Evaluating the Performance of Low Head Kaplan Turbine by Altering the Blades Angle

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This is certify that the work present in the thesis on **"Evaluating the Performance of low Head Kaplan Turbine by Altering the Blades Angle"** is entirely written by the following students under the supervision of Asst. Prof. M. Ishaq. The results obtained by us have not been submitted to any other university or institute, either in part or in full, for the award of any other degree.

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ABSTRACT

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The world is already facing numerous challenges over the excessive use of fossil fuels which are affecting the environment adversely. Under such circumstances, the use of renewable energy seems only viable option to mitigate global and national climatic concerns. Pakistan, being a developing country excessive use of thermal energy seems a costly project. The better sustainable option to shift energy dependence from primitive energy resources to the renewable one is hydro power production. Majority of the areas in Pakistan have canals, rivers, and flowing water streams. Low head Kaplan turbines can be easily utilized in such ideas to produce energy from available water streams. In addition, the better use of low head Kaplan turbine can effectively incentivize the lives of people at micro and industrial level.

This project aims to investigate the universally adopted low head Kaplan turbine and repetitive work on the optimization of rotor blade to have maximum efficiency of this turbine. By using different schemes of blade angles and different shapes of router we will be trying to manufacturer Kaplan turbine with higher efficiency. Various experimentation techniques will also be done in the prototype in the local industry to ensure the possible efficiency event optimization blade angle. Also, this project aims to investigate the universally adopted low head Kaplan turbine and repetitive work on the optimization route shape and blade angles.

Keywords:

Higher efficiency, Low head, Optimization, Blade angle, efficiency

DEDICATION

We dedicate this project thesis to our parents and teachers,
Without their patience, understanding, support, and love, the completion of this project would not have been possible.

ACKNOWLEDGMENT

We as a team work collectively to get maximum output from it. All the fellows cooperated with each other. And above kind behavior and gratitude of our worthy Supervisor, **Assistant Prof. Engr. Muhammad Ishaq** helped us to gain much from our final year project. He always welcomed our problems and counseled us in the proper direction. This final year project would have not been successful without their cooperation and timely assistance.

AUTHORS

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ABBREVIATIONS

CFD:	Computational Fluid Dynamics
CAD:	Computer aided design
$\boldsymbol{\theta_{nt}}$:	Pitch angle
$\mathbf{x_c}$:	Cord length,
θ_s:	Skew angle.
$\mathbf{x_p, y_p, z_p}$:	Coordinates of blade material in space.

Chapter No. 1

Introduction

Over the last few years hydro energy is increasingly demanded in various areas of the country it is cost effective and radially available many countries considering their hydro-potential have already started installing turbines for energy production similarly Pakistan have also boosted its hydro production to address the low production to high consumption Energy Trends moreover low head Kaplan turbines are being manufactured at a large scale in the country some of the construction companies and local people in abundant hydro potential regions are using the turbine for their needs.

1.1 Problem statement

Increasing less-efficient low head water turbines are adding to the worries of people rather incentivizing them. In addition, hydropower projects are in excessive use to meet the growing demands of energy needs. If properly efficient turbines are not utilized with maximum efficiency, it will appear as a financially paralyzed project. Instead, people will start using archaic energy resources-fossil fuels in Pakistan. Low head turbines are approximately ten percent efficient. It means these are not producing much energy that can be easily utilized and transport it to various regions in the country no doubt no doubt turbines are being manufactured at a larger rate but blade optimization in eagle upgrade is not for achieving next film efficiency.

1.2 Hydro-potential in Pakistan

Pakistan is a country which possesses huge reserves of hydro energy potential. According to Pakistan water and power development authority, there is an approximate of 60000 MW hydro power potential and among them only 7320 MW has been developed successfully. There is a huge gap between potential and utilization of hydropower assets in the country [1].

Table 1.1: Turbine Types and their production Capacities [1]

S. No	Type	Unit Capacity
1	Micro-Hydro	Up to 100 kW
2	Mini-Hydro	101 to 1000 kW
3	Small-Hydro	1001 to 5000 kW

Through this graph, we can easily find out that there is a lot of hydro-potential in the country. Considering all the needs and capacity of energy around many areas of the country, installing low turbine can better address the energy woes. Among renewable energy resources, hydro energy has maximum contribution. It is all about its availability and presence

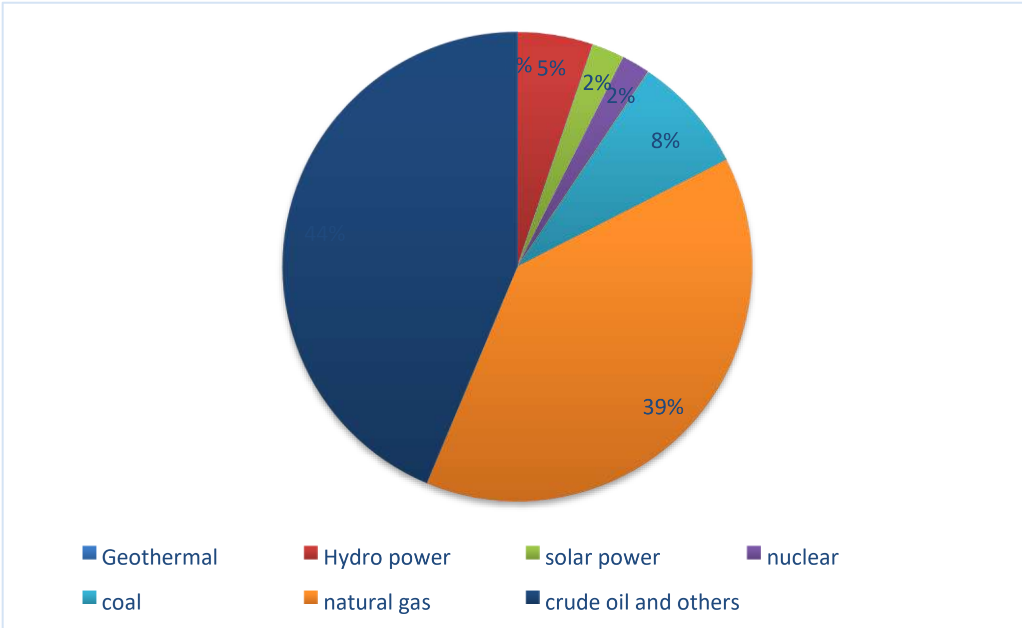

Figure 1.1: Hydro Potential in Pakistan

It clearly indicates that there is a huge need for water turbine and due to the availability of river water low-head Kaplan turbine can turn out as the most feasible option to deal with energy crisis in the country. Currently, 18 percent of the total electricity production is coming from hydro power projects. Abundant regions can be traced depending on the energy projects installed in most areas possessing high hydropower potential lies in KPK region and a few lies in southern Punjab and Baluchistan [2].

1.3 Objectives

1. Our objectives are broadly focusing on design on the low head Kaplan turbine.

2. To design and fabrication of low head Kaplan turbine.

3. To optimize of blades angle to achieve maximum efficiency.

1.4 Research Objective

Due to the increasing demand of energy around the world, there is large demand of renewable energies. All the depleting natural energy resources are urging for urgent focus towards renewable energy resources. Among all the other renewable energy potential, hydro-energy is widely available. Depending on the need and availability of resources, we will be focusing on the designing of turbine.

Based on locality and potential of any area, different types of blades can be used. All the turbines require different heads and flow rate to perform clear functioning. Through this project, we will be designing a Kaplan turbine. This turbine requires low head which is readily available in different areas of the country. For this reason, Kaplan turbines are highly utilized in various areas. In this case, it is required to design these turbines for the proper functioning.

Also, by increasing the efficiency of such turbine, a huge amount of energy can be saved. Already, many low-head turbines installed in the country are not working well. So, there is a need of proper work on the blade angle to improve the efficiency of turbines to make them more usable for energy production.

1.5 Research Outline

This project is divided into three main chapter. Each chapter covering the main aspects of this report. All the chapters are designed to easily understand the basic concepts of this report.

Chapter-1 explains the introduction of the project with a touch to the problem statement. Also, hydro-energy potentials are covered in this chapter Chapter-2 indicates the literature review/research knowledge of other writers. An extensive study of many research paper helped us to keep the foundation of the for our methodology. Chapter-3 describes the preliminary work which we have done regarding our project. In the initial phase, our basic focus was to read many research knowledge about our project. And we used some of the software like solid works to get design of the runner. After that in the coming year, we will be aiming for manufacturing and mass experimentation on our project.

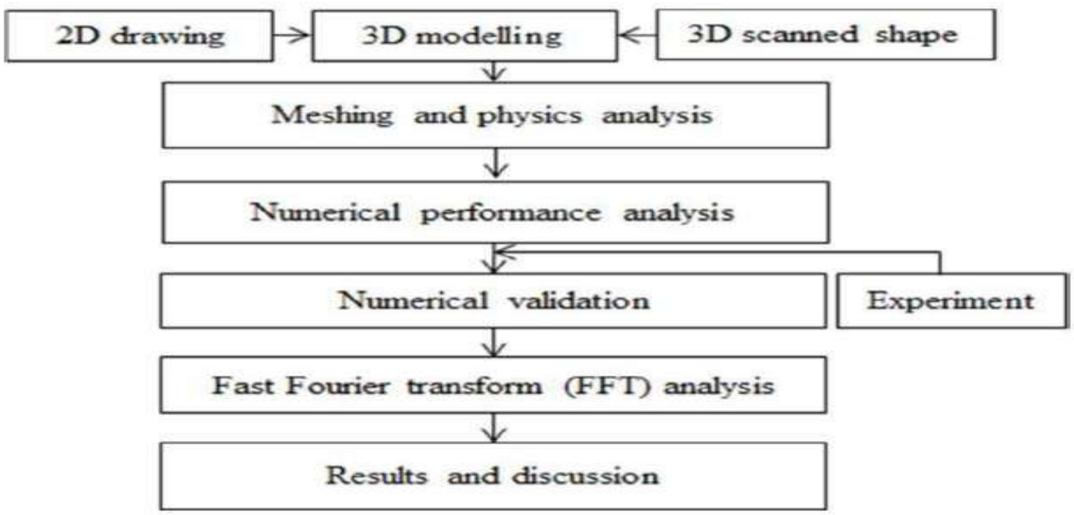

Figure 1.2: Study Analysis Approach

1.6 Kaplan Turbine

The Kaplan turbine was an evolution of the Francis turbine. Its invention allowed efficient power production in low-head applications that was not possible with Francis turbines. The head ranges from 10–70 meter and the output from 5 to 200 MW. Runner diameters are between 2 and 11 meter. Turbines rotate at a constant rate, which varies from facility to facility. That rate ranges from as low as 69.2 rpm (Bonneville North Powerhouse, Washington U.S.) to 429 rpm. Kaplan turbines are now widely used throughout the world in high-flow, low-head power production [1].

A Kaplan turbine mounts on the 3-kW pump and turbine test set base unit. The working section of the turbine outlet is transparent. The turbine guide vanes are individually adjustable. The unit includes three interchangeable rotors, each with different blade angles. The centrifugal pump on the base unit powers the turbine. Water from the turbine outlet discharges back into the base unit tank and recirculates. A yaw probe indicates the magnitude and direction of the flow from the turbine outlet. The turbine shaft connects to the base unit dynamometer. This measures torque and speed.

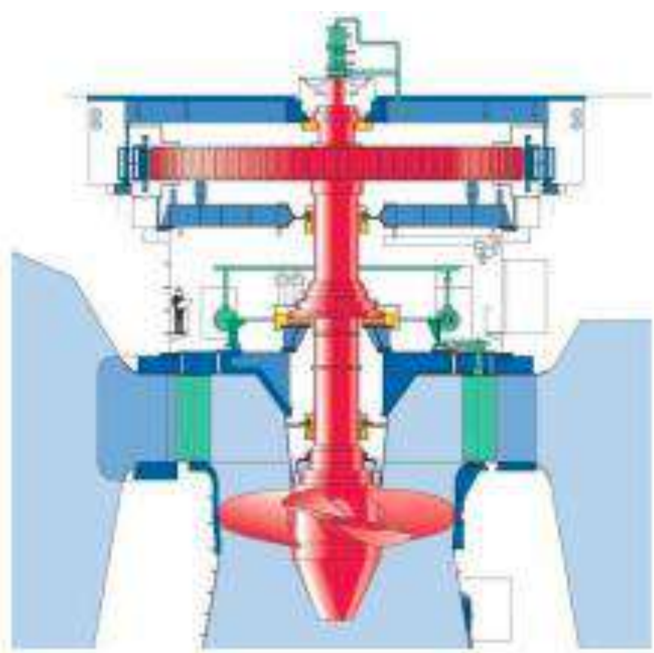

Figure 1.3: Kaplan Turbine

1.7 Working Principle

The Kaplan turbine is an outward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. Power is recovered from both the hydrostatic head and from the kinetic energy of the flowing water. The design combines feature of radial and axial turbines. The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially through the wicket gate and spirals on to a propeller shaped runner, causing it to spin. The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy. The turbine does not need to be at the lowest point of water flow as long as the draft tube remains full of water. A higher turbine location, however, increases the suction that is imparted on the turbine blades by the draft tube. The resulting pressure drop may lead to cavitation. Variable geometry of the wicket gate and turbine blades allow efficient operation for a range of flow conditions. Kaplan turbine efficiencies are typically over 90%, but may be lower in very low head applications [1].

Table 1.2: An overview of different type of turbine technologies

Parameters	Pelton turbine	Frances turbine	Kaplan turbine
Turbine type	Impulse turbine	Combination of impulse and reaction turbine	Purely reaction turbine
Flow type	Axial flow turbine	Mixed flow turbine	Axial flow turbine
Number of vanes and buckets	Wheel with 20–40 buckets	Impeller with 16–24 vanes	Impeller with 4–8 vanes
Head requires	Very high head (above 300–400 m)	Medium head (about 100–300 m)	Low head (below 100 m)
Flow rate	Low flow rate	Medium flow rate	Very large flow rate
Specific speed	Low specific speed	Medium specific speed (about 50–250 rpm)	High specific speed (about 250–1000 rpm)
Adjustment of runner vanes	Fixed buckets at the periphery of the wheel	Runner vanes are fixed with the shaft so it can't be adjusted	Runner vanes are adjustable
Force on the blade	$F_{blade} = F_{impulse}$	$F_{blade} = F_{lift} + F_{impulse}$	$F_{blade} = F_{lift}$
Overall efficiency	About 85%–95%	Above 90%	About 90%–93%

Chapter No. 2

Literature Review

Turbine plays a vital role in global energy generation. Turbines consist of number of mechanisms that convert kinetic and pressure energy of fluid into rotational energy of shaft and in return generate electricity. Our analysis focus upon low-head water turbine (Reaction turbine). Low head water turbine usually works under low water head, typically less than 20m. These types of turbines usually have high flow rates. Kaplan turbine best falls in this category. Development of Small hydro low- head water turbine- is cheaper and more reliable than other sources of renewable energy. Although, the technology is very old trace back to 19-century, but still require a lot of modification to improve efficiency [2]. The key parameters that alter turbine efficiency are blade and vane angle, vane angle in result effect flow rate of water. People all around the world have done a lot of work upon these parameters to pursue an efficient mechanism. Here is some of the research paper review that would pinpoint design parameters of turbine.

2.1 Blade angle Analysis

Kaplan low head water turbine. The small hydro turbine designed as axial propeller turbine suitable for reservoir with water head range 10 to 20 meters. Efficiency is one the most common parameter with which one rank any type of machine. Similarly, efficiency of turbine is very important. Furthermore, founding is that efficiency can be altered by changing the turbine design, guide vane; give maximum efficiency in range between 70-80% for 35 to 45 degree of guide vane arrangement. The design of runner blade was marine propeller shape with reversed mean camber line that obtained a high performance hydro turbine. It has four fixed blades with a diameter of 0.4 meters, 0.35 hub to tip ratio and the 12 pieces of adjustable guide vanes. The turbine shaft directly coupling with a 160 kW induction generator at a rotational speed 1,000 rpm. The performance test results suited for water head all range of 10 to 20 meters with the guide vane angle 40 to 45 degrees and derived with the overall efficiency of 70% to 80%, maximum efficiency. Although the curve does not hold any definite trend but increases and reaches to a maximum point and the decreases. Turbine gives maximum efficiency in range of 0.45 to 0.55 (m^3/s) or 35 to 45 degree, **while the highest recorded at 10m and 14m head reaches- reaches to 80% efficiency**. Total cost of the small hydro turbine generator is USD233/kW [3]

Another most relevant work is done in UET Taxila. In which a Kaplan turbine, Runner diameter 4.24 m and Hub diameter 1.76 m that work under maximum 766 ft. and minimum head of 744 ft. operated under low head of 7.6 m with flow rate of 87.7 m^3/s having efficiency of 80% (4.6 MW). Results of the research study carried out on the CAD model of original blade and modified blade profiles have shown improvement in the turbine power output, resulting in the power output increase from 4.6 MW to 4.85 MW i.e. 5.43% increase. The same improved output of 4.85MW have also been verified at site. It resulted an increase of around 6000 kWh units per day or 180,000 kWh per month. Analysis shows that as flow rate increases the power output increases and reaches maximum output at maximum flow rate, linear increase roughly. The span of rotor greatly alters the pressure difference across blade side. Higher the pressure difference greater would be the torque. On the other hand, there is certain value of rotor span for which the pressure difference is high. Research was conducted under 25%, 50%, 75%, result shows that pressure difference is high for 25% span and 75% give lowest pressure drop [4].

Another analysis was performed in china institute to optimize the low-head water turbine by varying vane angle. The tubular turbine vane angle was set at 31 ° with water head of 5.8m.

The analysis was conducted under three working conditions, The guide vane increased from 53.9 ° to 56.9 °, the output power of the tubular turbine increased from 8.6 MW to 9.01 MW by increment of 0.45 MW , the tubular turbine efficiency increased from 92.79% to 93.04%, when reduced to 92.74%, that is to say, the tubular turbine's settling angle is 31 °, by changing the way of guide vane, the energy characteristics first increased and then decreased, this characteristic is exactly the same as that of hydraulic loss and the parameters theoretical analysis. Similarly flow rate also cause increment in efficiency, reaches maximum and then there is gradual fall as further flow is increased. Experiment is performed under different head condition.

The design of runner blade was marine propeller shape with reversed mean camber line that obtained a high performance hydro turbine. It has four fixed blades with a diameter of 0.4 meters, 0.35 hub to tip ratio and the 12 pieces of adjustable guide vanes. The turbine shaft directly coupling with a 160 kW induction generator at a rotational speed 1,000 rpm. The performance test results suited for water head all range of 10 to 20 meters with the guide vane angle 40 to 45 degrees and derived with the overall efficiency of 70% to 80%, maximum efficiency. Although the curve does not hold any definite trend but increases and reaches to a maximum point and the decreases.

Although efficiency- flow rate graph holds same trend, but maximum efficiency moves forward across flow rate axis as water head increases. Through the analysis of the fixed - oar numerical calculation results of 31° with different guide vane opening, we can conclude that when the guide vane opening at the angel of 56.6 °, there is no impact inlet, the efficiency is high and the flow field is relatively stable, which is the optimal condition area. There is more vortex vorticity under various working condition of turbine. When vane blade angle was 53.9º, there is a certain amount of vorticity and there is a certain energy dissipation at the draft tube, the tail water energy recovery is good. When vane blade angle was 56.6º, vortex number added and the energy dissipation of tail water increased, which has the highest energy recovery. Similarly for 58.8º vane angle, the vortex number decreased [5].

Moreover, Guide vanes, sometimes called wicket gates, are located in the annulus between bulb and casing to control the flow of water to the runner. Several combinations of guide vane/runner blade control are possible:

2.2 Variable guide vanes and runner blades

This combination provides the best efficiency over the load range. It also allows a useful variant for tidal power schemes. Thus, as well as operating as a turbine in either the ebb or flow direction, there is the capability for pumping in either direction to improve the head available for the next generation cycle.

2.3 Variable guide vanes, fixed runner blades

Load is satisfactorily controlled over the complete operating range by varying the guide vane angle, but the fixed runner blades cause a rapid fall-off of efficiency with change of load on either side of the design point.

2.4 Fixed guide vane, variable runner blades

It has been found that both efficiency and the way that it is maintained over the power range is nearly as good for this combination as for variable guide vanes and runner blades. A disadvantage is that the turbine cannot be shut down by closure of the guide vanes and some form of flow shut-off, such as stop gates, must therefore be provided.

2.5 Efficiency Improvement Analysis:

Efficiency of turbine can be affected by changing vane blade angle. Efficiency is one the most common parameter with which one rank any type of machine. Similarly, efficiency of turbine is very important. Furthermore, through testing we found out that efficiency can be altered by changing the turbine design, guide vane; Give maximum efficiency in range between 70-80% for 35 to 45 degree of guide vane arrangement [3].

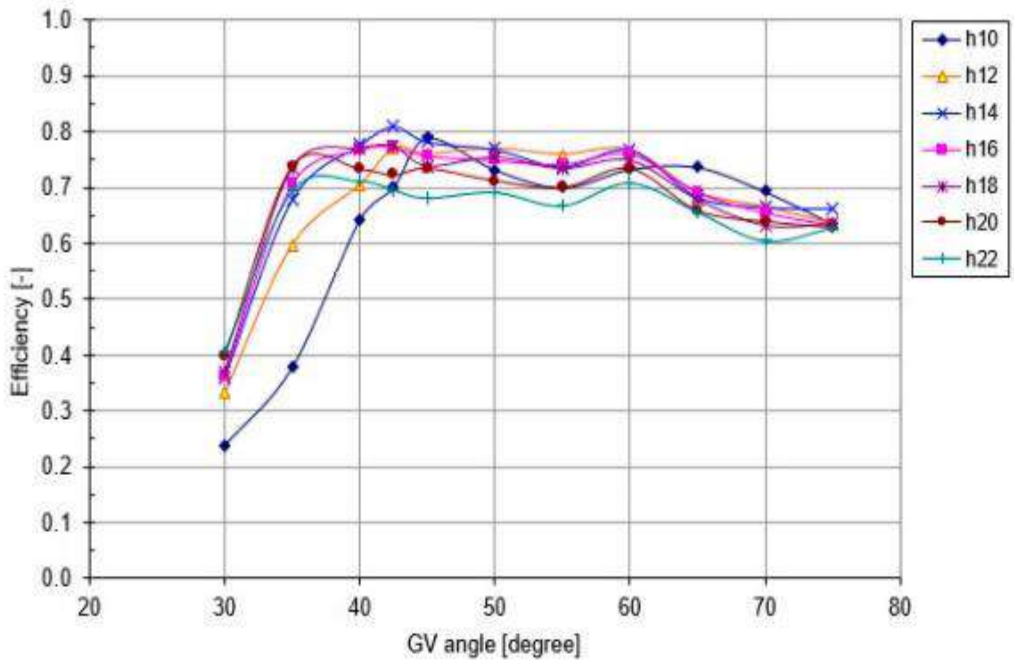

Figure 2.2: Efficiency indicators for Kaplan Turbine

Chapter No. 3

Preliminary Work

In the preliminary work we have done work related to the basic research of Kaplan turbine. By studying various we build an understanding that how several turbines are working around the world. All those research papers enabled us to further enhance our knowledge about the working of several turbines.

3.1 Methodology

Our method is basically based on the designing of runner. Actually, in any turbine efficiency depends on the blade angle connected with the runner. And runner occupies a special feature in developing a successful design. And all the working turbines in our country are unable to get maximum efficiency. For that purpose, working on the runner of Kaplan turbine.

3.2 Runner Design

Our research first task was to design runner visual model. Visual analysis gives one the most efficient way to probe feasibility of any design using Cad models with lowest possible cost. We have first design two different models, with different runner blades angle. Furthermore, selecting the best design, with the blade angles that gives the most promising results.

Points were measured physically from the runner blade on test bench example, surface table by using the well calibrated measuring instruments like height gauges to ensure the accuracy of the measurements taken by qualified quality personnel. True levelled surface of the test bench was taken as reference for these measurements.

In this procedure, runner blade was placed and levelled on the test bench / surface table. Blade upper and lower surfaces were properly cleaned before marking of points. Outer periphery of the blade on upper and lower sides was measured by using calibrated measuring tape. At start, initial reference point was marked as coordinate (0, 0, 0) and from this reference point, next point was marked on the periphery line at an interval of 100mm with the help of divider. This point was then measured with respect to initial point by measuring the dimensions along x-axis, y-axis and z-axis.

3.3 Software Models

Model 01

First model have 06 blades having blade angle of 43° as shown in below figure 3.1. The design is that of ship-propeller type having weight of 3.98 kg. Using ANSYS and simulating the flow analysis give maximum efficiency of 92% at the given available head. Moreover, keeping the corrosion problems in mind, steel is selected. The reason is the steel can easily withstand with corrosion and with fatigue loading. Furthermore, as head is varied across the blade the efficiency increases and then decreases because of higher input.

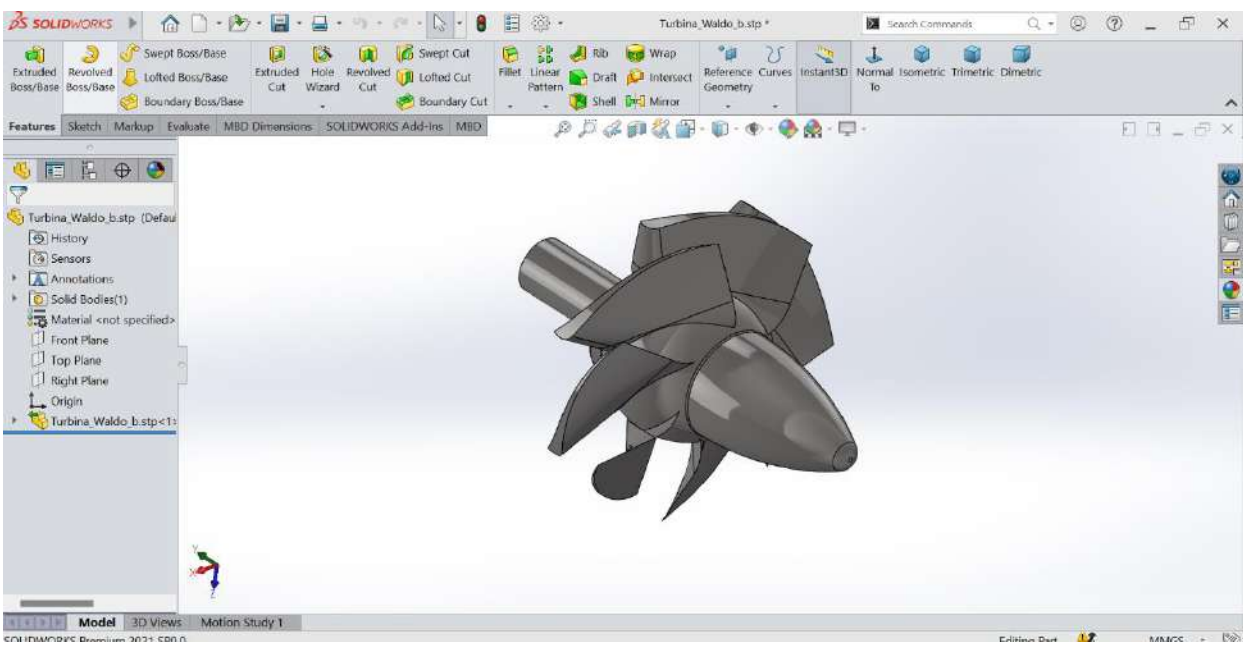

Figure 3.1: Model 01, Kaplan Turbine

Table 2.1: Model 01, Properties

S.No	Type Kaplan Turbine	Kaplan Turbine
1	Material	Steel
2	No. of Blades	06
3	Blades angle	43°
4	Mass	3.98 kg
5	Length of Hub	120mm
6	Diameter of Hub	3mm

Model 02

Second model have 04 blades having blade angle of 42° as shown in below figure 3.2. The design is that of ship-propeller type having weight of 3.47 kg. Using ANSYS and simulating the flow analysis give maximum efficiency of 91.2% at the given available head. Moreover, keeping the corrosion problems in mind, steel is selected. The reason is the steel can easily withstand with corrosion and with fatigue loading. Furthermore, as head is varied across the blade the efficiency increases and then decreases because of higher input.

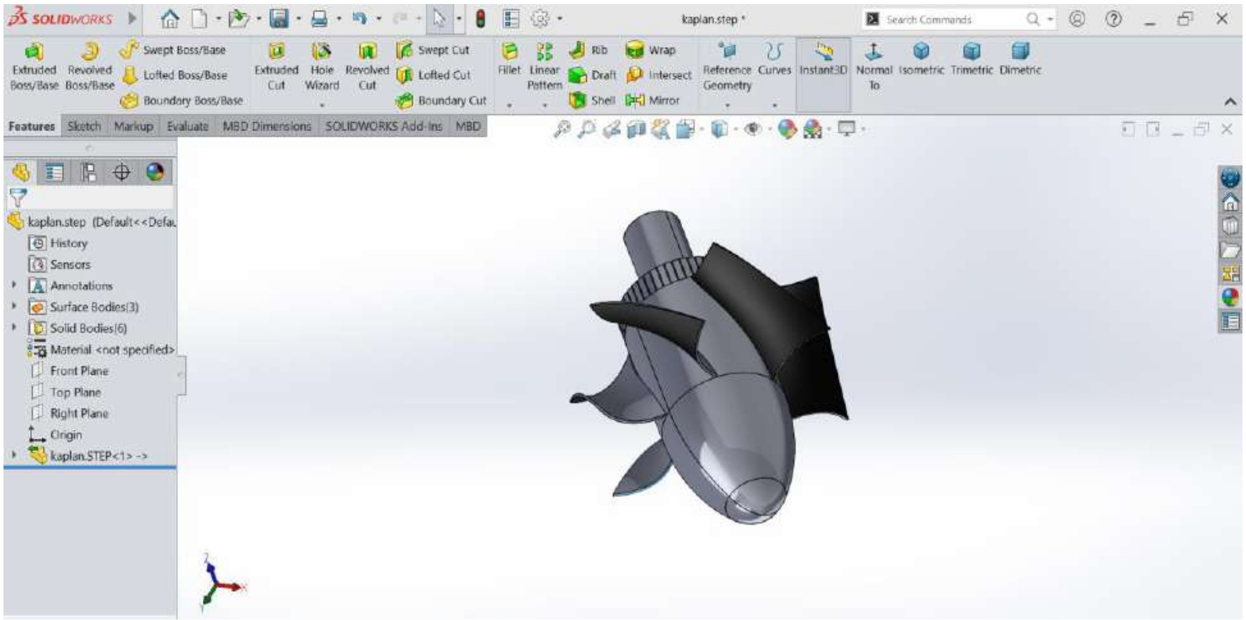

Figure 3.2: Model 02, Kaplan Turbine

Table 2.2: Model 02 Description

S.No	**Type Kaplan Turbine**	**Kaplan Turbine**
1	Material	Steel
2	No. of Blades	04
3	Blades angle	42°
4	Mass	3.47 kg
5	Length of Hub	71mm
6	Diameter of Hub	3.2mm

Chapter No. 4

Construction and Performance

4.1 Manufacturing

Design feasibility is the preliminary work before manufacturing. For that we have design couple of Cad models, using ANSYS. In each design we have changed blades angles and analyzed effect on efficiency. After probing different parameters of the selected model, we have moved towards Physical design. Physical design includes type of manufacturing process that we will use in order to design Turbine. Nature of manufacturing process massively affect the runner performance during operation. The design consists of two main components; the frame and Kaplan turbine assembly as shown in below 4.3.

Frame is made of cast Iron for economical point of view. The purpose of frame is used to support the turbine mechanism. The turbine cage is made of steel (see the properties in table 4.1) because of brilliant anti corrosive properties. The blade is also made of steel material having three blades on the hub periphery, having dia of 32.3mm. The blades are machined on the periphery of hub using relevant machining process.

Moreover, blade offset has much more negative effect on stage efficiency than other defections. On the other hand, blade bow and leading edge and trailing edge thickness have minor effect on the stage efficiency. In addition, the combination of aforementioned deviations is also studied. The results show that combination of all of these deviations causes the stage mass flow rate and efficiency to change, significantly.

Table 4.1: Chemical composition of ASTM A743 Grade CA6NM

Element %	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	Al
Specified	0.06 Max	≤ 1.00	≤ 1.00	≤ 0.03	≤ 0.03	3.5~4.5	11.5~14.0	0.40~1.0	-	-
Achieved	0.065	0.63	1.02	0.017	0.012	4.45	12.00	0.47	0.18	0.091

Figure 4.1: Turbine assembly

Figure 4.2: Output, Lighting Bulbs

Figure 4.3: Kaplan Turbine whole assembly

4.2 Performance Analysis

The turbine performance mainly depends upon the flow rate especially the load head turbine. Flow rate increases the turbine efficiency increases gradually. The turbine is being run and output is measured using dynamo. The flow rate is first kept zero and then increases gradually as shown in Table 4.2. Following data below shows performance-data of the Turbine.

Table 4.2: Performance Result

Sr. No	Pressure P (bar)	Flow rate Q (L/min)	Speed N (rpm)	Input power P_{in} (W)	Torque T (N.m)	Out power P_{out} (W)	η (%)
1.	1.89	89.5	144	20.10	0.21	18.1	90.1
2.	2.25	192.7	523	32.63	0.34	29.6	90.7
3.	2.47	344.1	897	51.47	0.5	46.94	91.2
4.	2.69	356.5	1439	93.90	0.57	85.85	91.42
5.	2.85	361.7	2043	151.88	0.65	138.99	91.51
6.	2.92	373.1	2101	189.73	0.79	173.72	91.56
7.	2.98	382.2	2301	230.81	0.88	211.93	91.82
8.	3.01	396.7	2464	336.46	1.2	309.47	91.98

Chapter No. 5

Result Analysis

5.1 Turbine Efficiency

The turbine performance mainly depends upon the flow rate especially the low head turbine. Flow rate increases the turbine efficiency increases gradually. The turbine is being run and output is measured using dynamo. The flow rate is first kept zero and then increases gradually as shown in Table 4.2. As the flow rate is increased the turbine efficiency increases gradually as shown in figure 4.4. The trend is approximately linear which state that there is direct relation between both the parameters; Kaplan turbine highly depends upon the flow rate as seen in performance.

Further analysis is made; efficiency as function of Input power. As discussed in chapter I the input power is the available head at the turbine blades. The Kaplan turbine uses the head loss across the blade in order to rotate the shaft. It has seen that as the input power is increased the turbine efficiency increases gradually then became linear as shown in figure 4.5, but afterword that increases.

5.2 Turbine Output Power

On the other hand, the torque available at the turbine blades also effect the turbine performance. The figure 4.6 shows that there exists a direct relationship between the torque at the efficiency of turbine. Output of turbine is the available mechanical energy at the output shaft, values of which is given in the table below 4.2. The fourth analysis is performed between the output power and the flow rate. As the flow rate increases the output power increases gradually except for the higher value of flow rate where the graph got a sharp steep, see figure 4.6. Furthermore, through testing we found out that efficiency can be altered by changing the turbine design, guide vane; Give maximum efficiency in range between 70-80% for 35 to 45 degree of guide vane arrangement.

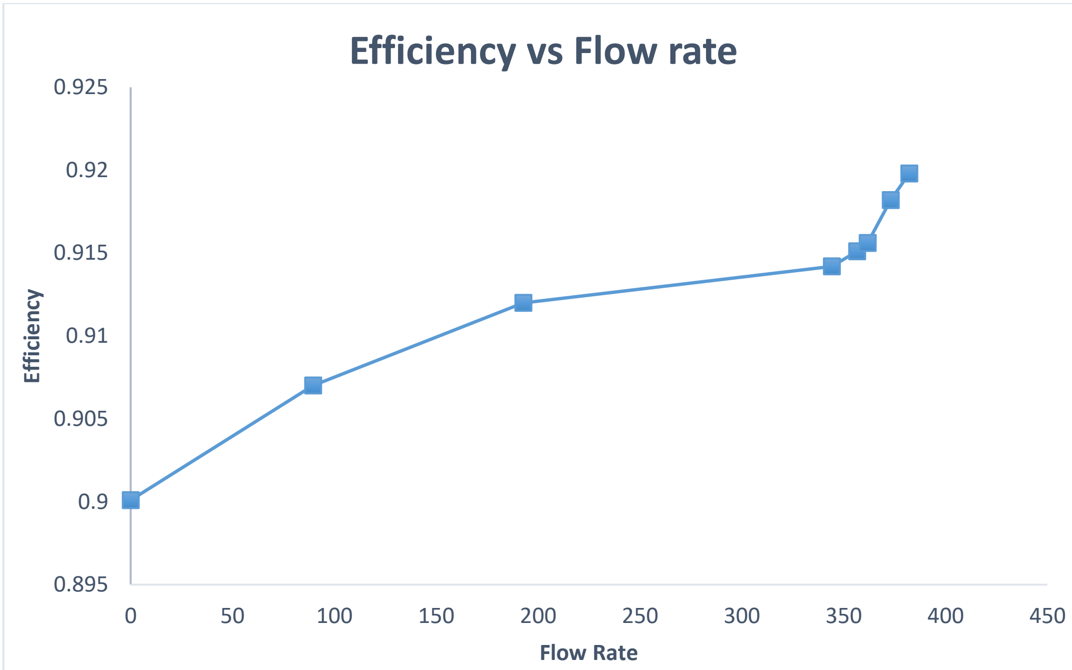

Figure 4.4: Efficiency as function of Flow rate

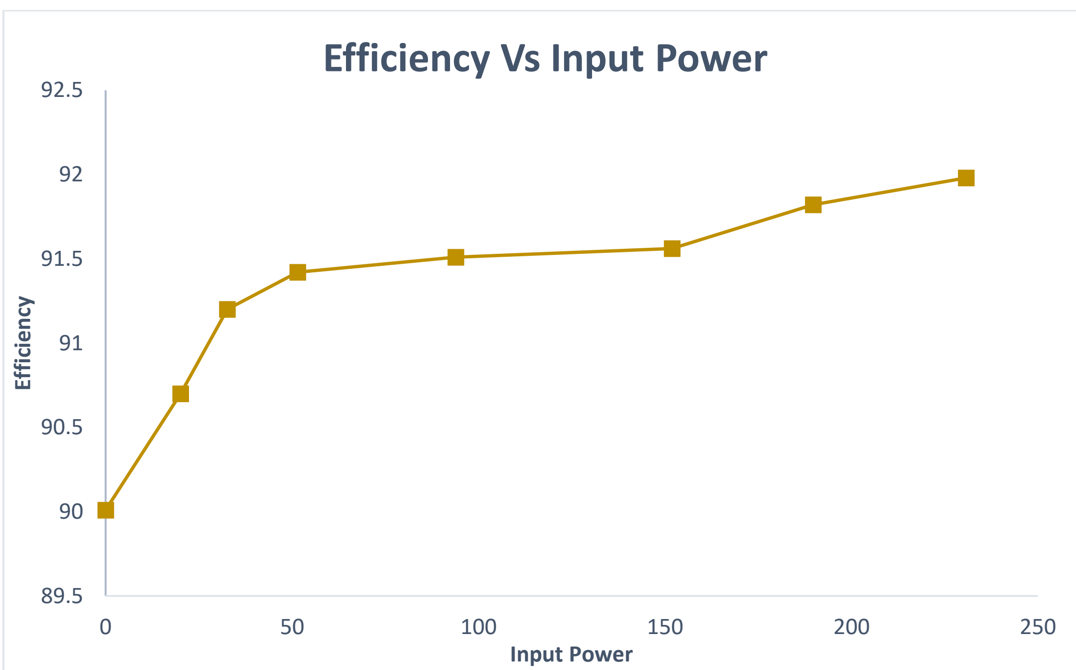

Figure 4.5: Efficiency as function of Input Power

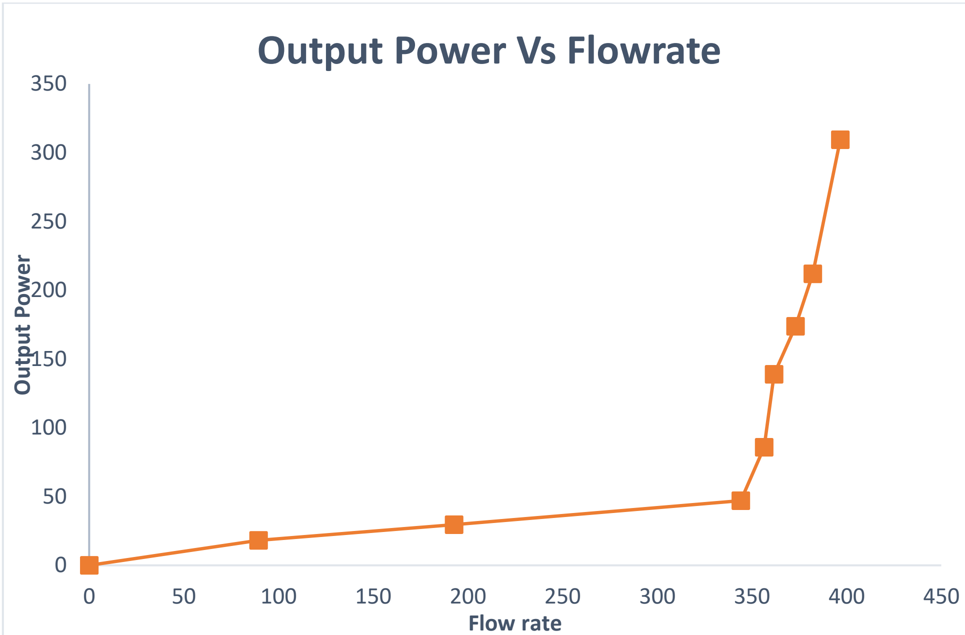

Figure 4.6: Output Power as Function of Flow rate

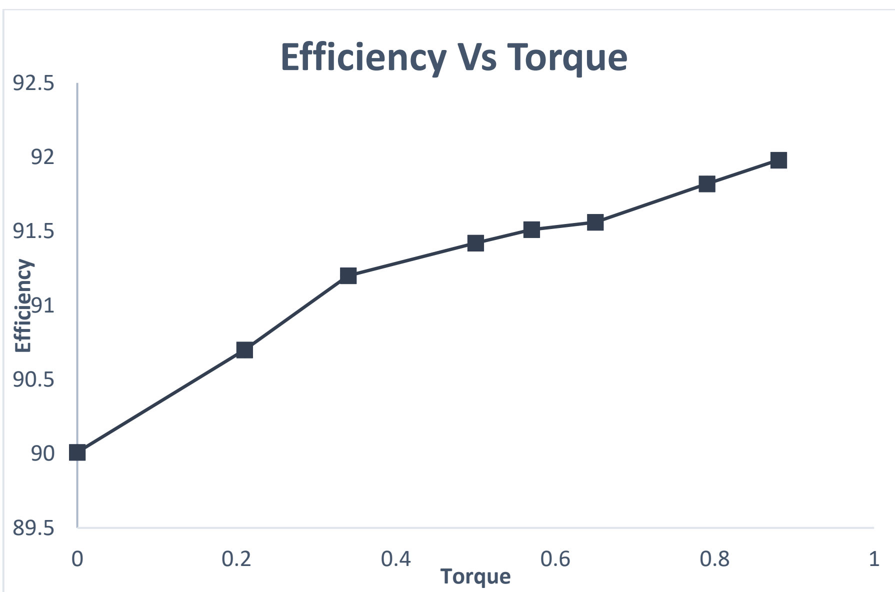

Figure 4.7: Efficiency as function of Torque

Chapter No. 6

Conclusion

We have started studying research papers about Kaplan turbine. And the purpose of those research papers was to enhance our knowledge and our understanding about the working of low head Kaplan turbines. Our basic objective is to work on the design of low-head Kaplan turbine to maximize its efficiency. Our literature review clearly indicates that in this first phase, our main focus was on the research data. We came to know that several Kaplan Turbines installed globally in various regions are less efficient.

Our work opens up with research Knowledge and then we have started working on the design of the turbine runner. Soon after that our work will be about the manufacturing of turbine runner. Similarly, it is of great importance to fabricate runner of turbine and working on and prototype based model to improve its efficiency.

At the several experimental analyses will be done in the local turbine industries in the vicinity of Islamabad and other regions of Pakistan to check its efficiency. It will be better to launch a turbine that has very improved efficiency and can be bitterly placed in rural areas to get maximum output. The developed methodology is applied for the Kaplan turbine runner blade design of an actual hydropower project.

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