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Development of Vertical Axis Wind Turbine (VAWT) using Magnetic Levitation (MAGLEV)

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ABSTRACT

Vertical Axis Wind Turbine (VAWT) is a turbine with similar principle as the Horizontal Axis Wind Turbine (HAWT) with exception to its fan blade design being on vertical instead of horizontal. The operation of a conventional Vertical Axis Wind Turbine (VAWT) uses the standard ball bearing which limits the rotational force of the turbine due to the friction exist within the bearing. This friction force limits the output the turbine can actually produce. By using MAGLEV concept, the resistance can be reduced as the turbine fan will levitate by magnetic force and encourages it to stay in motion without external force for a longer time period. This project was designed using Autodesk Computer Aided Design (AutoCAD) and the performance of the proposed prototype was tested based on the rotation speed and output voltage produced. The project results in producing higher output compared to a standard conventional VAWT. Lastly, the data recorded was analysed based on the total voltage produced by the MAGLEV implemented turbine.

Keywords:
VAWT; HAWT; MagLev; AutoCAD

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1. Introduction

Magnetic levitation, magnetic suspension, or MAGLEV is a method of suspending an object without anything holding or supporting it. The effect of acceleration of gravity or any other acceleration can be counteracted using magnetic force.

The two main problems involving magnetic levitation are the lifting or repulsive forces which are to provide sufficient lifting force to counteract the stability and the gravity of the levitated object which is to make sure that sliding or flipping to the point of neutralizing the lifting force of the system does not.

A permanent magnet retains several advantages over the conventional electromagnets as it does not require an input power and cooling power. Despite their loss-free property, magnets work better at room temperature compared to superconductors.

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2. Analytical Review

2.1 Magnetic Levitation (MagLev)

Levitation and suspension have been for centuries associated with psychic and strange phenomena in which an object occupies a fixed position in a gravitational field without any direct physical contact [13]. Magnetic Levitation (MAGLEV) is the term used to refer the phenomenon which usually can be found in high speed bullet train railings.

One of the major drawbacks of VAWT is its frictional losses and maintenance of thrust bearing. This problem can be resolved by the implantation of the MAGLEV bearing. Magnetic Levitation uses two similar pole (N-N or S-S) facing ring magnets for reducing friction to minimum [3]. MAGLEV is a system that uses magnets similar poles to produce a repulsing force that enables the object to levitate or float in place. This results in an almost none frictional moving object making the efficiency of it to be increased.

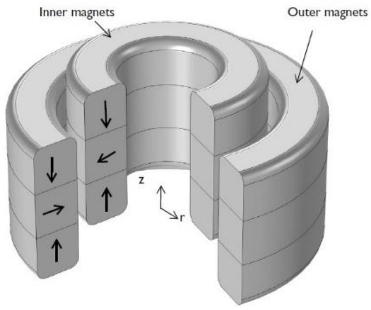


Fig. 1. Maglev Concept

2.2 Neodymium Magnet

Neodymium–iron–boron (Nd–Fe–B) magnet with very square, highly coercive hysteresis loops has expanded the application range of magnets to electrical engineering [10]. The MAGLEV part of the project consists of neodymium alloy magnet which harnesses strong magnetic properties. These magnets are used for the purpose of creating a floating bearing for the wind turbine, as well as for the induction of voltage to be produced as on output for the turbine.

2.3 Halbach Array

The Halbach array is an array of which, by rotating the magnetization direction, formed permanent magnets (PM) are placed in a line. As long as the cross section of the PM is square, a strong and sinusoidal distribution of magnetic flux density appears on one side of the array, while on the other side the weak distribution appears [5]. Magnetic force can be enhanced by using Halbach Array principle in which multiple magnets are aligned in specific way in order to increase the magnetic force of the magnet on one side and decreases it on the other side. The basic utilities for this principle can be seen on the refrigerator magnet.

Halbach array also reacts differently with copper as normal magnetic force does not apply to it. When magnets are moved in halbach array's configuration, a repulsive force reacts from the copper with addition to the copper's temperature also increase.

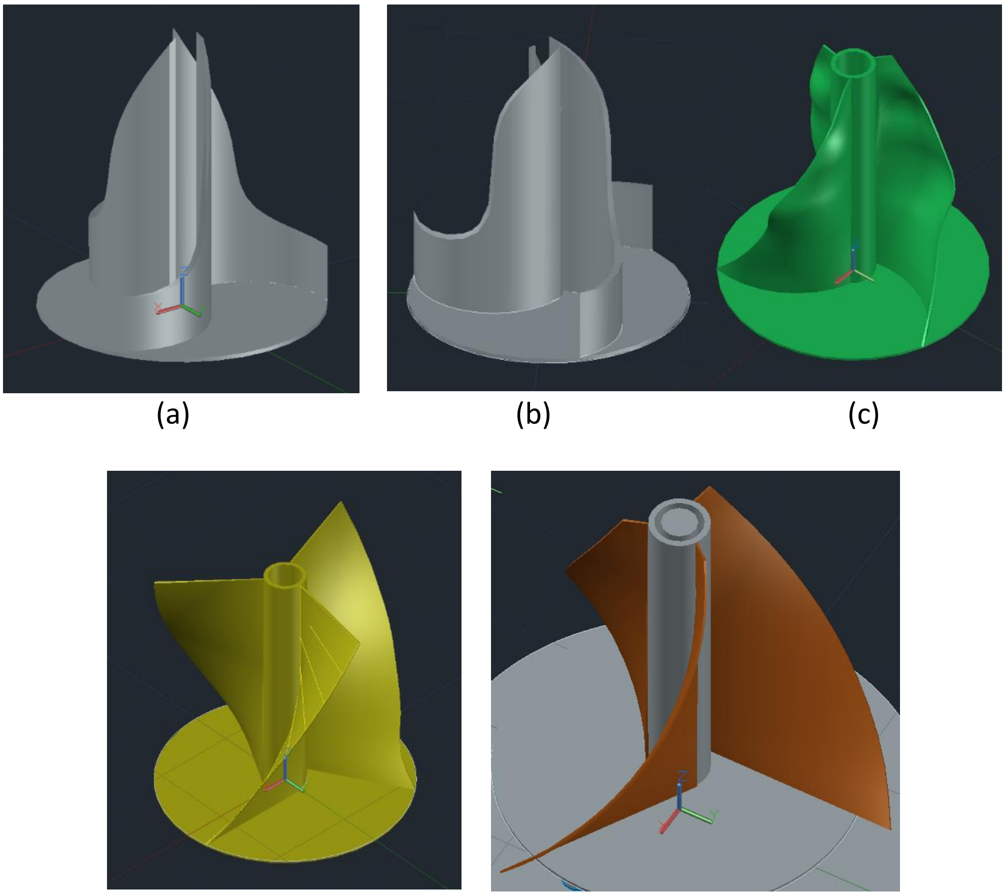
3. Methodology

3.1 Design Stage

In the design stage which is undoubtedly an important part in any development project, AutoCAD software was used as the drafting tool while Ansys software was used to simulate the effectiveness of the created design. Parts of the project that involves designing are the fan blade part, MAGLEV bearing part, and the induction coil part in 3D view.

3.1.1 Fan Blade Design

The development of a Vertical Axis Wind Turbine (VAWT) are generally consists of the 3 types of VAWTs, however the Savonius type for the VAWT family was chosen as its design are much simpler and can trap more airflow as well. Based on all the design created, design (b) was chosen and implemented on the hardware construction phase.



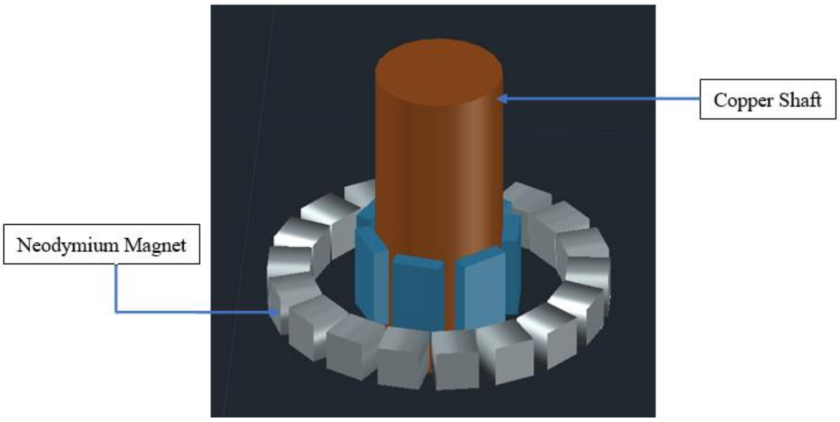
(a) (b) (c)

(d) (e)

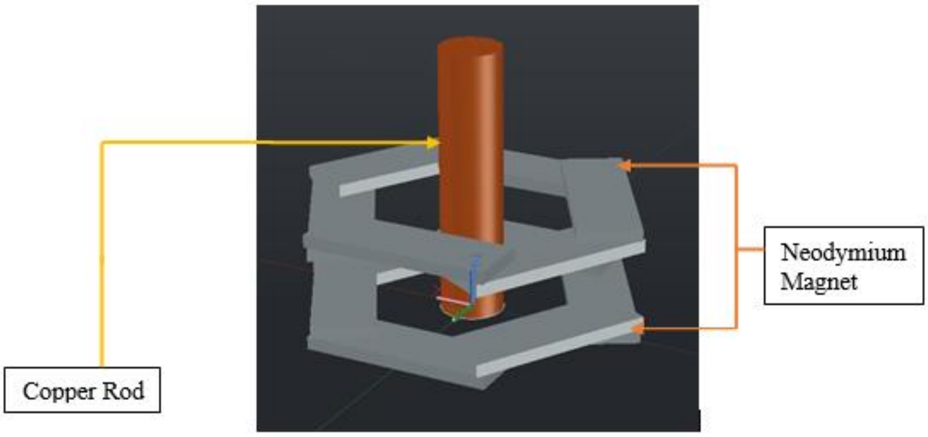
Fig. 2. Fan Blade Design

3.1.2 MagLev Bearing Design

The MAGLEV part of the turbine uses neodymium magnets of same polarity in order to repel the fan part of the turbine from the body of the turbine. The repelling force acting on the fan blade part will ensure it to be afloat and reduces the friction of the turbine from using a standard ball bearing. This will also lower the turbine’s starting torque as lower wind force are needed to rotate the fan blade.



(a)



(b)

Fig. 3. MAGLEV bearing

3.1.3 Coil Design & Arrangement

The diameter of the copper coil wire used is 0.6 mm thick. The number of turns made on each of the coil is 400 turns and are placed 10 units of them around the base of the turbine. The number of turns determines the total output voltage the turbine can produce as well as the number of units placed on the base.

Fig. 4. Inducing Coil design

3.1.4 Base Design

The Base of the prototype that are used consists of 6 metal rod in which they are linked to form a triangle. The base are made as such in order to minimalize the cost needed to make it while making it big enough to support the copper rod welded at the centre of the base.

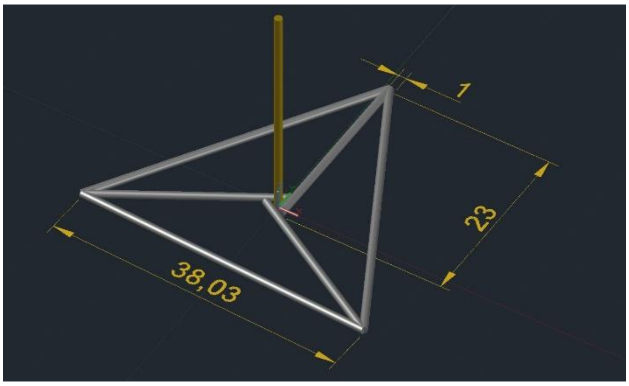


Fig. 5. Base structure design

3.1.5 Airflow Simulation Process

The fan blade designed needs to be simulated for the airflow in order to achieve the best result. Ansys software was used to simulate the air flow acting on the fan blade design. The air flows are critical in maintaining the speed of the fan blade and to make sure it can capture as much as airflow as possible without the risk of the fan blade to spin too fast encouraging an overload of output voltage.

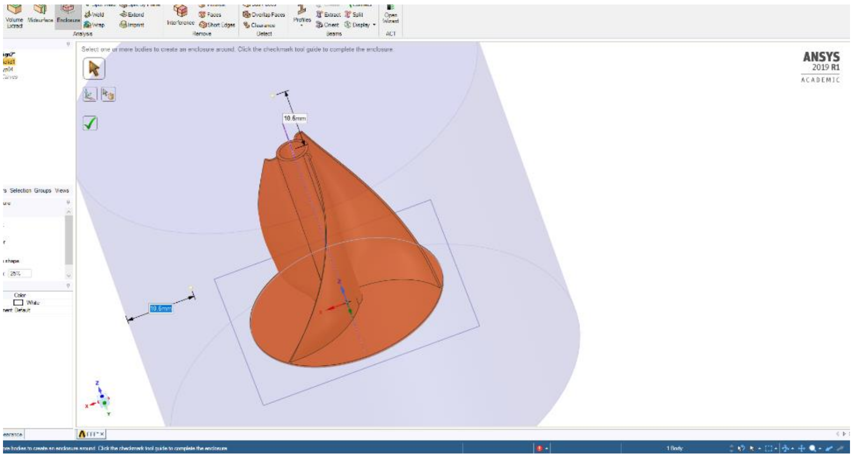


Fig. 6. Defining enclosure in Ansys.

3.1.6 Materials Selection

The materials that are needed to develop the prototype of this project needs to be light and strong enough. Therefore, the selection of materials is one of the most important things to consider. It is critical to choose only suitable and reasonable priced materials for the product's development.

3.2 Hardware Construction

The hardware part of the project shows the implementation of the software design into its hardware counterparts.

Table 1
Material selection for the Vertical Axis Wind Turbine (VAWT) using Magnetic Levitation (MAGLEV)

Classification	Material	Specification	Standards that needs Consideration
Shaft	-Metal or Steel Rod	-Used as the shaft and main body of the turbine	-Strong and Sturdy
Fan Blade	-Aluminium Sheet	-Used as the fan blade part. -Able to catch the airflow.	-Light and strong. -Easy to work with to produce specified shape.
Base	-Acrylic Sheet	-Used as the base of the fan blade and the turbine's base.	-The fan Blade part needs to be light and strong -The Base part needs to be heavy and sturdy
Bearing	-Ball Bearing -Neodymium Magnets	-Used to hold the fan blade part in place for rotational purpose.	-Ball bearing for the conventional turbine setup -Neodymium magnets for the MAGLEV bearing setup

3.2.1 Experimental Setup

Figure 7 shows the full configuration of the experimental setup used to measure the voltage output of the prototype, wind speed, as well as the rotational per minute (RPM) of the prototype. The wind input are generated by the industrial fan which supplies consistent amount of wind energy to achieve a stable output.

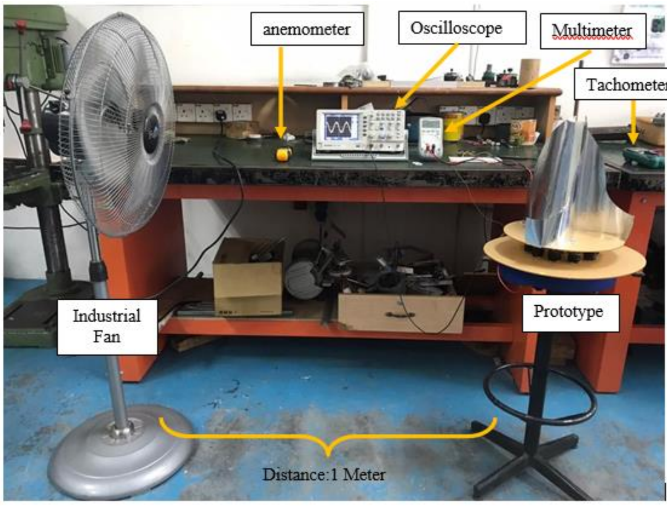


Fig. 7. Experimental testing configuration.

4. Results

Discussion on the results and analysis made from the achieved result of the project developed are found in this chapter. The data was taken was based on the developed VAWT with MAGLEV performance in comparison to a standard VAWT prototype. The airflow simulation shows the result of a better turbine blade design while the outputs of the product are recorded in output voltages and rotational speed of the turbine.

4.1 Airflow Simulation Result

By using the Ansys software, a result simulation based on the airflow of the fan blade design can be achieved as shown in Figure 8.

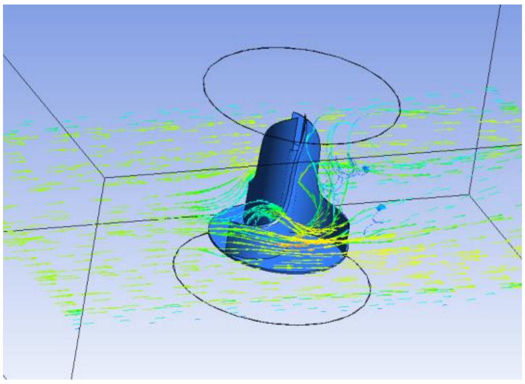


Fig. 8. Airflow simulation in Ansys

4.2 Performance of Wind Turbine Using Maglev

The results obtained from the experimental configuration were recorded in table as well as graphs form. Each iterations of the test, the wind speed were measured up to 3 times before the average of the readings was taken and set as benchmark values. Anemometer was placed near the turbine location to determine the amount of wind speed received at the fan blade.

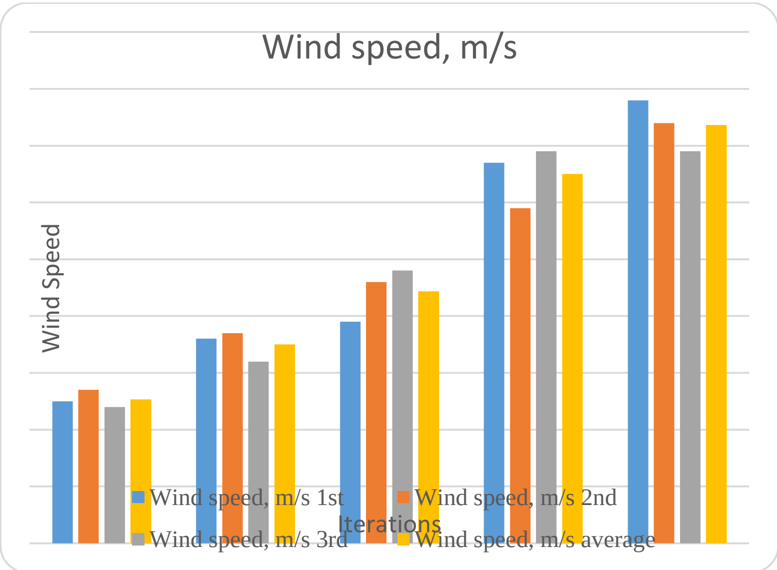


Fig. 9. Wind speed graph

Figure 10 shows the graph of wind speed against RPM values. The overall results shows the the increasing amount of wind speed increases the rotational speed of the fan blade. However, the fan speed shows its upmost potential speed to 253.33 rpm at 4.43 m/s before decreases slightly to 250 rpm at 6.5 m/s. The results show that a stale state was achieved after reaching 253.33 rpm.

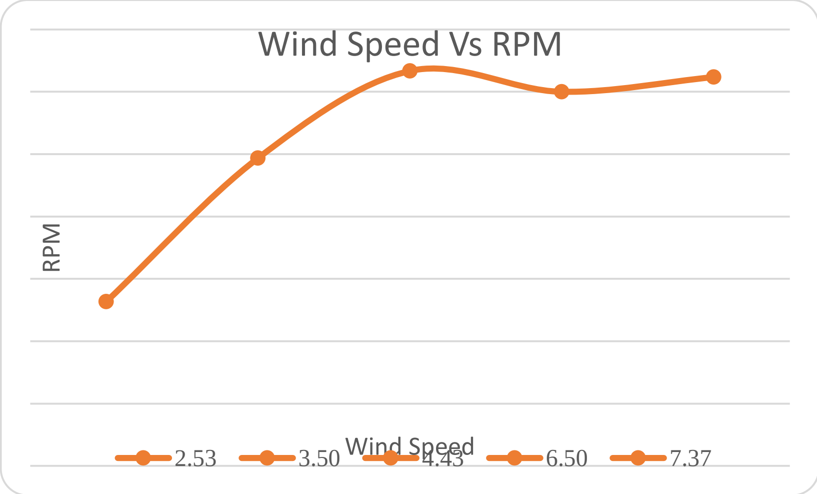


Fig. 10. Wind speed versus RPM graph

Figure 11 visualises the graphical results of wind speed against output voltage (mV). From the line graph, it can be said that the increase in wind speed will result in increased output voltage. However after reaching 4.43 m/s wind speed, the output can be seen to decrease slightly at 6.5 m/s before increasing slightly at 7.37 m/s. This shows the optimal wind speed for the turbine is at 4.43 m/s which it results in producing 212 mV.

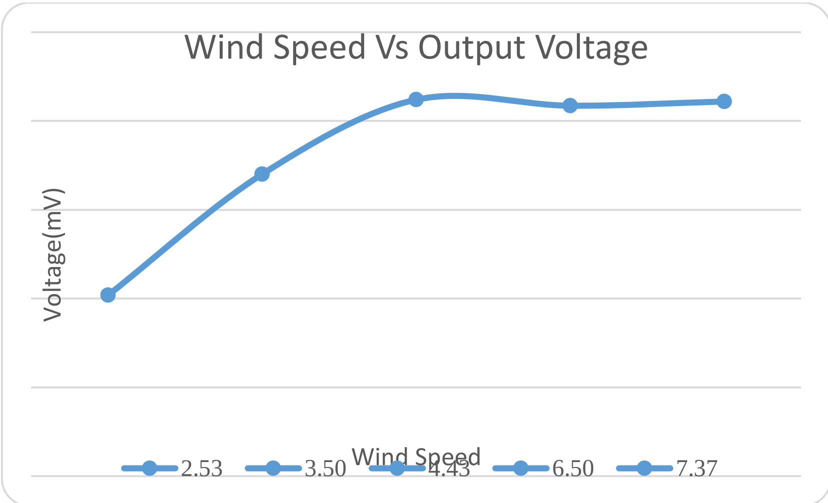


Fig. 11. Wind speed versus output voltage graph.

Figure 12 shows the graphical presentation of the current value generated by the turbine. The value recorded are around 0.1 µA which is small and its value changes slightly with the increase in wind speed.

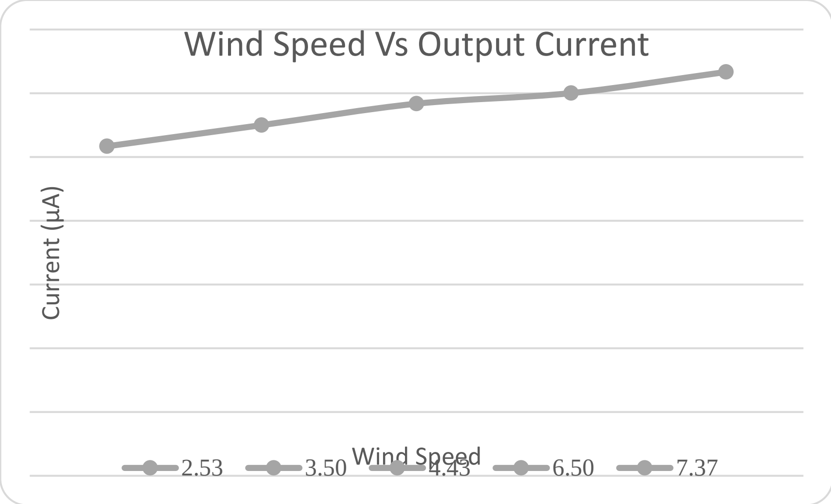


Fig. 12. Wind speed versus Current graph

4.3 Prototype Result (Conventional)

Data obtained from the equipment using the same experimental setup. However, the bearing of the turbine was changed into ball bearings in order to compare the difference between the usage of maglev bearing and ball bearing.

Figure 13 shows the graph of the wind speed used on the conventional ball bearing prototype. The test uses the result closest to the wind speed recorded in the maglev bearing value. It is critical that the wind speeds used are identical in both tests to ensure a more comparable result.

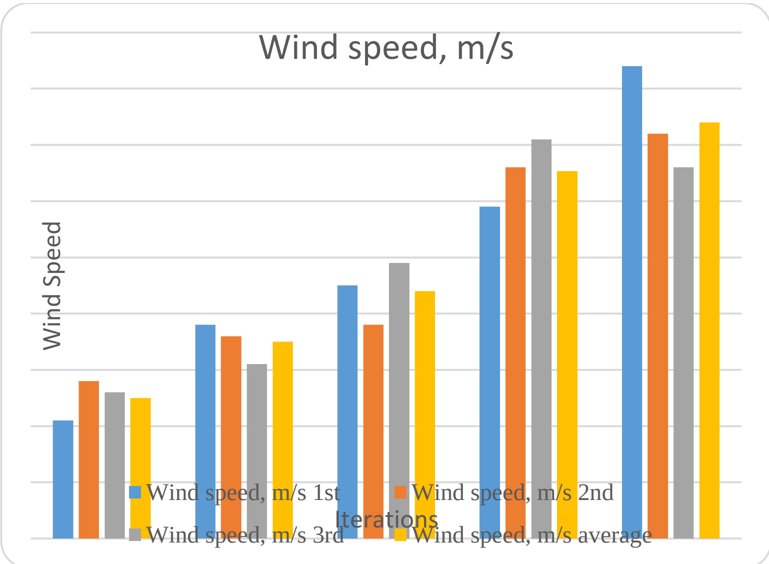


Fig. 13. Wind speed graph (conventional)

Figure 14 illustrate the graphical interpretation of the wind speed against the RPM value of the turbine. Here, it can be seen that the RPM vale are increasing steadily until at wind speed of 4.4 m/s where after that, the increment rate are minimal.

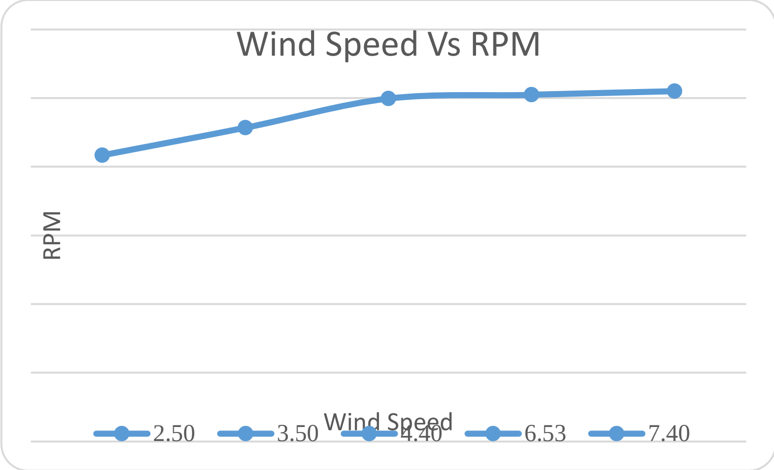


Fig. 14. Wind speed vs RPM graph (conventional)

Figure 15 shows the increasing trend of the wind against output voltage in graphical structure. The output shows and increasing rate with a slightly lower rate at the end of the graph.

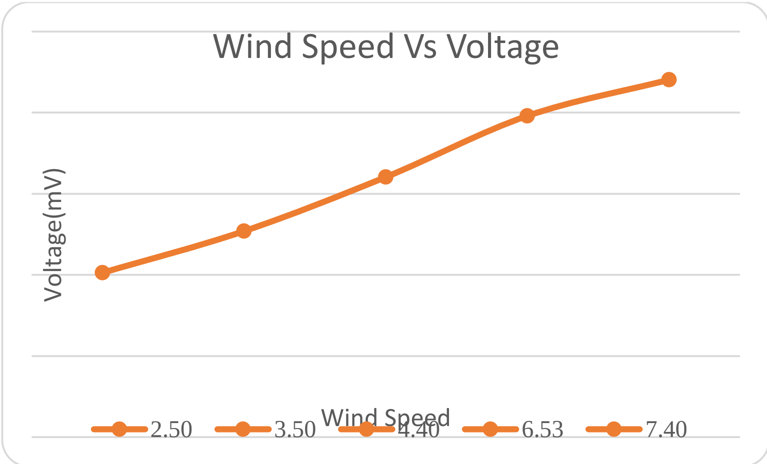


Fig. 15. Wind speed againts output voltage graph (conventional)

Figure 16 shows the graph of wind speed against currents generated from the turbine. The value of current generated are small in values but it follows an increasing pace with the increased wind speed applied to the turbine. However, the small values of the current also make it to increase slightly in each pace.

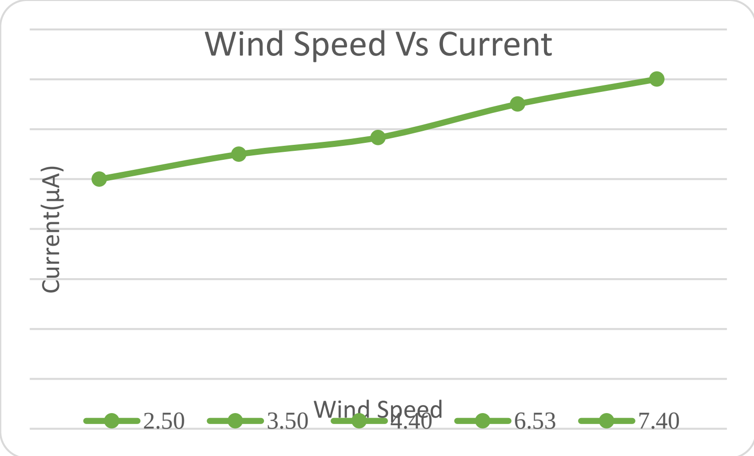


Fig. 16. Wind speed againts current graph (conventional)

4.3 Comparison between Conventional Wind Turbines versus MagLev Wind Turbine

The comparison of the output difference between the conventional and the maglev bearing can be seen from the Table 2 in which the percentage difference between the two bearings was calculated based on the formula below.

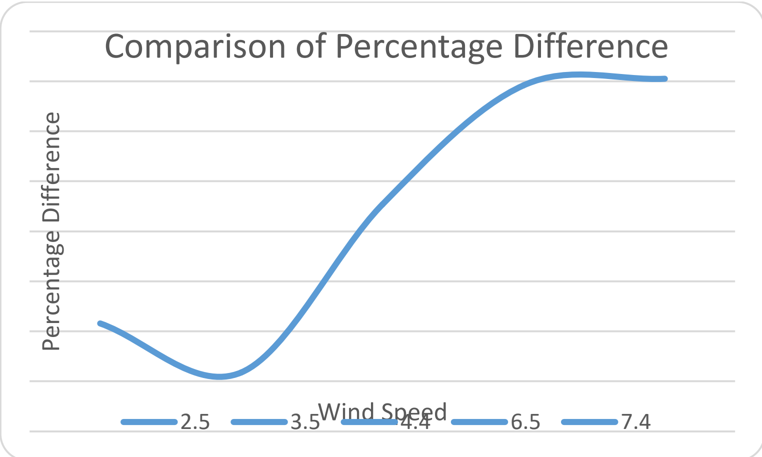


Fig. 17. Comparison of Percentage Difference

Table 2
Percentage difference of RPM on conventional against maglev bearings

Wind Speed	RPM (Conventional)	RPM (MagLev)	Percentage Difference
2.5	208.33	216.33	-3.84
3.5	228.33	239.33	-4.82
4.4	249.67	253.33	-1.46
6.5	252.33	250.00	0.92
7.4	255.00	252.33	1.05

Based on the result obtained above, the percentage difference of RPM value achieved by both maglev bearing as well as ball bearing shows that subtle difference depending on the wind speed acting on the wind turbine.

This shows that the maglev bearing is very suitable on low wind speed as it can rotate faster but as it receives more speed, the imbalance of the fan blade starts tumbling due to the high wind pressure received. The tumbling makes the fan blade spin inadequately, resulting lower speed that the ball bearing which is much more stable due to it being attached directly to the pole of the fan base. It also shows that in order to create a successful maglev propelled bearing, the fan blade needs to be very well balanced, and aero centric.

5. Conclusions

Wind turbines are separated into 2 types that is the VAWT and the HAWT. In this project, VAWT type was chosen instead of HAWT type due to the lower starting torque of the design which makes it ideal for low wind speed areas such as in Malaysia. The reading on the wind turbines fan blade speed can be detected using a tachometer while the output voltage are measured using a voltmeter or multimeter to be precise. This project aims to develop an integrated VAWT with MAGLEV system as it can increase its efficiency and output. The simulation result shows the success on the design part of the fan blade to create a stable and efficient fan blade design while the output result shows the measured result that compares the output between the MAGLEV integrated VAWT and a standard one's. The Halbach array theory can be proven by the halbach array holder which acts to firmly hold the turbine blade to its shaft during high wind speed turbulence.

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