Design and Analysis of Low Speed Multi-Blades Wind Turbine with Compressed Air Energy Storage (Part 1) - Design of Low Speed Multi-Blades Wind Turbine

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Abstract

The objective of this research is to study the electricity generation system using the low-wind speed multi-blade (30 blades) wind turbine and the system used a reciprocating compressor (piston compressor) to store the wind energy. Wind energy are the general energy sources in nature with infinite energy that can generate electricity. With the limitation of wind speed performance in Thailand (less than 6 m/s.), supplementary of air compressor has been included for electricity production using low speed wind turbine. This research study is aimed to design and fabricate an electricity generator by using the technology implementation in the country for the purpose of price reduction and less parts importation from the other countries. Then, the numerical analysis from CFD is decided to discuss on its performance adaptation for low speed wind turbine especially in the southern region of the country. Under this particular reserch work, a guideline is used to conserve and protect the environment and aslo suitably adjusted the equipment for the country.

Keywords: Design, Analysis, Low speed wind turbine, Multi-blades, CFD Analysis

I. Introduction

Since Thailand suffers from electricity energy crisis, Thailand imports all enery sources from other countries with values not less than 1,000,000 million baht per year and it tends to be increased contiuously. With this reason, it causes the production capital and operational costs to increase in all regions of the country. Thailand consumes energy about 1.4 times of the growth of economy of the contry. In other words, if the economy increased 5%, the energy consumption increased by 7%. It can be seen that energy consumption of Thailand is higher than the developed countries. Therefore, the production capital in The country is high-cost, also, the unstable of internal energy policy in the country had been affected on the project investment of renewable energ. However, the government has been set up the policy to support the incremental use of the renewable energy in the country such as solar energy, biomass, wind energy, and manucipal waste.

Comparison between alternative energy and fuel energy, technically the use of alternative energy provides more energy, is easily moved and cost-effective for users. As for energy production, alternative energy production is cheaper than the fuel energy production including transportation and management (Kaldellis et al., 2017). Solar energy, geothermal energy, wind energy are the general energy sources in nature with infinite energy, thus they are classed as green energy that can generate electricity (Department of Alternative Energy Development and Efficiency Ministry of Energy, 2003). From the study the wind performance in Thailand, it was found that many areas of Thailand (92.6%) have average wind speeds of less than 6 m/s as shown in Table 1 which is at the very low end of wind speeds and it is not suitable for electricity production using wind turbines for high electric energy [HVDC/HVAV] (Lemofouset, 2003). With the limitation of wind speed performance in Thailand, which has low wind speed,

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the energy management processes for electricity production using low wind speed and air compressor shall supplementally be included (Palasai et al., 2010). Wind energy always changes in both amplitude and direction so a wind turbine is used to produce electricity in areas which have high-speed wind and it can result in higher electrical current (Lemofouset, 2003; JIA et al., 2004; Palasai et al., 2010). However, wind energy has the limitation in inconstant wind speeds and thus, it requires many techniques to store the energy for more benefits: especially, to respond to the user need to store daily the left-over energy.

Therefore, in this research study is aimed to design and fabricate an electricity generator using the multi-blade wind turbine (30 blades) by using the technology implemented in the country to reduce price and imports from the other countries. After design the multi-blades wind turbine prototype, CFD analysis befor fabrictaion is decided to discuss on its performance adaptation for low speed wind velocity of the country.

II. Material and Method

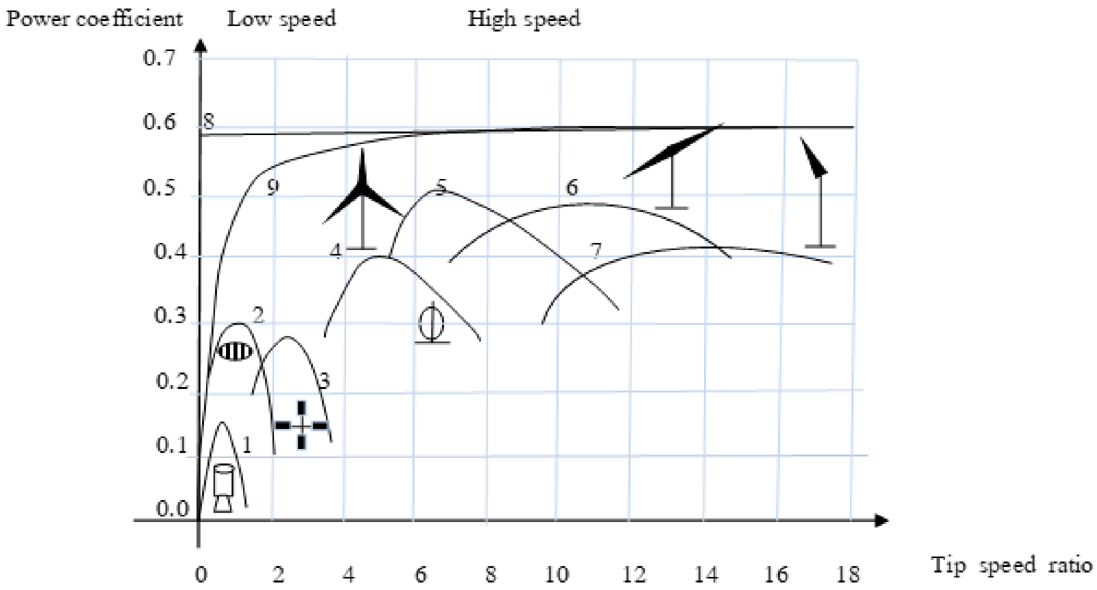
1. Design of low speed multi-blades wind turbine with compressed air energy storage

The application of the CAES is to produce electricity using a multi-blades turbine. The 30 blades turbine is chosen since it meets with the wind turbine standard for water pumping that are widely used in Thailand and it is suitable for wind-speeds less than 6 m/s.

Table 1. Wind speed in Thailand at the height of 65 m.

Average wind speed and characteristic	Poor	Fair	Good	Very Good	Excellent
	(< 6 m/s)	(6-7 m/s)	(7-8 m/s)	(8-9 m/s)	(>9 m/s)
Land area (sq.km)	477,157	37,337	748	13	0
% of Total land area	92.6	7.2	0.2	0	0
M W potential	N A	149,348	2,992	52	0

Table 2 Results of parameters affecting the power coefficient.



1. Savonius rotor
2. Wind pump
3. Dutch windmill
4. Darrieus rotor
5. Three-blade rotor
6. Two - blade rotor
7. One – blade rotor
8. Betz' limit
9. Ideal rotor

According to previous studies, it was found that the use of a muti-blades turbine can provide more torque, as shown in Table, 2 which is suitable for the low-wind speeds of Thailand. The energy storage for this compressed air is very small and provides very low compressed air. This is consistent with low wind speeds and therefore the turbine can spin continuously and constantly. The compressed air from the compressed air tank is passed to a compressed air generator to generate the electricity and connected to the power line of the Provincial Electricity Authority of Thailand (PEA). The PEA has funded and supported the compressed air energy storage using low speed multi-blade wind turbines in Thailand which is similar to this topic.

The electricity generation system using the multi-blade wind turbine has the concept as follows: it will store the compressed air while the turbine is spun. The axle of turbine is connected to a piston and it functions to pump air into the compressed air tank. Once the tank is full, the valve is opened with a suitable pressure and the air is then transmitted to drive another piston in which its shaft is connected to the generator to supply the AC electricity to the distributed power line of PEA. Such systems can accumulate the wind energy for all wind speed that can drive the turbine to spin. The storage in the form of compressed air is low in the operation and maintenance costs with a long-term life time (20-30 years) which is longer than a battery life time (3-5 years). This research studies can creates the prototype of the electricity storage system using a multi-blade turbine (30 blades) to compress the air in a low wind speed environment. The researchers selected the compressed air system with pressure less than 7 bar which is standard for compressed air storage and accumulate energy in the compressed air tank to produce the electricity as shown in Fig. 1. The experimental and calculated results of the performance and efficiencies of each system are compared with those in the laboratory as shown in Fig. 2.

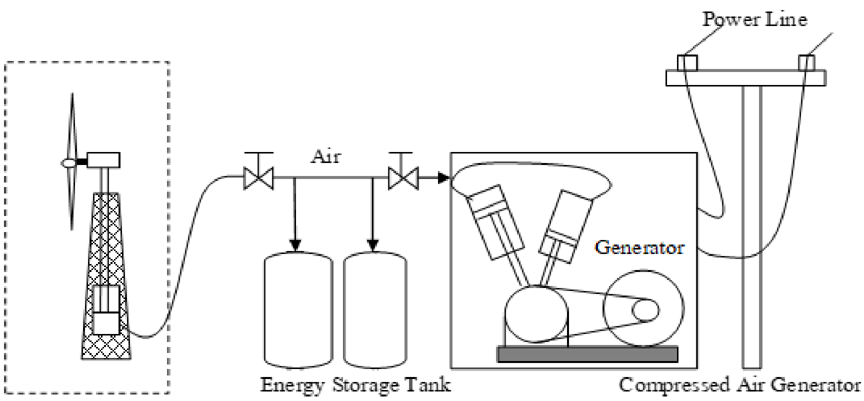


Figure 1. Electricity Generation System using Multi-blades Turbine and Compressed Air Storagev

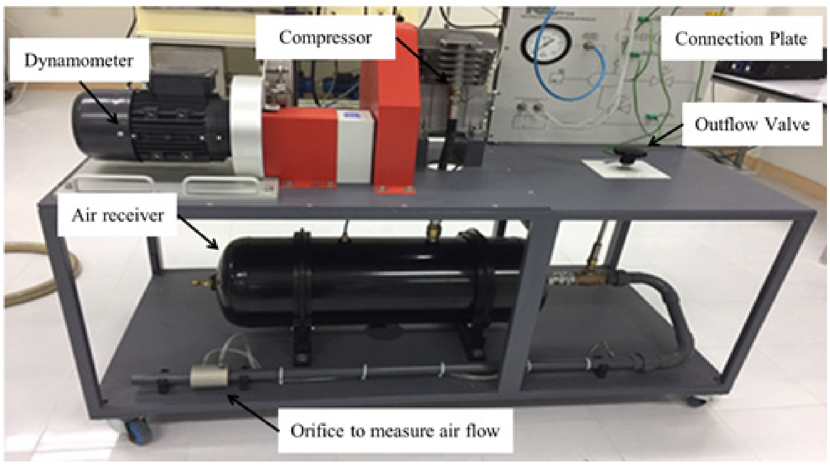


Figure 2. Laboratory test set for measuring the compressed air system using piston (The motor is used to replace the wind turbine)

2. Design and fabrication of multi-blades wind turbine prototype for compressed air

The guideline to use the wind energy at highest efficiency of this research (As shown in Fig. 3) focuses on the design of the turbine to be suitable for air compression and for areas of installation of the turbine. The wind turbine can produce energy if the wind speed is not too high or too low. Once the turbine is stopped, the rotor cannot produce energy. It is important to find the proper wind speed to obtain the maximum power.

$$\text{Power coefficient } C_P = \frac{P}{\frac{1}{2}\rho A V^3}$$

$$\text{Torque coefficient } C_Q = \frac{Q}{\frac{1}{2}\rho A V^2 R}$$

3. Analysis of low speed multi-blades wind turbine

As a results, the design before calculating by Computational Fluid Dynamics, CFD has been shown in Fig. 4.

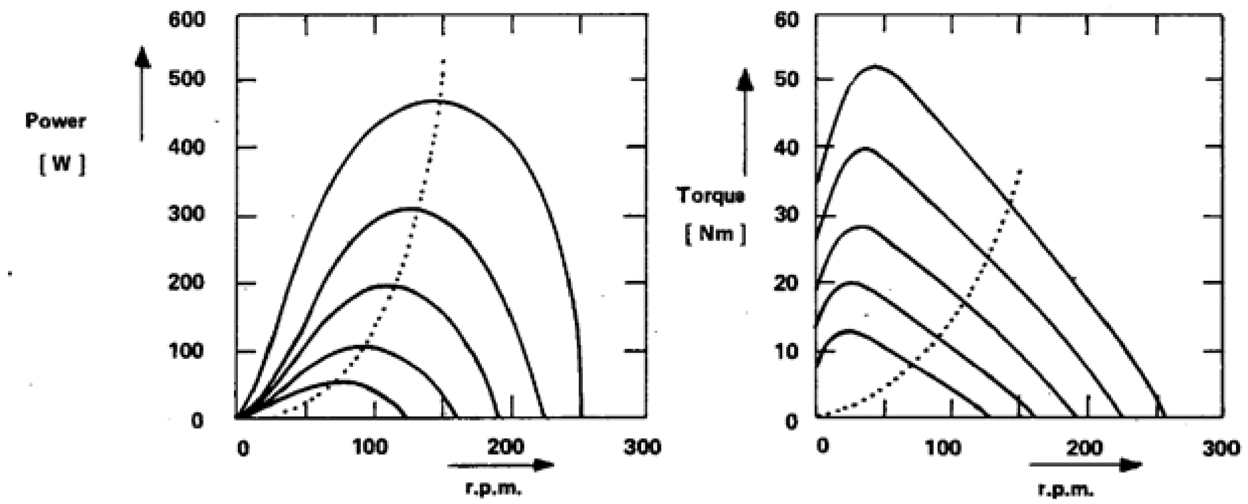


Figure 3. Relationship between the power and torque of rotor at different wind speed

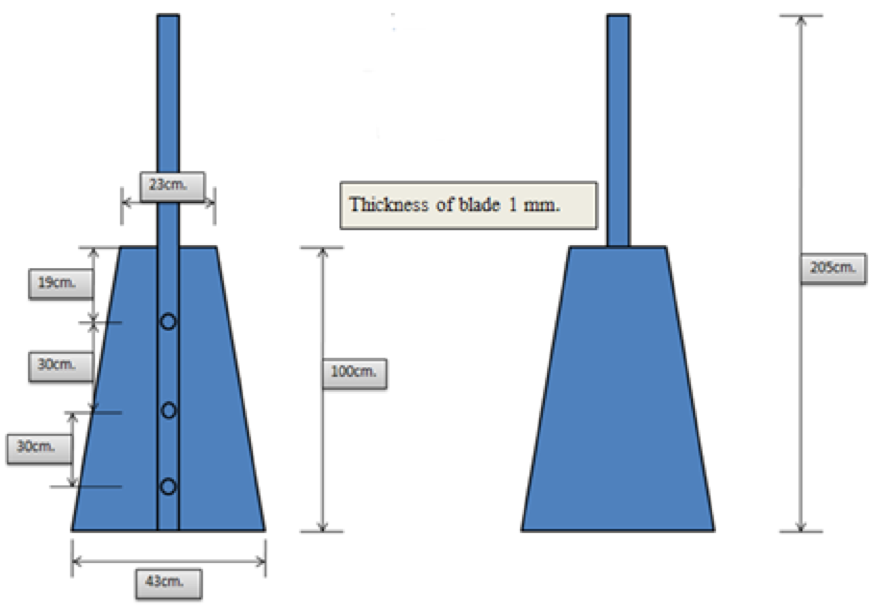


Figure 4. Shapes and dimensions of multi-blades wind turbine

The model has been designed and engineered by using the CFD including with the momentum theory verification. as follow:

Blade materials = Flat plate; Blade radius = 2.75 m. ; Number of blades = 30 ;

Wind turbine = Non twist blade ; Cut in wind speed = none ; Cut out wind speed = none

III. Result and discussion

1. Analysis simulation vector of low speed multi-blades wind turbine

Fig. 5 shows a model for numerical analysis. ANSYS FLUENT V.15 was used to study the behavior of air flow through a multi-rotor wind turbine by defining the conditions of the wind speed of 2-5 m/s. Under this particular studies, the results show the effects of power and torque and also the algorithms used in the calculation are SIMPLEC (Semi-Implicit Method for Pressure Linked Equations-Consistent) and turbulence models k-ε, which are commonly used in turbine flow calculations due to their less resources and high accuracy. The condition will stop at the error value below 1.0E-5. And the inlet boundary condition is defined as the velocity inlet with uniform wind velocity across the cross-section. While the back will be the outlet of the pressure (pressure outlet). The model mesh is set to rotate around the center of rotation (Turbine Axis). The grids near the surface are optimized to increase computation accuracy. For the case of a displacement effect in the boundary layer, the y + value of the turbine surface in the case of a 5 m / s wind speed is controlled to be less than 10 m/s. Then, the number of grids of the entire model become 6.5 million.

Figs. 6 and 7 show the behavior of the inlet air flow and the back of the turbine at wind speed of 2 m/s. The velocity vector shows the spinning of air as it

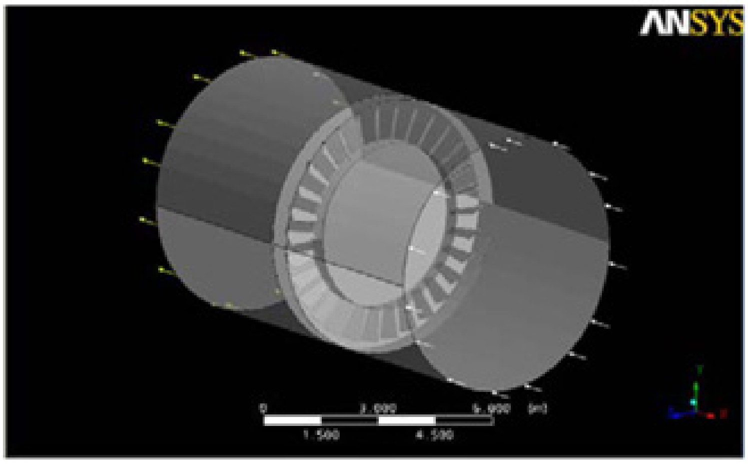


Figure 5. Simulation of multi-blades turbine in wind tunnel

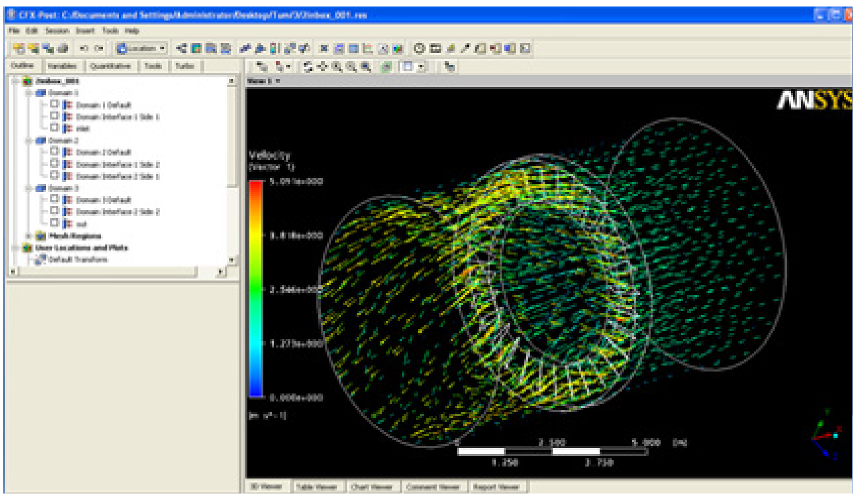


Figure 6. Vector of wind speed of 2 m/s

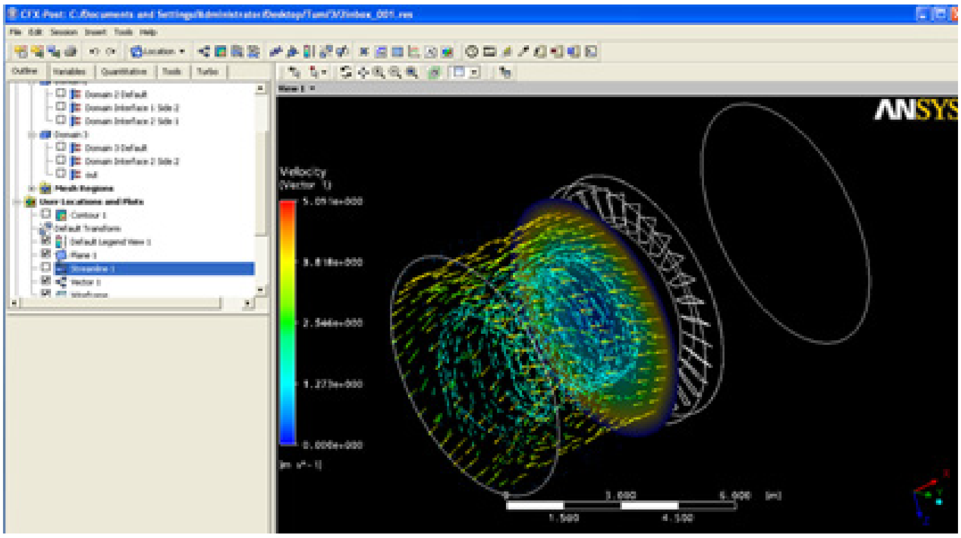


Figure 7. Vector of the back of the wind turbine at wind speed of 2 m/s

Figure 8. Installation of the multi-blade wind turbine

flows through a turbine. Then, the impact of the flow against the turbine blades affects the direction of the axial air flow sides due to the installation of the turbine blades with torsional angles. The turbulence flow will occur at the rear even after passing through the turbine. But the intensity of the turbulence is reduced, which is observed from the vector orientation that has begun to align the flow to the axis again. Then, the fabrication and installation of the multi-blades wind turbine has been done as shown in Fig. 8.

2. Analysis Results

Fig. 9 shows the relationship between torque and rotational speed of a multi-blades turbine. From the simulation with wind speed conditions in the range of 2-5 m /s, the results of the study showed that the correlation lines in each velocity were similar. And the torque increases with the the increasing of the rotational speed within 4 rpm. And also at the rotational speed of 4 rpm, the torque is maximal in all wind speed conditions and decreases continuously with the increasing of wind speed. The decreasing rate of torque after the initial peak is higher than the range of higher rotational speed. Under this study, the rotational speed range at the maximum torque value has been corresponded to the wind speed where the maximum speed condition is 5 m /s. Then the multi-blades turbine is able to generate 3100 N.m of torque.

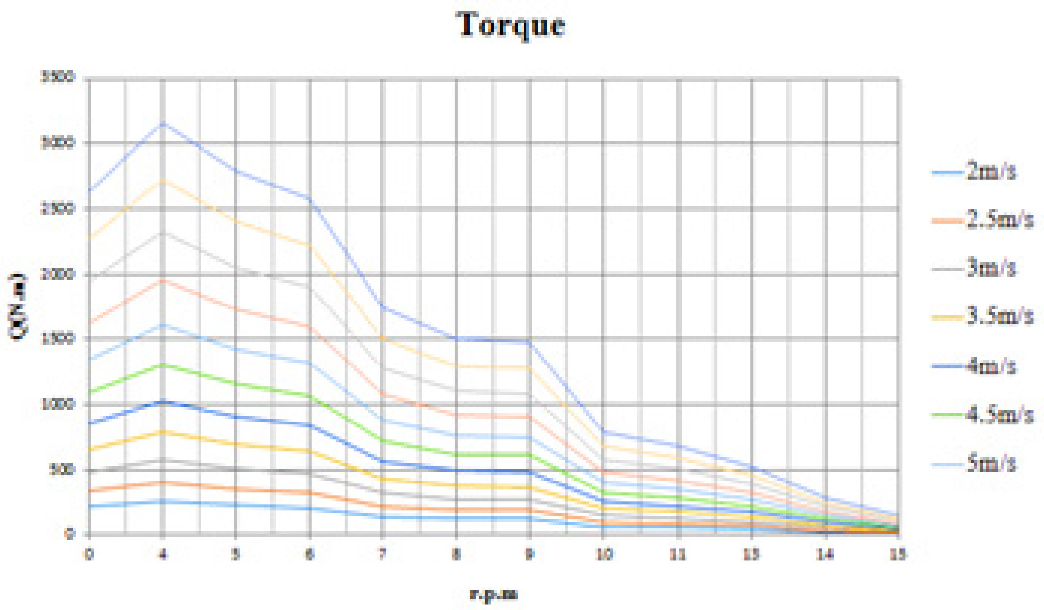


Figure 9. Torque of multi-rotor blades Turbine

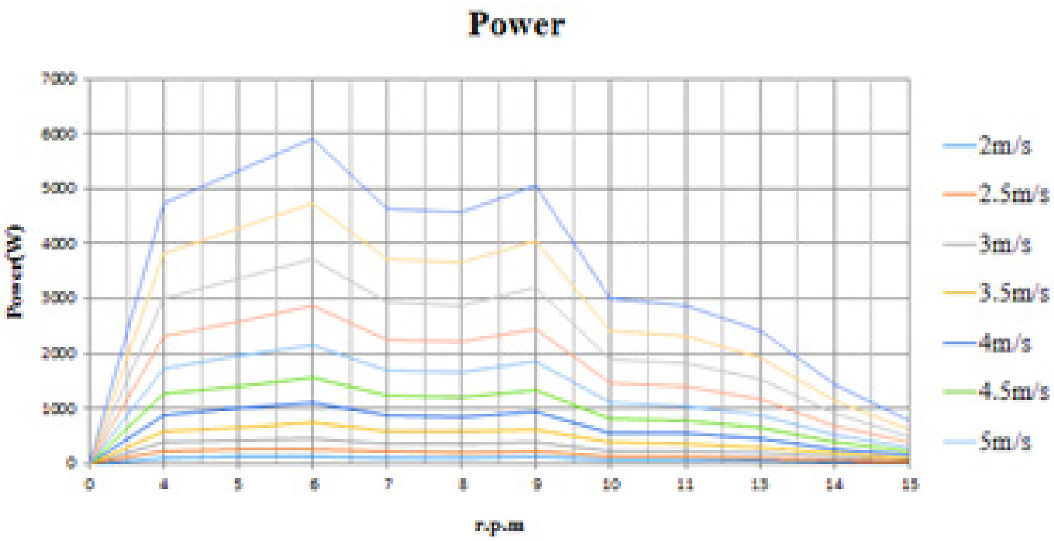


Figure 10. Power from multi-blade Turbine

Fig. 10 shows the relationship between power and speed of a multi-blades turbine in the range of 2-5 m /s wind speed. From the study, it was found that the relative speed of each speed was similar to the results of torque. But the maximum power will occur at a higher rotational speed at 6 rpm. A turbine with a higher wind speed has a greater maximum power. And the reduction rate of the power after the initial peak is less than the range of the higher rotational speed.

Fig. 11 shows the comparison between torque and turbine power at the wind speed conditions of 5 m /s which is a condition in which the turbine has maximum torque and power. The comparison results will determine the optimal rotational speed in the multi-blades turbine applications due to the torque and power peaks occur at the different rotational speeds. The optimal turbine speed in this study was 5.2 rpm.
which is in the range of the maximum torque and power of the multi-blades turbine. At this rotational speed, the torque and power of the multi-blades turbine has been reduced from the max value of xx and yy percent respectively.

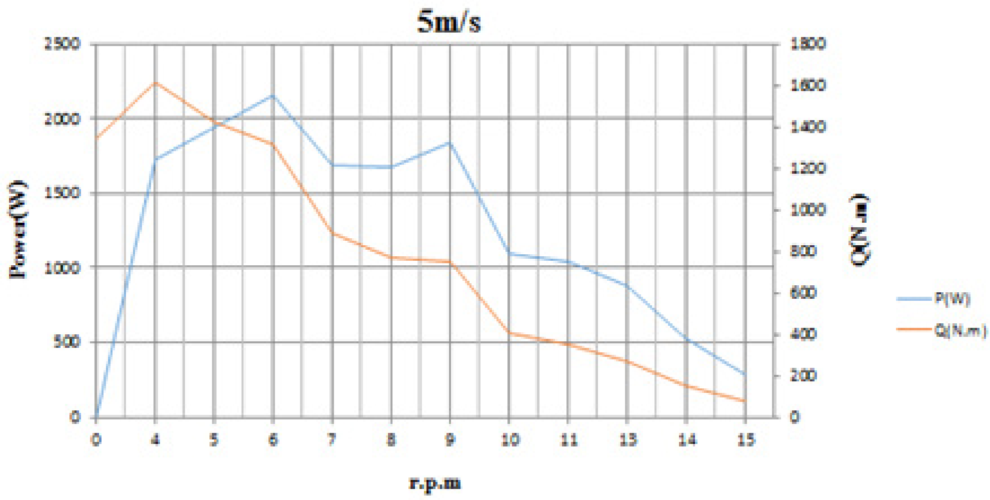


Figure 11. Simulation results at wind speed of 5m/s

IV. Conclusion

The study results of the electricity generator using the multi-blade turbine (30 blades) and air compressor to store the wind energy using a piston are shown a model for numerical analysis by defining the conditions of the wind speed of 2-5 m/s. Under this particular studies, the effects of power, torque and also the algorithms used in the calculation are SIMPLEC and turbulence models k-ε, which are commonly used in turbine flow calculations. The correlation lines between torque and rotational speed of a multi-blades turbine in each velocity were similar. And also the torque increases with the the increasing of the rotational speed and at the rotational speed of 4 rpm, the torque is maximal in all wind speed conditions and decreases continuously with the increasing of wind speed. For the case of the relationship between power and speed of a multi-blade wind turbine in the range of 2-5 m/s wind speed, the maximum power will occur at a higher rotational speed at 6 rpm. And the optimal rotational speed in the multi-blades wind turbine applications in this research study was 5.2 rpm which is in the range of the maximum torque and power.

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