PERFORMANCE ANALYSIS OF HORIZONTAL AXIS WIND TURBINE USING MODIFIED BLADE OF NACA 5510 AEROFOIL

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ABSTRACT

In current scenario, pollution has become the issue of prime concern. International community is holding meeting, after meeting to control the pollution and save the environment from pollution. The main factors which are responsible for the pollution are conventional method of power production by burning coal and other fossil fuels which emits an enormous amount of co2 gas and pollutes the environment. In the present work the power production by wind turbine has been emphasized and research has been carried out on design of rotor blade of wind turbine to have maximum mechanical power output and absolutely pollution free power produce. In this work the rotor blade of the wind turbine aerofoil section NACA 5510 has been roughened to have maximum drag at the lower face and to offer more and more lift on the rotor blade. Also to increase the blade area, a flap has been added at the end of blade trailing edge so that braking torque can be achieved at the lower wind speed. After taking the experiment in all cases it has concluded that power of the wind turbine has increased by 10% when rough surface blade are used and 21% when flap at trailing edge are used while compared to the wind turbine using smooth surface blade.

Keywords: blade, airflow, Aerofoil, pressure distribution, velocity distribution.

INTRODUCTION

Wind power comes with the sun and sun heats the ground which air around of ground warms up and rises. The hot air rises heavier or cool air rushes in to fill its place. The rush of air is wind which made of gas particles. Wind turbine absorbs kinetic energy or turning it into electricity.(Islam et al., 2019) Wind power (Pw) is written the equation where ρ is the density of air or A is the area covered by the wind turbine blades and v is the wind speed.

$$Pw = \tfrac{1}{2} \rho A V^3$$

One of the most important parameter of wind turbines is wing because wind comes and strikes to the wings then energy of wind is transformed into the mechanical energy by wings.

Wings profiles are known as Airfoils. (Pandey, 2019)Airfoil profile is the most important parameter for wing design because wing efficiency increases depend on Airfoil profile. The studies over the Airfoil profile as numerical and experimental in the literature.

The demand for power is increasing day by day in the world .we are depend upon the traditional resources for power production but we know that our traditional recourses are something which are getting short day by day. Wind power is a renewable energy source which easily reduces the world's dependence on oil and natural gas, while not polluting the environment.(Rahman et al., 2017) However, there are many things that affect the efficiency of a wind turbine. Coming decade would be the glorious for the wind power industries. The cost of power production is increasing fastly day by day and it is going beyond the common people reach. The power production by wind mill technology is very cheap or easy and pollution free too.

Aerofoil Shape of blade and Concept of Wind turbine blade

Aerofoil shape and design of blade is very important role in the field of wind turbine technology. It has slightly twisted from outer tip to the root. Our concept of blade is that how to maximum efficiency find at thin blade than thick blade. Maximum lift produce at thin blade and low lift is generated at thick blade. The design of blade of Aerofoil shape which more lift generated thin blade and low lift generated thick blade.(Sauvageat et al., 2016) The Chord length and camber area affect duo to amount of lift Produced by airfoil shape. Aerofoil is aero shapes. the design change of Some simple blade can be experiment with advanced technology in the wind turbine blade design, the two important principles Newton's laws of motion and Bernoulli theorem is described that how lift is generated by airfoil shape. The forces are acting on an airfoil shown Fig.

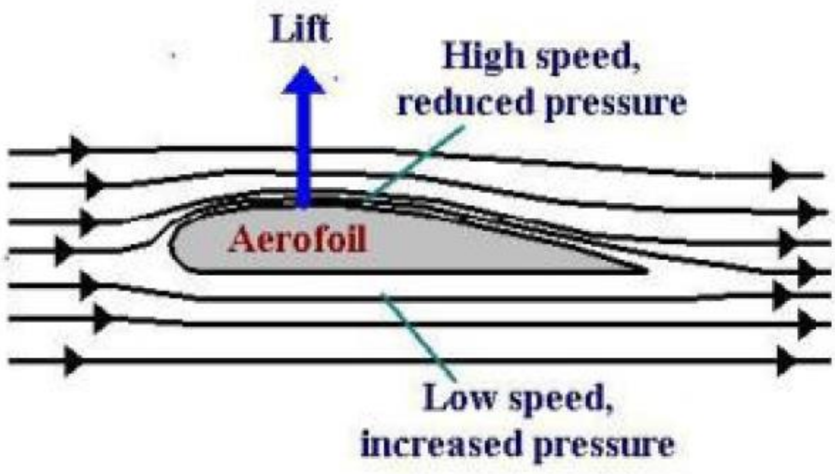

Figure 1: Airfoil producing lift

LITERATURE REVIEW

The number of the previous work has been carried out on the Wind turbine. Our direction is that all previous work was mainly concentrated on design of blade, blade angle and twisting angle to produce the maximum lift which obtained the maximum efficiency of the wind turbine.

(Thresher & Robinson, 2008) observed Wind energy is one of the fastest-growing electrical energy sources in the United States. The United States installed over 5,200 MW in 2007 and experts are forecasting for as much to be installed in 2008. The United States cumulative installed capacity as of Dec. 31, 2007, was 16, 596 MW. Wind turbines have evolved rapidly over the past 20 years and the turbines have grown in size from 100 kW in the early 1980s to over 2.5 MW today. The evolution of wind technology is expected to continue over the next two decades resulting in a continued improvement in reliability and energy capture with a modest decrease in cost. The development of new and innovative rotors, drive systems, towers, and controls is expected to enable this continued improvement in the cost effectiveness of wind technology. Wind energy can supply 20% of the United States' electricity needs by 2030 and will be a significant contributor to the world's electricity supply.

(Schubel & Crossley, 2012) reviewed the current state-of-art for wind turbine blade design is presented, including theoretical maximum efficiency, propulsion, practical efficiency, HAWT blade design, and blade loads. The review provides a complete picture of wind turbine blade design and shows the dominance of modern turbines almost exclusive use of horizontal axis rotors. The aerodynamic design principles for a modern wind turbine blade are detailed, including blade plan shape/quantity, aerofoil selection and optimal attack angles. A detailed review of design loads on wind turbine blades is offered, describing aerodynamic, gravitational, centrifugal, gyroscopic and operational conditions.

(Rehman, 2018) analyzed that among renewable sources of energy, wind is the most widely used resource due to its commercial acceptance, low cost and ease of operation and maintenance, relatively much less time for its realization from concept till operation, creation of new jobs, and least adverse effect on the environment. The fast technological development in the wind industry and availability of multi megawatt sized horizontal axis wind turbines has further led the promotion of wind power utilization globally. It is a well-known fact that the wind speed increases with height and hence the energy output. However, one cannot go above a certain height due to structural and other issues. Hence other attempts need to be made to increase the efficiency of the wind turbines, maintaining the hub heights to acceptable and controllable limits. The efficiency of the wind turbines or the energy output can be increased by reducing the cut-in-speed and/or the rated-speed by modifying and redesigning the blades. The problem is tackled by identifying the optimization parameters such as annual energy yield, power coefficient, energy cost, blade mass, and blade design constraints such as physical, geometric, and aerodynamic. The present paper provides an overview of the commonly used models, techniques, tools and experimental approaches applied to increase the efficiency of the wind turbines. In the present review work, particular emphasis is made on approaches used to design wind turbine blades both experimental and numerical, methodologies used to study the performance of wind turbines both experimentally and analytically, active and passive techniques used to enhance the power output from wind turbines, reduction in cut-in-speed for improved wind turbine performance, and lastly the research and development work related to new and efficient materials for the wind turbines.

(Deisadze, 2013) studied the potential for installing roof-mounted vertical axis wind turbine (VAWT) systems on house roofs. The project designed several types of VAWT blades with the goal of maximizing the efficiency of a shrouded turbine. The project also used a wind simulation software program, WASP, to analyze existing wind data measured on the roofs of various WPI buildings. Scale-model tests were performed in the WPI closed- circuit wind tunnel. An RPM meter and a 12 volt step generator were used to measure turbine rotation speeds and power output at different wind speeds. The project also studied roof mounting systems for turbines that are meant to dissipate vibrations to the roof structure. Turbine vibrations were measured during the wind tunnel tests and in impact tests on a scale-model house. Recommendations were made for future designs of roof-mounted VAWTs.

(Zuheir et al., 2019) examined that owing to the fast development in the energy filed, the demand is increasing to improve energy efficiency and lifetime of wind turbine. Therefore, it's important to understand deeply the behavior of wind turbine under different load conditions. This research paper provides an approach to study and analyze the stresses and deformations under the steady-state condition. Also, it was investigated the vibration characteristics of the NREL offshore 5-MW blade (HAWT) with a long of (61.5 m) and with rotor diameter (126 m). The 3D model of wind turbine blade was created by using SOLIDWORKS and then exported to ANSYS/Workbench19 in order to achieve the numerical simulation based on Finite element method. The steady-state analysis of the selected wind turbine blade was performed at maximum rated power (maximum rotation velocity =12.1 rpm). In this work, three different materials (E-glass fiber, Kevlar, and Carbon fiber reinforced plastic) were selected to build the body of the wind blade parts. The results presented the von-Mises stresses, total deformations, first ten natural frequencies and mode shapes of NREL 5-MW wind turbine blade. In steady-state analysis, it was found that the optimum material was (CFRP) where the minimum level of stresses occurred. In vibration analysis, it was found the material that has a higher structural stiffness is CFRP material which avoids high frequencies and mode shapes.

(Zhang et al., 2019) analyzed that currently in the process of wind farm inspection, wind turbine blade appearance inspection mainly adopts the telescope or high-definition cameras, low detection efficiency, labor intensity and the precision is limited, in order to solve this problem, a kind of wind turbine blades defect recognition system based on image array is proposed. Through the joint of array camera and image processing server, the functions of the image acquisition, processing, and defect recognition and detection results output are implemented. The software of artificial intelligence deep learning based on neural network algorithm is used to identify the defects of blade image, and output quality analysis report, to realize automatic detection of wind turbine blade surface defect. The field measurement results show that the system greatly improves the efficiency and accuracy of wind turbine blade defect detection.

(Bin & Kashem, 2020) observed Wind power generation is playing a pivotal role in adopting renewable energy sources in many countries. Over the past decades, we have seen steady growth in wind power generation throughout the world. This article aims to summarize the operation, conversion and integration of the wind power with conventional grid and local microgrids so that it can be a one- stop reference for early career researchers. The study is carried out primarily based on the horizontal axis wind turbine and the vertical axis wind turbine. Afterward, the types and methods of storing this electric power generated are discussed elaborately. On top of that, this paper summarizes the ways of connecting the wind farms with conventional grid and microgrid to portray a clear picture of existing technologies. Section-wise, the prospects and limitations are discussed and opportunities for future technologies are highlighted. It is envisaged that, this paper will help researchers and engineering professionals to grasp the fundamental concepts related to wind power generation concisely and effectively.

METHODOLOGY

In this section a typical modal of wind turbine is made and experiment was performed on the modal at the different tower height and the different wind speed and obtaining the RPM of the wind is registered for further analysis. Also analysis effects of RPM in term of efficiency are shown. The major components of the model are discussed below:

Figure 2: Experimental setup

Measurement Methodology

In this experiment various type of instrument used to measure the data.

Measurement of the RPM

Digital Tachometer is used to measurement of RPM of the rotor shaft. By the used of Digital Tachometer we have observed the number of rotation of the rotor shaft.

Figure 3: Digital Tachometer

Measurement of Wind Speed
In experiment on the time basis the Digital anemometer is used to measure the wind speed. By the used of Digital anemometer we have measured the inlet and outlet velocity of the rotor shaft.

Figure 4: Digital Anemometer

RESULT AND DISCUSSION

Variation of RPM with respect to wind speed for Smooth surface Blade
When the tower height increase from ground level to 25 m then wind velocity varies from 3.0 m/sec to 4.2m/sec and RPM varies from 75 rpm to 100 rpm.

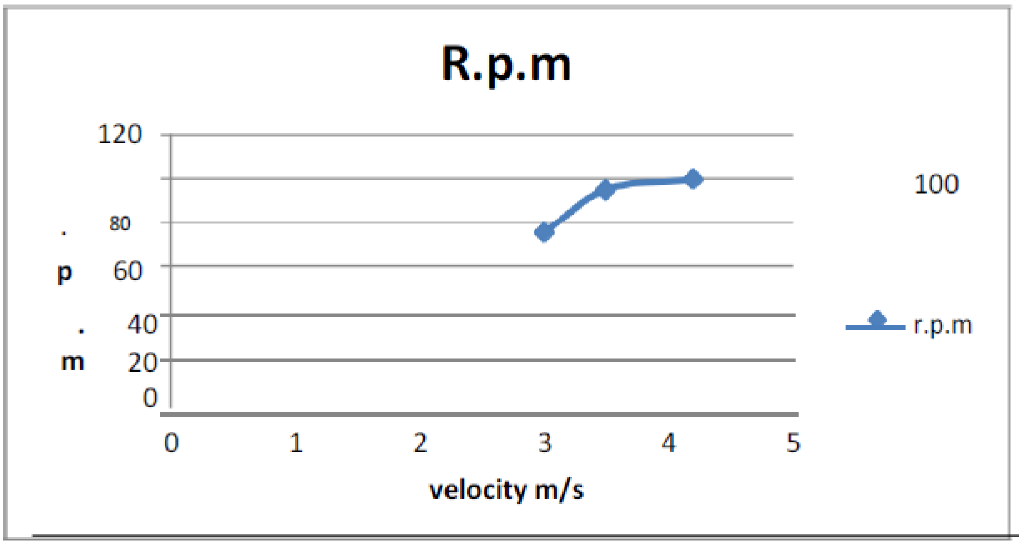

Figure 5: Variation of RPM with Wind Speed

Variation of Actual Power with respect to wind speed for Smooth Surface Blade

When the tower height increase from ground level to 25m then wind velocity varies from 3.0 m/sec to 4.2m/sec.which actual power varies from 4.1203w to 12.89w.

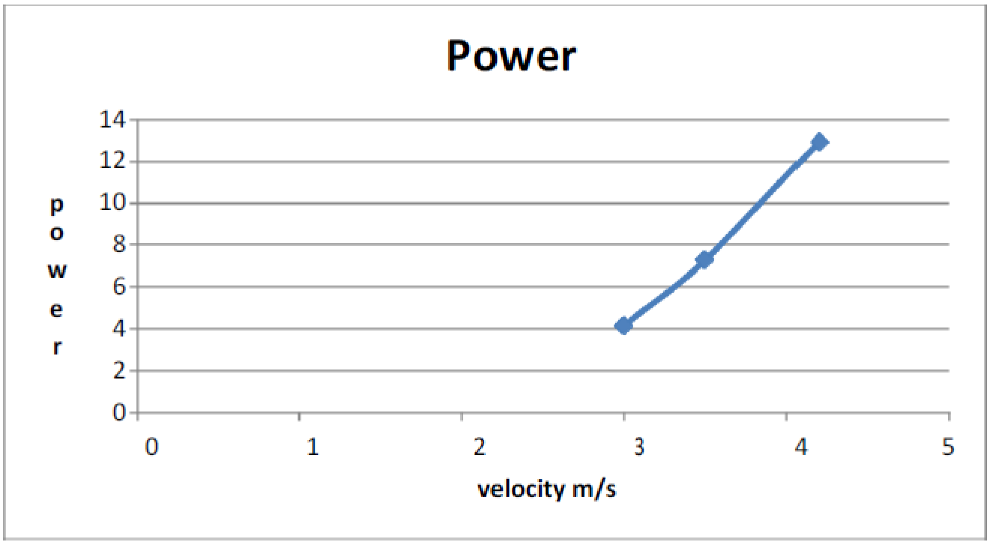

Figure 6: Variation of actual power

Variation of Efficiency with respect to wind speed for Smooth Surface Blade

When the tower height increase from ground level to 25 m then wind velocity varies from 3.0 m/sec to 4.2m/sec.which efficiency varies from 32% to 36%.

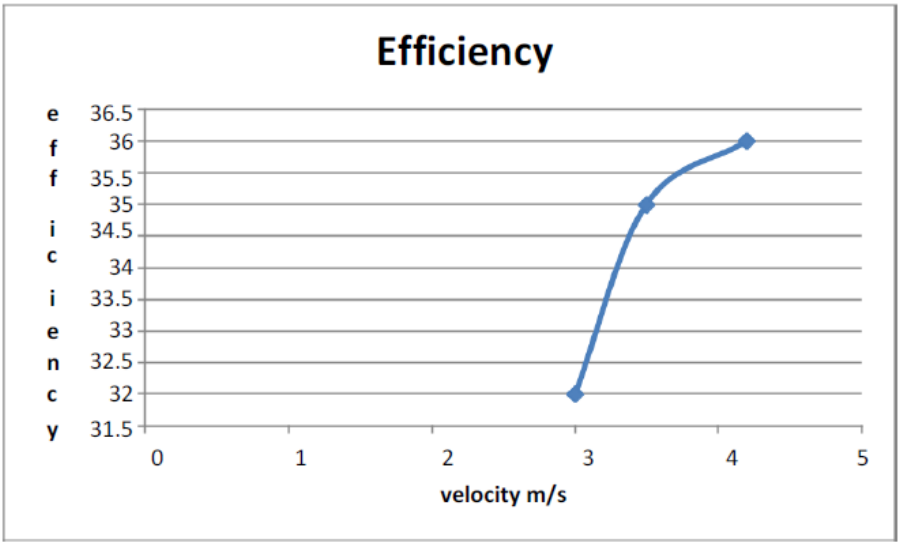

Figure 7: Variation of Efficiency with wind speed

Variation of RPM with respect to wind speed for Roughened Blade

When the tower height increase from ground level to 25 m then wind velocity varies from 3.0 m/sec to 4.2m/sec.which rpm varies from 85 rpm to 115 rpm.

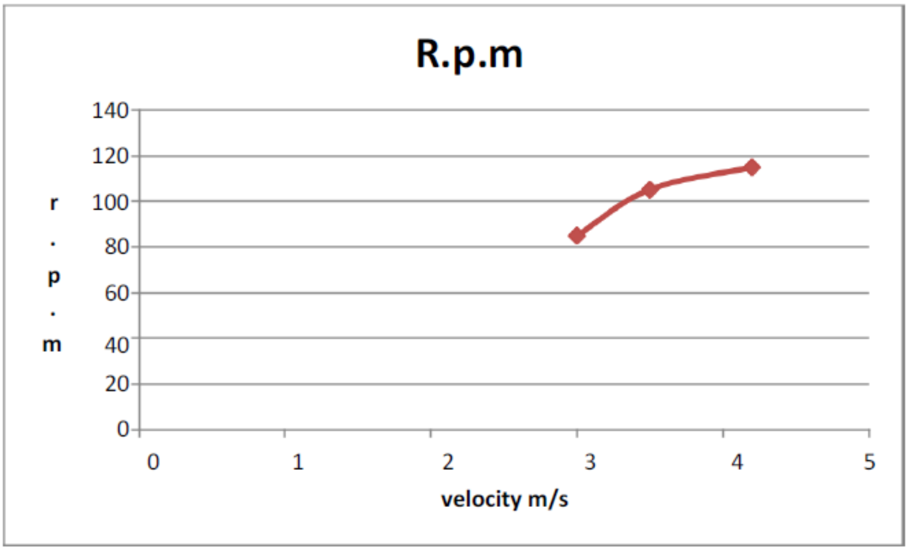

Figure 8: Variation of RPM with wind speed

Variation of Actual Power with respect to wind speed for roughened Blade

When the tower height increase from ground level to 25 m then wind velocity varies from 3.0m/sec to 4.2m/sec.which actual power varies from 5.094w to 16.1553w.

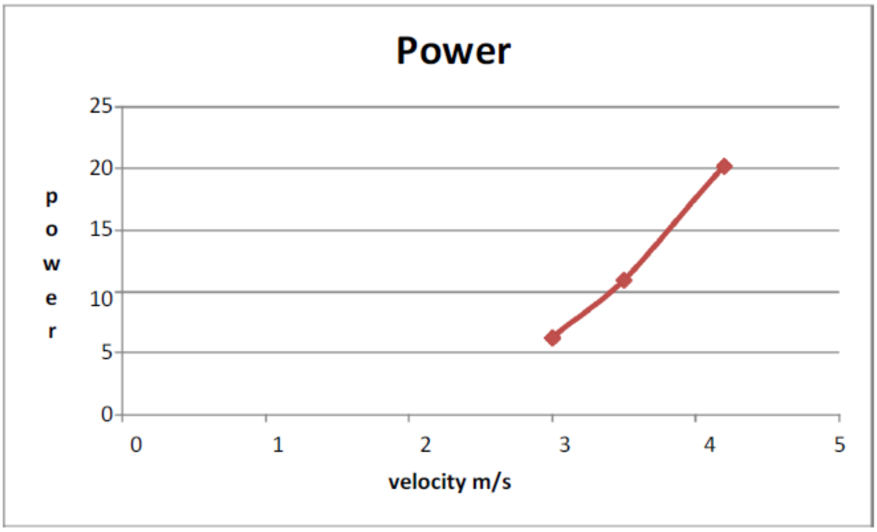

Figure 9: Variation of Actual Power with wind speed

Variation of Efficiency with respect to wind speed for Roughened Blade

When the tower height increase from ground level to 25 m then wind velocity varies from 3.0m/sec to 4.2m/sec.which efficiency varies from 40% to 46%.

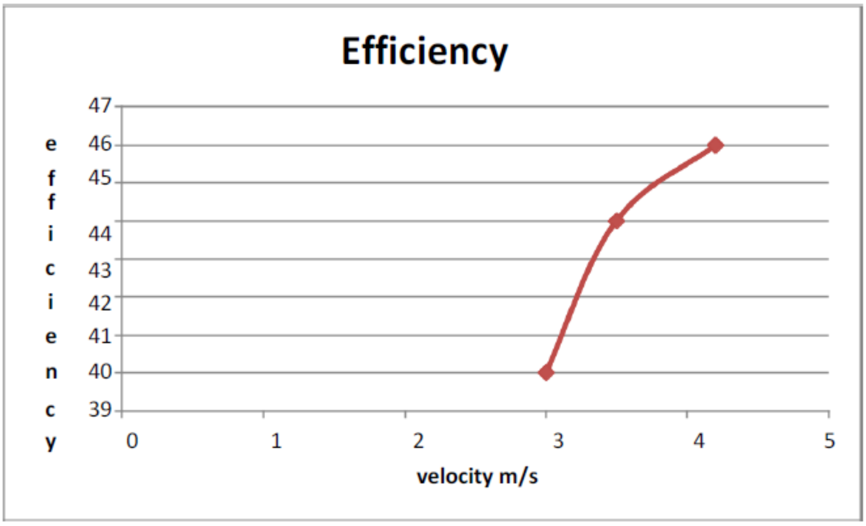

Figure 10: Variation of Efficiency with Wind speed

Variation of RPM with respect to wind speed for Roughened Blade with flap

When the tower height increase from ground level to 25 m then wind velocity varies from 3.0 m/sec to 4.2m/sec.which rpm varies from 100 rpm to 130 rpm.

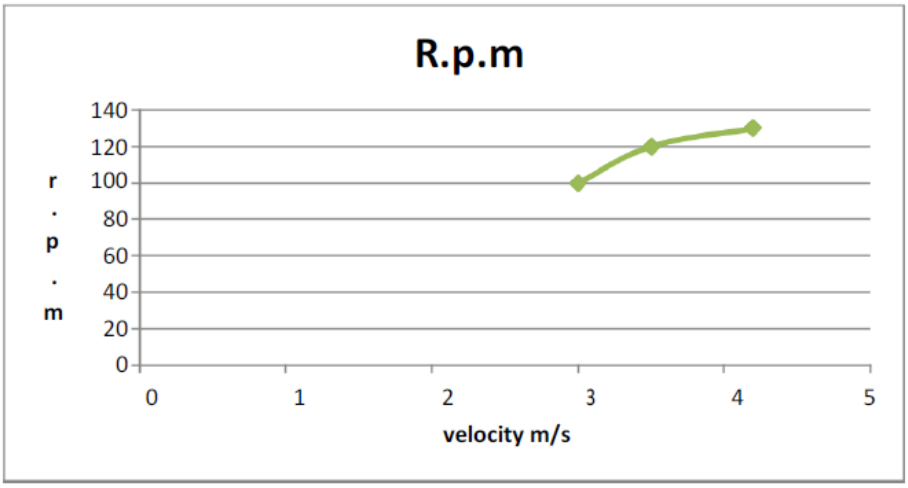

Figure 11: Variation of RPM with wind speed

Variation of Actual Power with respect to wind speed for Roughened Blade with flap

When the tower height increase from ground level to 25 m then wind velocity varies from 3.0m/sec to 4.2m/sec.which actual power varies from 6.265w to 20.24w.

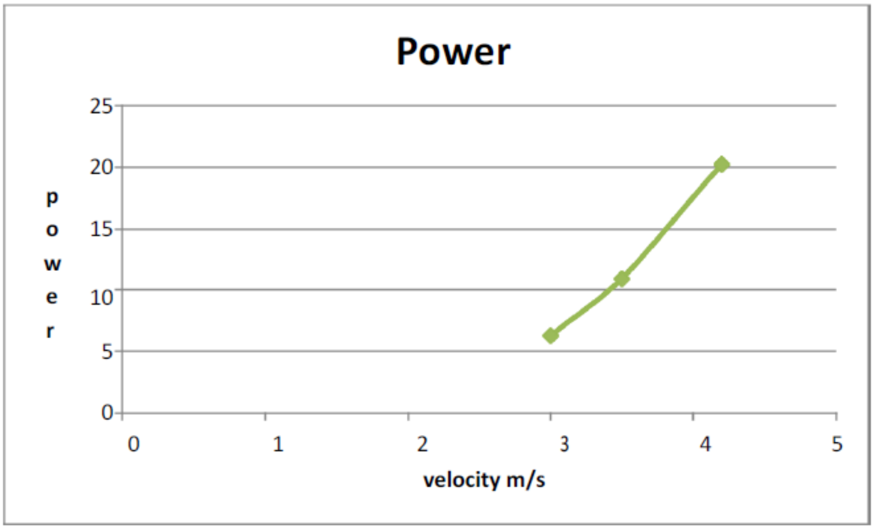

Figure 12: Variation of Actual Power with wind speed

Variation of Efficiency with respect to wind speed for Roughened Blade with flap

When the tower height increase from ground level to 25 m then wind velocity varies from 3.0 m/sec to 4.2m/sec. which efficiency varies from 49% to 57%

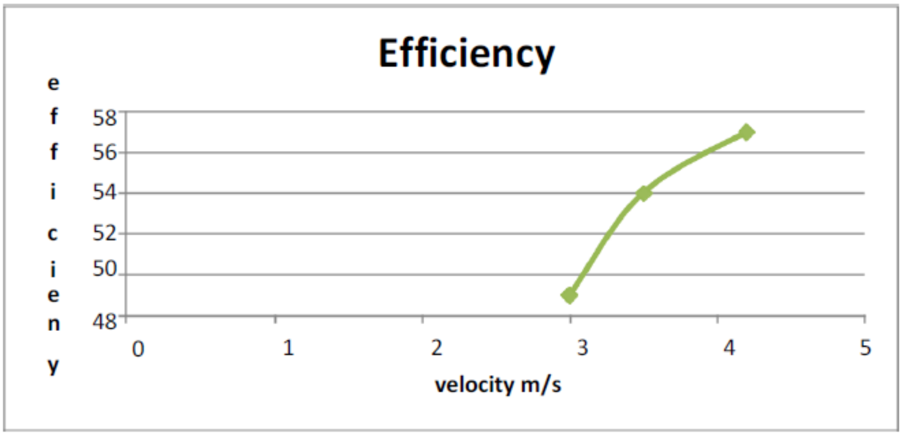

Figure 13: Variation of efficiency with wind speed

Combined variation of RPM with respect to wind speed for smooth, rough and rough surface with flap

When flap are used with rough surface blade Then RPM is optimum. This graph shows that combined variation of RPM of wind turbine with respect to wind speed. In three cases rpm is optimum for rough surface blade with flap used.

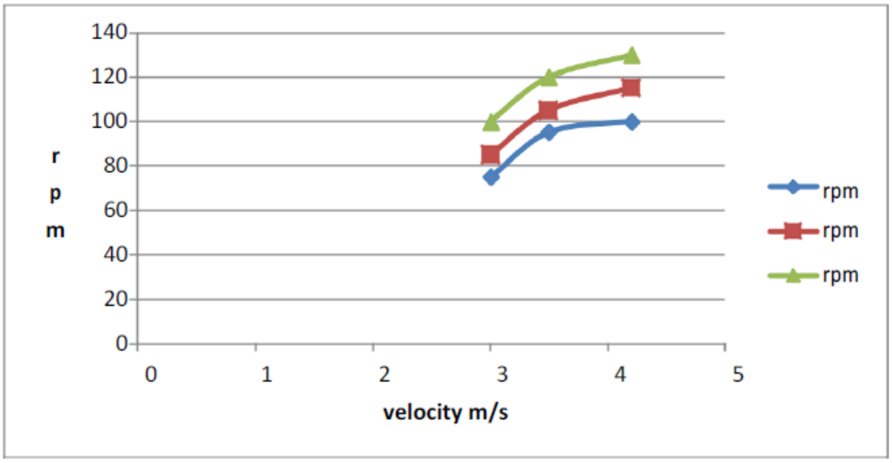

Figure 14: Combined variation of RPM with wind speed

Combined Variation actual power with respect to wind speed for smooth, rough and rough surface with flap

When flap are used with rough surface blade then actual power is optimum. This graph shows that combined variation of actual power of wind turbine with respect to wind speed. In three cases actual power is optimum for rough surface blade with flap used.

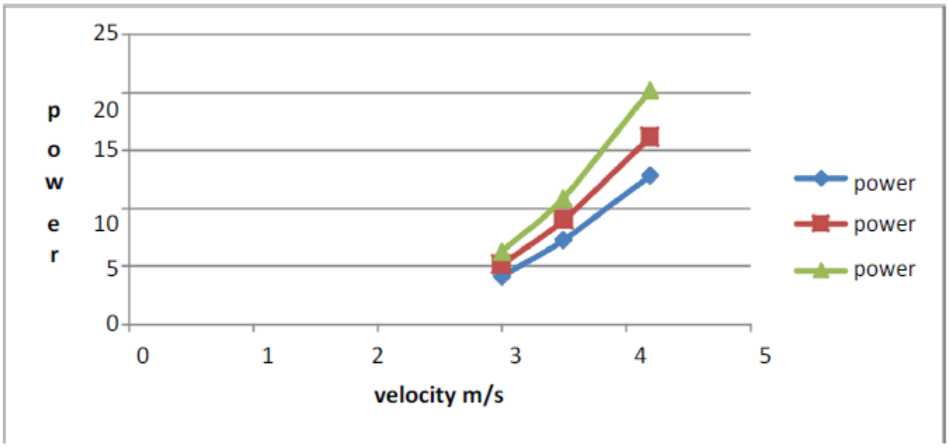

Figure 15: Combined variation of actual power with wind speed

Combined variation of efficiency with respect to wind speed for smooth, rough and rough surface with flap

When flap are used with rough surface blade then efficiency is optimum. This graph shows that combined variation of efficiency of wind turbine with respect to wind speed. In three cases efficiency is optimum for rough surface blade with flap used.

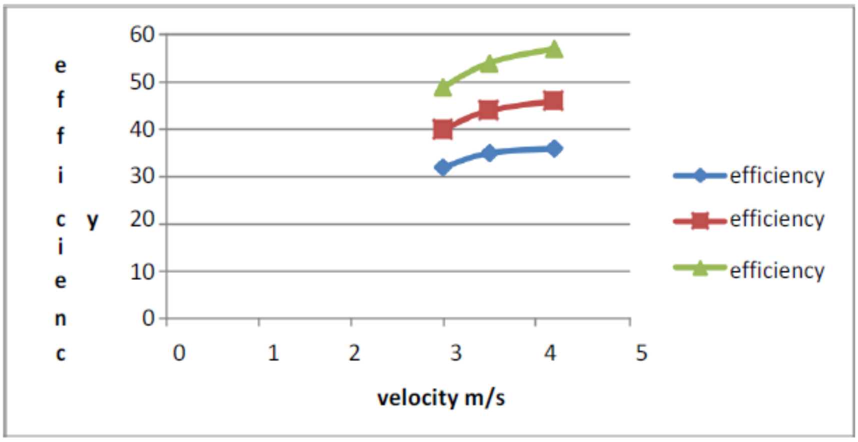

Figure 16: Combined variation of Efficiency with wind speed

CONCLUSION

On the basis of results obtained by horizontal axis wind turbine by using blade of NACA 5510 aerofoil with modified design of lift increasing techniques, following conclusion have been drawn. The results obtained from parameters. The actual power and efficiency of wind turbine were found optimum for the case while using flap with roughened surface blade when compared to the cases of roughened surface blade and smooth surface blade. The efficiency of the wind turbine has increased by 10% when rough surface blade are used and 21% when flap at trailing edge are used while compared to the wind turbine using smooth surface blade then It has also concluded that the efficiency of the turbine using the flap with roughened surface blade found optimum.

- Case-1 Improvement of efficiency for smooth surface blade is 32% to36%.

- Case-2 Improvement of efficiency for rough surface blade is 40% to 46%.
- Case-3 Improvement of efficiency for rough surface blade with flap is 49% to57%.

Further experiments may be conducted for the analysis of Horizontal Axis Wind Turbine by adopting the following recommendations.

- By changing the aerofoil section of the blade.
- By changing the location of the flap for lift optimization
- By changing the material of blade for weight minimization.

REFERENCES

Bin, S., & Kashem, A. (2020). *Wind Power Integration with Smart Grid and Storage System : Prospects and Limitations*. *11*(5), 552–569.

Deisadze, L. (2013). *Vertical Axis Wind Turbine Evaluation and Design*.

Islam, R., Bashar, L. Bin, Saha, D. K., & Rafi, N. (2019). *Comparison and Selection of Airfoils for Small Wind Turbine between NACA and NREL ' s S series Airfoil Families*. *4*(2), 1–11.

Pandey, B. (2019). *Wind Energy : A Review Paper*. *January*. https://doi.org/10.21058/gjet.2018.42004

Rahman, M., Ahmed, M., Bashar, M., Mitra, A., & Salyers, T. (2017). *Numerical and Experimental Investigations on Vertical Axis Wind Turbines of Different Models*. *January*. https://doi.org/10.4236/oalib.1103273

Rehman, S. (2018). *Horizontal Axis Wind Turbine Blade Design Methodologies for Efficiency Enhancement—A Review*. https://doi.org/10.3390/en11030506

Sauvageat, E., Rolin, V., & Port, F. (2016). *Prediction and Comparison of low-Reynolds Airfoil Performance*.

Schubel, P. J., & Crossley, R. J. (2012). Wind turbine blade design. *Wind Turbine Technology: Principles and Design*, *36*(4), 1–34. https://doi.org/10.1201/b16587

Thresher, R., & Robinson, M. (2008). *Wind Energy Technology : Current Status and R & D Future*.

Zhang, N., Lu, C., & Wang, A. (2019). *Study on wind turbine blade defect detection system based on imaging array*. *02041*, 3–6.

Zuheir, S., Abdullah, O. I., & Al-maliki, M. (2019). *Journal of Mechanical Engineering Research and Developments (JMERD) STRESS AND VIBRATION ANALYSES OF THE WIND TURBINE BLADE (A NREL 5MW)*. *42*(4), 14–19.