Volume 5 Issue 4 (2017) 456-458 ISSN 2347 - 3258
International Journal of Advance Research and Innovation

A Review on Design and Flow Simulation in an Axial Flow Hydro Turbine

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Article Info

Article history:
Received 25 January 2017
Received in revised form
20 June 2017
Accepted 28 July 2017
Available online 15 December 2017

Keywords: Axial flow, hydro turbine, energy

Abstract

Turbines are the most important part in a hydro power plant because here fluid energy is extracted from water and is converted into mechanical energy. Most of large hydro energy sources are already in use at present time so we need to concentrate on small sources to utilize their energy capacities. Axial turbines are best suited for low head power plants than other type of turbines in terms of performance. To extract the highest possible amount of energy from water, turbines should be designed to have maximum efficiency. There should be a better flow distribution inside the turbine space to have its increased efficiency. Flow behaviour inside turbine space largely depends on geometry of runner and distributor blades. In this paper a brief review of different design criteria and flow simulation techniques used for hydro turbines has been presented.

1. Introduction

As more and more need for sustainable development is felt, we need to increase the use of renewable sources of energy over other sources of energy like fossil and nuclear energy sources. Out of available renewable sources of energy, hydro energy is having low operating and maintenance cost after its installation[11]. Hydro power plants are the most generally used way for using water energy for electricity generation and around one-fifth of power requirement is fulfilled by hydropower 4. Hydro energy is comparatively clean energy when greenhouse gas emission is taken into account [Table 1]. Other benefit of hydropower is that water after extracting energy from it, can be used for other purposes like irrigation and often it also provides flood protection. Turbines are the devices where energy from water is extracted and converted into mechanical energy which further converted into electrical energy by generators. There are many ways of classifying hydraulic turbines like head, specific speed, discharge, direction of flow of water etc. According to direction of flow in the runner, turbines can be categorized as: Tangential flow, radial flow, axial flow turbines and mixed flow turbines.

2. Axial Flow Turbine

Water flows along the axial direction in this type of turbines. These are low head and high flow rate turbines. The blades of axial flow turbines are highly twisted due to which there occurs change in angular momentum which forces the rotor to rotate along with generator shaft which in turn generates electricity[8]. Axial flow turbines are having better performance at part load conditions in comparison to other turbines so these are best suited at the sites where there is more frequently variation in load. The vanes in Kaplan turbine runner are adjustable which makes it more efficient at varying flow conditions. There is no such arrangement in Propeller turbines.

3. Literature Study

Recent development in CFD and numeric processors has made it easy to study the complex flow structure in turbo machinery. But at initial stage of turbo machinery design there is lack of information on necessary geometric definition for advanced CFD code application so we need some design criterion to assure certain performance requirements such as optimal operation parameters, aerodynamic loading etc. Minimum suction pressure coefficient criterion was used for designing an axial fan[1] and axial turbine[3] and results were validated. Secondary flows and tip clearance effects are not accounted in studies which are required for better methodology. Five turbines A, B, C, D, and E were designed and design c with least pressure coefficient was found to have maximum efficiency of 86 percent verifying the design criteria. Comparisons of other numerical results is given in Table 2.

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Table 1: Comparison of energy amortization time and emissions of various technologies

Technology		Energy Payback Time (months)	SO_2 emission (Kg/GWh)	NO_2 emission (Kg/GWh)	CO_2 emission (Ton/GWh)
Coal Fired		1.0-1.1	630-1370	630-1560	830-920
Gas CCGT		0.4	45-140	650-810	370-420
Large Hydro		5-6	18-21	34-40	7-8
Small Hydro		8-9	24-29	46-56	10-12
Wind Turbine	4.5 m/s	6-20	18-32	26-43	19-34
	5.5 m/s	4-13	13-20	18-27	13-22
Photo Voltaic	Mono Crystalline	72-93	230-295	270-340	200-260
	Multi Crystalline	58-74	260-330	250-310	190-250

Table 2: Comparisons of numerical results for the designed runner[3]

Global Parameters	Design				
	A	B	C	D	E
Specific energy (J/kg)	42.35	41.73	41.12	43.62	43.08
Total head (m)	4.317	4.254	4.191	4.446	4.392
Torque (N. m)	1250	1249	1258	1317	1293
Pressure coefficient (-)	0.269	0.265	0.261	0.277	0.274
Velocity coefficient (-)	1.475	1.488	1.505	1.440	1.453
Efficiency (-)	0.830	0.840	0.860	0.850	0.846

There is decrease in performance with increase in size of turbines due to hydraulic instability problems in large turbines. If we know pressure fluctuation in turbines we can put a check on extent of hydraulic instability by improving pressure distribution. Liu et. al.[5]. predicted pressure fluctuation by 3D unsteady turbulent flow simulation of the complete flow passage starting from the point before stay vanes to the point at the front wall of draft tube elbow as shown in Fig. 1 in a model Kaplan turbine and verified the predictions from test results. The low frequency (3.84 Hz) pressure fluctuation was found to influence turbine stability during its operation. Experiments cannot be performed on prototype turbine before a power plant is built. It would be much helpful if pressure fluctuation can be predicted during design stage. The similarity study of pressure fluctuations between very large prototype and small model turbine was conducted by Wu et. al.[7].By comparison it was found that similarity exists except at low frequencies indicating similarity of the pressure fluctuation between prototype and model is mainly effected by Strouhal number. Vortex flow in draft tube is the main inducing agent of pressure fluctuation at low frequencies and similarity fails due to difference of the Reynolds number between the prototype and model turbine.

By employing CFD performance can be studied based upon both global and local parameters. Prasad D.V.8 simulated viscous 3D turbulent flow at different guide vane opening and at different rotational speeds of an experimentally tested axial turbine model using SST Ʞ-ω model in Ansys CFX software. The difference between pressure and suction surface in both velocity and pressure distribution was found to decrease with speed indicating more loading at low speed as shown in Fig 2. The numerically simulated results for variation of discharge factor, efficiency and specific energy were agreeing with experimental results of any axial turbine.

Bulb turbines are horizontal axial low head turbines used in small hydro power plants. The rotor blades are enclosed by to coaxial cylindrical surfaces. Quasi three dimensional method was used to define shape of runner blade by prescribing constant angular momentum at the rotor inlet and exit section along the span6. Streamline curvature method and singularity surface method was used to compute meridional through-flow and blade to blade flow respectively. The design method was validated by a turbine rotor tested in airflow rig. The fluent code was used to compute the three dimensional inviscid flow through runner and showed very good agreement with design values as shown in Fig. 3.

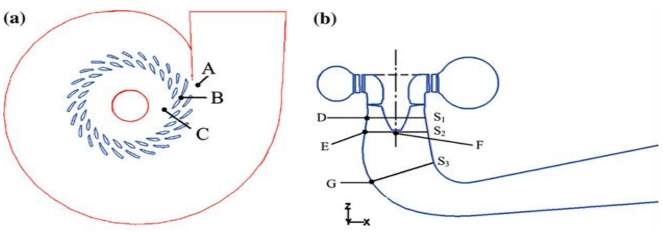

Fig.1 Locations where numerical and experimental sampling for the pressure fluctuations were taken: (a) Plan view and (b) Side view

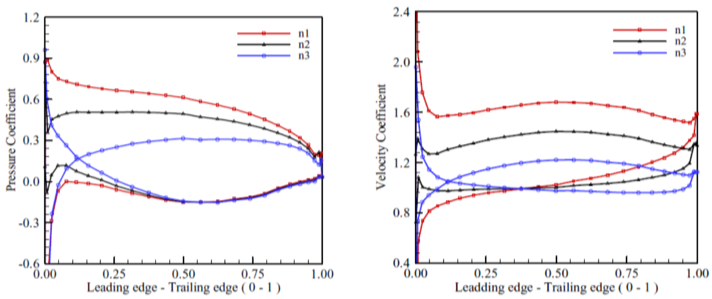

Fig.2 Variation of pressure and velocity with speed on runner blade surfaces

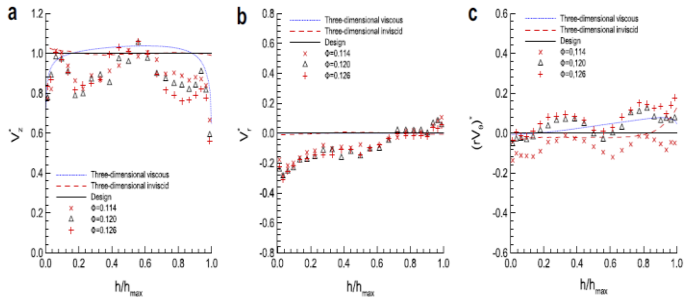

Fig. 3 Comparison of numerical, experimental and design velocity and angular momentum distribution at runner exit section (a) axial velocity V_z (b) radial velocity V_r and (c) angular momentum rV_Θ

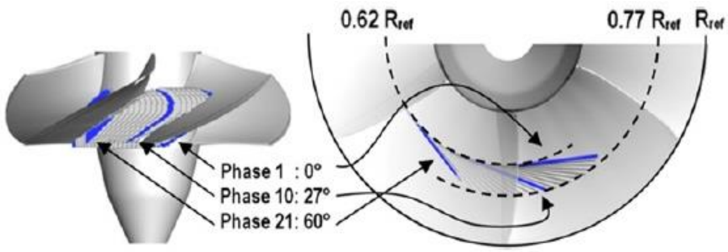

Fig. 4 Measurement volume reconstruction from 21 measurement planes

Vojtko et al.[9] studied SHPP Sulin with three Kaplan turbine installed, with some of its technical problems, eliminated them and proposed construction of new blades. To stop tearing of the water column and great under-pressure the authors proposed the radius diameter of the back part of the rib of the blade to be only 10 mm. to reduce the cavitation on the impellor, the foundations of the building was designed so the axis of the turbine remains under the water surface 1200 mm, it also increased efficiency. The length of the blades in comparison to the original blades was elongated by 45 mm, which removed the problem of vibrations of rotor in the certain critical conditions e.g. when one of the rotor blade is held by some polythene or PVC bottle it created vibration. For the production of new blades the material of steel plate of thickness 10 mm according STN 42 5310 – 11523 was used due to its good weld-ability and increased strength.

Accurate prediction of secondary flows and vortex formation is very important for runner optimization because low pressure at the vortex center can cause cavitation. Experimental and theoretical approach have been used to study secondary flows and vortex formation. Langston, L.S.2 has provided a review on secondary flows in axial turbine. The junction of hub and blade leading edge was found to be main place for origin of the vortices. Accurate flow prediction can be made if measurements are done without causing any intrusion to the flow. Aeschlimann et.al.10 used SPIV techniques, a non-intrusive method, to study velocity

field inside the inter-blade channel of Kaplan turbine runner. Recordings were made every 30 of runner rotation, with 21 phases, covering 600 of runner rotation

covering one blade passage. So the measurement area in this study was covering span extended only from 0.62 Rref to 0.77Rref. Authors used $\lambda 2$ definition to detect position and origin of vortices. The mean and secondary flows were recorded and analysed for nine different operating conditions from part load to full load. Leading edge vortices were identified which significantly affected relative flows inside inter-blade channel.

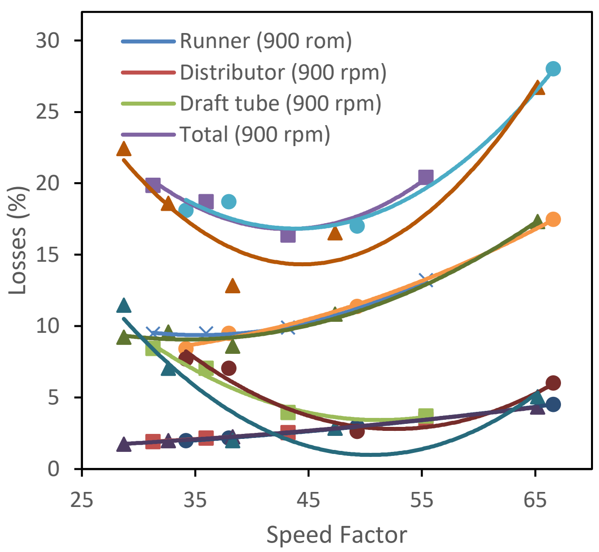

Fig. 5 Variation of hydraulic losses in Straflo turbine at different rpm[13]

Straflo turbine is the best choice for the hydro power generation where water is conveyed through pipe line at slope. The efficient design of straflo requires detailed flow behaviour inside the turbine space which largely depends on geometry of runner and distributor blades. Straflo turbine has been designed and flow simulation has been carried out using Ansys CFX to assess its performance at design and off design operating parameters[13, 14]. The predicted performance results were found to be in accordance to an axial turbine characteristics.The turbine was found to have maximum hydraulic efficiency of 83.05% for design operating conditions and it was decreased at off design conditions. There was smooth flow to runner blade and the pressure distribution along span of runner blade is also uniform except at leading edge at design condition. The design can further be improved by modifying the geometries of runner blade and draft tube.

4. Conclusions

A review of flow study and some design criterion for axial turbines is presented in this paper. Different methods of design have been suggested by many researchers which has contributed towards improvement in design and efficiency of turbine. A significant research work has been done regarding the study of both primary and secondary flows in runner by employing experiments, numerical techniques and also non-intrusive techniques. Minimum suction coefficient is a better criterion for turbine design. SPIV technique can be extended to cover more measurement area to study flow behaviour inside the turbine runner. Simulated results were found to agree with experimental results at design condition and their gap increases when conditions changes from that of design. So numerical techniques need to be developed so that we can get better results at off design conditions also. More research work is required to account for the effect of tip clearances on primary and secondary flows in runner. So it can be concluded that opportunities still exists to explore more in the field of axial flow turbines.

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