renewable energy. Hydropower turbines achieve great significance in the social, commercial, and economic sectors. Furthermore, this paper also highlights various types of Hydropower turbines that give a basic description of their system and their components. It also provides some proper guidelines to modify the working capacity of hydropower turbines. Hydropower turbine performance provides specific recommendations for developing a system that will be free from erosion and will provide high efficiency in electricity generation.

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