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Improved Operation and Method of a Reaction Turbine for Enhancing Net Head

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ABSTRACT

In a reaction turbine, the amount of energy harnessed depends on discharge and net head. The two variables are mutually exclusive or in which one variable is dependent on another and in which the increase of head will decrease the flow required by the hydraulic turbine or vice versa. There is a need for improving the existing hydropower system and the method for enhancing the net head of a reaction turbine is essential. The present invention will hold the key in novelty during the design and excavation of tail race channel or for Renovation, Modernization and Uprating (RMU) of the existing old hydro power plants. The proper redesign of tail water channel, selecting suitable width, depth and by adopting flow regulating means will yield improve the net head substantially and thereby saving of discharge to an extent. The present invention enables to improve net head and saves discharge considerably, thereby enhancing the capacity factor of the hydro plant. The novelty and the innovation is granted an Indian patent for the method of enhancing the net head of a reaction turbines.

1. Introduction

Hydro power is a one of primary sources of renewable power source and India is a place to many hydroelectric power plants, positioned fifth in the world having potential in waterpower generation, which currently stands at more than 50 gigawatts (GW) [1]. Renewables are replacing fossil fuels in the power sector giving benefits against the pollution [2]. The need of unconventional energy sources has been ever growing due to scarcity of fossil fuels and environmental concerns. Hydropower converts the dynamic energy into useful one [3].

Furtherance to the India’s commitment and pledge at Conference of the Parties (COP) 26 at Glasgow in 2021 calls to cut emissions to net zero by 2070, reduce the carbon emission by one billion tons by 2030 and improve the share of renewables in the energy mix to 50% among others. In India, the share of hydro power is 34.1% among the overall renewable energy of 150 GW. Scientists and researchers need to play a major role in achieving net zero emission to reduce the climate change

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impacts. This basic mantra calls for new technologies, innovation, and improvements in the existing renewable energy systems [5].

During the operation of hydraulic turbines especially reaction turbines under low load and low flow conditions posing severe noise, vibration, and cavitation. Hence, the Original Equipment manufacturers (OEM) have also issued a statuary instruction for the safe running the units under low load and low flow conditions of Kaplan turbines [4]. Limited research has been progressed in this area.

The pressure head at the inlets of the draft tube or outlet of the turbine is less than the atmospheric pressure. So, the net head on the turbine with the draft tube increases. The draft tube helps in converting the kinetic energy rejected at the outlet of the turbine into useful pressure energy. Therefore, the phenomenon of total increase in net head plays an important role in improving the marginal efficiency of the reaction type hydraulic turbine and the huge saving of water utilized by the hydraulic turbine. In practical conditions, the turbine operate under variable load and the flow causes the change in the tail water level. Generating additional power through modifying tail water in existing channel is attempted rarely. Providing other turbines may be financially non-viable for the irrigation requirement of Rice crop, fetching low head and low scale water energy. Hence Darrieus and Savonius type water turbines were suggested by Kaprawi Sahim *et al.,* [13]. The experimentation on two turbines Darrieus turbine resulted with two blades. Dan Mugisidi *et al.,* [14] experimented on Water energy to electrical energy conversion by means of Dethridge wheel. This waterwheel very low water head heights convenient for irrigation canals. The authors have worked upon the increasing the performance of the Dethridge wheel by changing the shape of the wheel blades. The wheel was tested for various flow rates. Experimental and numerical methods were used to test the developed wheel. A review by Maksud Bekchanov [15] on hydropower development since 20th century was published stating the present condition and future scope. Environmental, social, economic aspects were also discussed in this paper.

2. Problem Statement

The efficiency of power plant is the most important factor which decides the feasibility of any power plant. The performance characteristic of powerplant which may be considered are maintenance of turbine and energy output from plant. The very significant factor in maintenance of turbine is the cavitation and resulting noise and crack propagation. The increasing energy output from existing plant is need of an hour, as new HEP is very expensive and time-consuming affair. An integrated approach of reducing cavitation and increasing energy output HEP is exercised and succeeded in attaining a significant level of improvement in mentioned two aspects.

During the operation of hydraulic reaction turbines especially Kaplan and Francis turbines at low/medium load and high flow conditions, a system for enhancing a net head of a reaction turbine is provided. The reaction turbine also includes a draft tube mechanically coupled to an outlet of the runner. The draft tube is configured to discharge the flow of water from the outlet of the runner towards a tailrace at an exit of the reaction turbine. Further, the system also includes a first flow regulating means disposed in the tailrace of the reaction turbine. The first flow regulating means is configured to reduce a water level in the tailrace to a minimum threshold level from a maximum threshold level when the reaction turbine is operating at a load power corresponding to a high load, upon operating the first flow regulating means. The first flow regulating means is also configured to maintain the water level in the tailrace to the minimum threshold level to avoid cavitation during the flow of water in the tailrace, thereby enhancing the net head of the reaction turbine from a first predefined level to a second predefined level.

Worldwide multipurpose reservoirs are built and stored water for crop irrigation and hydro power generation activities. The hydro power – irrigation system may yield benefits of downstream flooding, increasing groundwater recharging and streamlining base flows etc. To utilize the basin wide benefits, most of the basins are installed with irrigation dependent small hydro plants of Kaplan turbine. The rated power of the most mini –hydro turbine units are chosen based on the capacity factor which are normally within the range of 40 to 60% to give a satisfactory return on investment.

For better performance of turbine, a particular flow rate is necessary. Failing this, as shown in Figure 1, will rapidly degrade its performance during useful life. Turbines factors can be compared at different design parameters. Pelton and Kaplan turbines shows very high efficiencies working below design flow. The Cross flow and Francis show efficiencies drop more rapidly below half of normal flow.

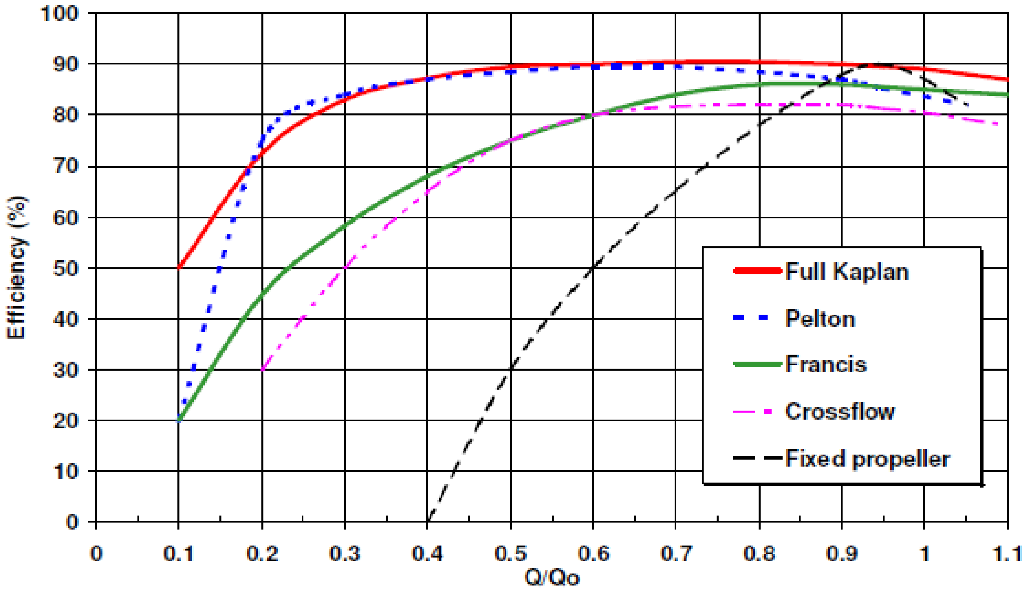

Fig. 1. Part-Flow efficiencies of Hydraulic turbines

Apart from the above facts, presently strong scientific evidence show that global warming is increasing. This causes certain types of extreme weather events including heat waves, coastal flooding, extreme precipitation events and more severe droughts. Hence, global warming impact on the extent and timing of agricultural – to – hydropower water transfers cause inconsistent on the availability of water to the power units. So, most of the existing hydropower – irrigation plants could not be operated due to the lower release of water irrespective of maximum head in the reservoirs. These effects on the reversal impact on the basin – wide net benefits.

Generally, below 40% of the design flow, the Kaplan turbines are subjected to drop in efficiencies and noise and vibration of the units. The turbines are subjected to cavitation where the Thoma's Coefficient σ of the turbine falls less than the critical cavitation factor σ_c. In this scenario, cavitation occurs due to the fall in the elevation difference of the turbine centreline and the tail race level when operated under low flow conditions. Hence the hydro turbine units are not operated in low part flow conditions. Limited research has been progressed in this area. Behm [9] has proposed a system for controllably adjusting spent water levels in the tailrace pool area of a hydroelectric power-generating dam installed into a waterway. A patent [10] by English electric company suggested an adjustable weir for hydroelectric dam installations. An US patent [11] invented a method and apparatus for improved hydropower generation at existing impoundments.

3. A Salient Detail of Kaner Hydroelectric Plant

A large share of water goes fulfilling drinking water needs, uncertain irrigation loads and survival of flora and fauna. Thus, plant needs to be operated considering these primary requirements of water as per the identified time lags. The reaction type turbines have limitations to extract the energy during the lower release.

This paper proposes a system and method for enhancing a net head of a turbine by proper design consideration of tail race channel at Kaner (4X1 MW), irrigation dependent hydroelectric plant, Maha Genco, Satara, Maharashtra.

3.1 The Features of Power Plants

The Features of Power Plants are:

i.	Installed capacity	4 X 1 MW
ii.	Annual design Energy generation	8 MUs
iii.	in Million units (MUs)	
iv.	Average Rain fall in catchment area	1500 – 6250 mm
v.	Average inflow of water in	423.91 MCM
vi.	Million Cubic Meters (MCM)	
vii.	Gross dam storage	382 MCM
viii.	Live storage	331 MCM
ix.	Full reservoir level	690.98 m
x.	Minimum draw down level MDD	671.24 m
xi.	Design head	21.2 m
xii.	Design discharge	21.2 m^3/sec
xiii.	Diameter of penstock	2.5 m

During high flow and high head, the maximum threshold tail level is at 661.5m of 750 cusecs and during the lower release of water through irrigation canal below 300 cusecs. The turbine operates between the tail water level of 661.625 m to 659 m. Further, the units were not able to operate due to the operational restrictions imposed on the plant. The unit can be operated flow only above 300 cusecs. During the lower release period, the generation loss is quite high, as the plant is irrigation dependent nature where the release of irrigation water is uncertain, there is a loss of net head of turbine when operated between minimal and maximum threshold levels and limitations on lower release of water. Hence, huge generation loss was occurred since the commissioning of the units.

4. Proposed Methodology for Enhanced Net Load Operation

In order to overcome the above-mentioned problem, there exists a need for an improved apparatus to regulate water level at the tail race to maintain net head and thereby avoiding the cavitation. It is an objective of the present work to provide an apparatus and a method to reduce cavitation by regulating the water level at the exit of a reaction turbine. The proposed work, shown in Figure 2, relates to an apparatus in the form of regulating gate for assisting in regulating the elevation difference of turbine and the tail water level to avoid cavitation when the part flow conditions. During the part load flow conditions, the regulating gate will be raised so that the tail water level is raised to the condition where there is no cavitation occurs at this part flow conditions.

The position of the regulating gate section is placed where the flow in the tail water is streamlined and should not have any impact of turbulence on the exit of the draft tube outlet.

The details with respect to the apparatus is shown in Figure 2.

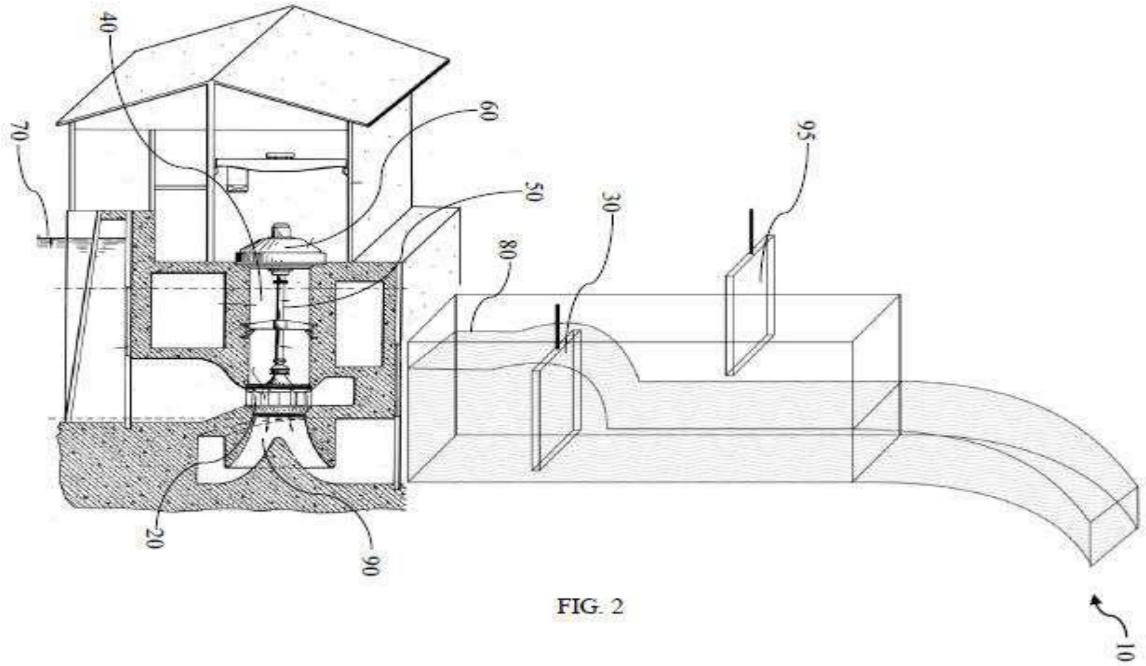

Fig. 2. Schematic representation of the proposed method

The position of runner above or below the tail race level is determined by the Thomas's Cavitation factor,

$$\sigma = \{(H_a - H_v) - H_s\}/H \quad (1)$$

where,

σ = Thoma's cavitation factor
H_a = Atmospheric pressure head in meters generally 10.3 meters
H_v = Vapour pressure head in meter head which is based on the elevation of the place above sea level
H_s = Height of the runner above or below the tail race
H = Net head on the runner in meters

The minimum elevation required is decided by,

$$\sigma = \{(H_a - H_v) - H_s\}/H = \sigma_c \quad (2)$$

where σ_c = critical cavitation factor decided during the model studies

So based on the equation, the position of the elevation of the turbine runner above or below the tail race is decided.

The maximum tail water level elevation is 661.525 m at 4 MW power and the minimum tail water level is 659 m at 1.65 MW of power. During the lower release and the low below 1.65 MW of power, the tail water level falls below the elevation 659 m. The elevation level of tail race below 659 m, the atmospheric air ingress into the turbine through draft tube where the draft tube is under negative pressure. This effect causes the cavitation effect on the turbine leads to noise and vibration on the unit during the part flow operations.

Referring to Figure 2, the tailrace of the reaction turbine is an open channel passage through which the water flows and has an upper surface exposed to the atmosphere. An open channel design involves determining cross-section dimensions of the channel for the amount of water the channel must carry (i.e., capacity) at a given flow velocity, slope and, shape or alternatively determining the discharge capacity for the given cross-section dimensions of the channel. In one exemplary embodiment, the flow velocity of the water in the channel may be computed using Manning's equation or Chezy's equation. As used herein, the "Manning's equation" and the "Chezy's equation" refers to empirical equations that apply to the uniform flow of water in open channels. Later, based on the flow velocity computed using the Manning's equation or the Chezy's equation, a base breadth and a depth of the tailrace may be evaluated.

Moreover, the water level in the tailrace of the reaction turbine may vary between a maximum threshold level and a minimum threshold level. The water level in the tailrace may be at the maximum threshold level, when the flow rate of the water discharged from the draft tube is at the high flow rate at the high load. In another embodiment, the water level in the tailrace may be at the minimum threshold level, when the flow rate of the water discharged from the draft tube is at the low flow rate at the low load power.

Also, cavitation may occur, when the water level in the tailrace goes below the minimum threshold level. Thus, the water level in the tailrace is an important factor because the maximum threshold level obtained at the high flow rate and the high load may be reduced to the minimum threshold level, thereby increasing the net head of the reaction turbine. Therefore, the system also includes the first flow regulating means disposed in the tailrace of the reaction turbine. The first flow regulating means is configured to reduce the water level in the tailrace to the minimum threshold level from the maximum threshold level when the reaction turbine is operating at the load power corresponding to the high load, upon operating the first flow regulating means. The high load of the reaction turbine corresponds to a maximum threshold load power obtained upon operating the reaction turbine. For example, suppose the first flow regulating means may be disposed in the tailrace of the reaction turbine including the Kaplan turbine. Suppose the Kaplan turbine operates based on the following parameters:

Maximum threshold load power (high load) = 4 megawatt (MW)
Net head (H) = 21.2 meters (m)
Flow rate (Q) of water discharged by the draft tube at the net head (H) and the maximum threshold load power = 21.3 cubic meter /seconds (m^3/s)
Maximum threshold level of the water level in the tailrace at the maximum threshold load power of 4 MW = 661.525 m

Minimum threshold load power of the Kaplan turbine specified = 1.650 MW
Water level in the tailrace at the minimum threshold load power = 659 m

Hence, there is a difference of about 2.525 m. Further, the input hydraulic power (P) at the maximum threshold load power of about 4 MW may include about 4.429 MW at the efficiency of the Kaplan turbine being 90.3 percent (%).

Further, during the high load, if the water level in the tailrace is maintained at 659 m, then about 2.525 m of the net head (H)may be enhanced, Thus, the flow rate (Q) of the water discharged by the draft tube required for the input hydraulic power(P) being the same which is 4.429 MW may reduce to 19.030 m^3/s, thereby leading to saving of 2.27 m^3/s of the water. This is equivalent to about 0.472 MW of power. Thus, the input hydraulic power (P) saved is about 0.472 MW by considering the efficiency at 90.3%.

The proposed steps/flowchart for attainment:

i. Working out head above and below the centreline of turbine.
ii. Working out possible improvement of net head.
iii. Designing the tail race for improved performance by altering the geometrical parameters viz. breadth, depth.
iv. Calculating improved output for power, discharge, and capacity factor.

5. Results and Conclusion

It is evident from the calculations that the suggested modification can improve:

i. The net head from 21.198m to 23.723m so effective increase of 2.525m.
ii. Power generation from 4.19 MW to 4.91MW so effective betterment of 0.472MW.
iii. The possible reduction of flow rate from 21.3 m^3/s to 19.030 m^3/s i.e., saving of 2.27m^3/s.

The invention has helped in improving the Capacity factor of plant by increasing the power output by operating at part flow conditions. Further possibility of improvement is possible by modifying the tail race design. The possible work will hold the key in the design and excavation of tail race channel or for Renovation, Modernization and Uprating (RMU) of the existing old hydro power plants. The proper design of tail water channel, selecting suitable width, depth and by adopting flow regulating means has potential in improving yield, the net head substantially and thereby saving of discharge to an extent.

6. Future Scope

This opens the door for exploring the various ways or options to generate energy by setting up energy tapping set ups with:

i. Better efficiencies
ii. Financial viability
iii. Little or no modification in existing structure.

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