INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

Development of a Wind Turbine Prototype as a Potential Teaching Aid in Renewable Energy Applications

[*1,2]Nazri bin Md Daud, [1,2]Mohd Nizam bin Sudin, [1,2]Kamarul Ariffin bin Zakaria, [1,2]Shafizal bin Mat, [1,2]Fadhli bin Syahrial, [1,2]Shamsul Anuar Shamsudin, [3]Safarudin Ghazali Herawan

[1]Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[2]Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[3]Industrial Engineering Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

[*]Corresponding Author

DOI: https://doi.org/10.47772/IJRISS.2026.100701123

Received: 10 August 2026; Accepted: 15 August 2026; Published: 22 August 2026

ABSTRACT

This study examines the design and development of a Vertical Axis Wind Turbine (VAWT) prototype, specifically as a hands-on teaching aid to enhance students' understanding of the wind turbine concept. Due to the rapid expansion of wind energy applications, students are required to possess a good understanding of both theory and applications, as well as effective educational tools for practical purposes. This paper describes the elements of educational methods for understanding the concept of wind turbines, such as process design, fabrication, and performance studies of a vertical-axis wind turbine (VAWT). The wind energy was captured by moving vehicles on the street. Two types of VAWT, Banki and Savonius, were designed and fabricated using SOLIDWORKS software and a 3D machine printer, respectively. To ensure a controlled learning environment while maintaining safety protocols, the range of possible wind speeds generated by moving vehicles on the street was simulated using a table fan to analyze the performance of the wind turbine due to the safety precautions. As a result, a VAWT with a Banki rotor produces more power output than a Savonius rotor. The prototype serves as a bridge between educational application and theoretical knowledge.

Keywords: Banki; Savonius; 3D printer; Wind speed; Power output

INTRODUCTION

Wind as an energy resource is used to generate electricity or mechanical power from the kinetic energy of moving air by using a wind turbine. In the context of engineering education, understanding the conversion of this kinetic energy into rotational and then electrical energy is a fundamental competency. The amount of electrical energy generated depends on wind speeds, which vary based on season, geography, and topography. Based on a report by Saqr and Musa (2011), it is clear that since 2002, Malaysia's highways have experienced an estimated 1.2 MTOE (million tonnes of oil equivalent; 1 TOE=4.5 × 107 KJ) annual loss of aerodynamic energy from moving vehicles. Depending on its size and speed, the wind produced by moving vehicles can reach speeds of up to 24 m/s, where it can strike wind turbine blades at up to 6 m/s (Banihani et al., 2018).

The mechanical principle of these systems is straightforward, but it is essential for students to observe the system. Wind turbines convert the kinetic energy from moving air into electricity. This is done when the wind rotates the blades of the wind turbine, which converts kinetic energy into rotational energy. Then the rotational energy is transferred through a shaft to the generator, where electrical energy is produced. Basically, there are two types of wind turbines, which are horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). For

HAWT, the rotor and shaft are oriented parallel to the wind direction, while for VAWT, the shaft is oriented vertically, which is perpendicular to the wind direction.

The pedagogical advantage of focusing on VAWT lies in its versatility. VAWT has the advantage of capturing the wind from moving vehicles, where it can take energy from the wind regardless of direction without the yaw system, which is applied in HAWT (Johari et al., 2018). Besides, the size of the blades for VAWT is much smaller than the HAWT. Therefore, VAWT seems more suitable to be developed on highways where space is at a premium to harvest wind energy from moving vehicles.

A vehicle moving through a fluid medium is subject to a force known as drag, which is created when the wind pressure differs, and there will always be some amount of wind produced by the vehicle at any speed (Zarkesh & Heidari, 2013). Different sizes and speeds of the vehicles provide different wind pressure. The flow of wind produced by the moving vehicles is in the form of turbulent flow. Vehicle-induced turbulence (VIT) is a term used to describe the turbulence created by moving automobiles on roads (Al-Aqel et al., 2017 and Gordon et al., 2012).

In the early 1990s, the first commercial wind farm in the world started its operations off the coast of Denmark, where the installed capacity is between 120 and 150MW (Zhixin et al., 2009). Starting with the introduction of wind farms, offshore wind power has sparked interest worldwide. Then, wind energy technology has become increasingly mature in line with modern technological developments, thus leading to remarkable advances. Aerodynamics, structural dynamics, and micrometeorology advancements have contributed to a 5% yearly increase in turbine energy production since 1980 (Islam et al., 2013 and Hameed Z et al., 2009)

Conventional energy sources such as oil, natural gas, coal, and nuclear will be depleted one day. So, it is crucial to conserve the existing conventional energy sources and try to find new alternative resources simultaneously. One of the things being actively worked on worldwide, including in Malaysia, is urging people to take advantage of renewable energy sources such as wind, solar, biomass, and other sources.

Besides, the energy generated by conventional sources from the burning process can cause several types of environmental pollution. For example, greenhouse gasses, air pollution, and acid rain. Slowly replacing conventional sources with renewable sources of energy in certain areas that can be developed can help reduce the impacts of climate change due to the damage done to the environment. Regarding power generation, wind energy is the cleanest among the other renewable energy sources since there is only a minor environmental impact.

In addition, using conventional energy sources to power the street lights is less economical in the long run and not environmentally friendly. This is because the amount of energy required to power the street lights is low. So, if no improvements are made regarding this matter, electrical power generated from conventional sources will not be utilized properly, and the sustainability of resources in the future will not be guaranteed. Therefore, based on the problems stated, a small model of vertical axis wind turbine has been developed in order to analyze its performance in producing electricity from wind energy of moving vehicles.

METHODOLOGY

The idea to produce the final design of the wind turbine to harvest wind energy from moving vehicles was generated based on the conceptual designs and some of the previous projects or research related to the development of wind turbine technology. After several considerations based on the literature review, VAWT has been decided as the most suitable configuration of the wind turbine to be developed compared to HAWT. One of the main reasons is that VAWT can take energy from the wind regardless of direction (Saad, M., et al., 2014). In this project, Savonius and Banki rotors were selected for the first exposure to the students.

Design and fabrication

The first design of VAWT for this project utilizes the Savonius rotor, as shown in Figure 1. This type of rotor is chosen to be developed due to its simplicity in design compared to the Darrieus rotor. Besides, the turbulence

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

produced by the moving vehicles on the roads is more suitable to be harvested using the Savonius rotor to generate electricity since it can self-start at low torque. This VAWT consists of three curved blades that will be used to capture the wind to rotate the shaft. It was made using the 3D printer based on the design produced in SOLIDWORKS software. The rotor's diameter and height are 160 mm. A few “L” brackets will be used to attach the blades to the top and bottom circular discs. The center shaft is connected with two KFL002 bearings to ensure smooth rotation during the operation. Meanwhile, a pair of pulleys with different diameter sizes are attached to the shaft to transfer the rotation of the shaft to the DC motor. The box or rectangular shape of the base is designed to provide stability to the wind turbine to withstand uncertain wind speeds on the roads.

Figure 1: Design of VAWT utilizing the Savonius Rotor

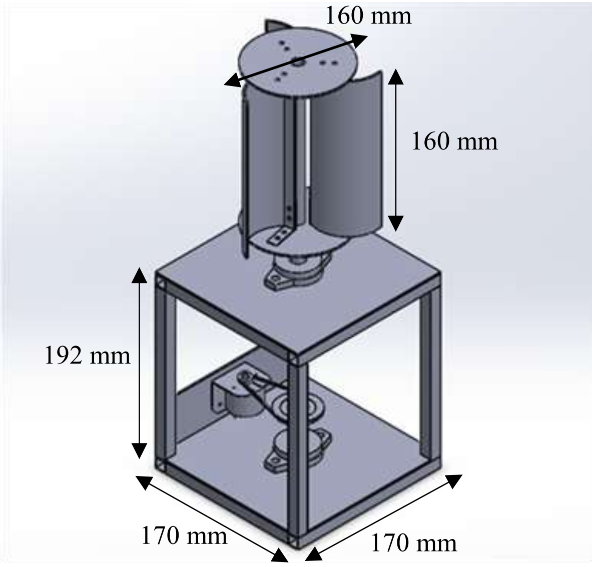
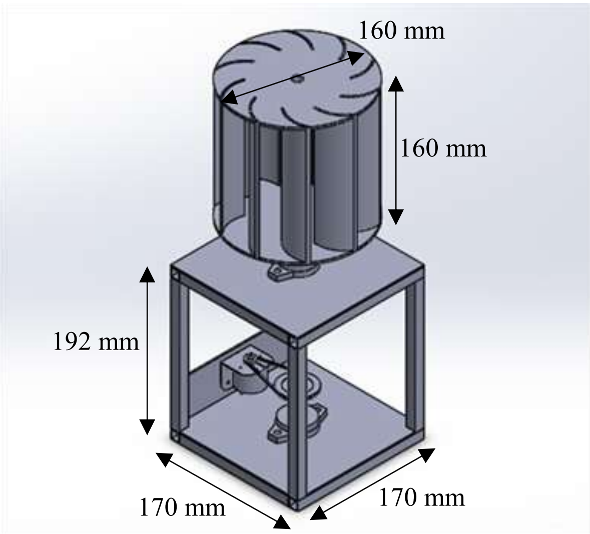


Figure 2: Design of VAWT utilizing the Banki Rotor

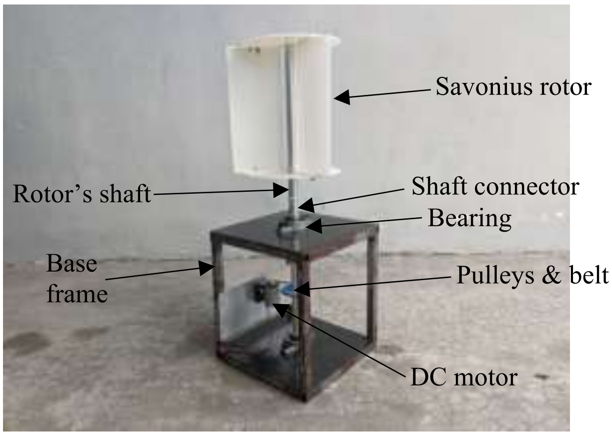


A Banki rotor is another design of VAWT in this project. The concept of the Banki wind turbine originated from the Banki water turbine, a turbine with a crossflow runner (Dragomirescu, 2011). According to Qusai et al. (2021), the drag is the primary driving force to move the Banki rotor, assisted with aerodynamic lift. This multiple-curved blade wind turbine could be an alternative to other small wind turbines with poor overall performance or difficulty starting at low wind speeds. In Figure 2, there were ten blades attached to both the top and bottom circular disc, and PLA will be used to produce the blades. The diameter and height dimension of the rotor are the same as the design of the Savonius rotor, which is 160 mm. The Banki rotor with multiple curved blades was said to perform better when operating at a lower tip speed ratio (TSR) due to a high degree of solidity (Wenlong et al., 2014). Besides, according to research by Tian et al. (2020), the Banki rotor generates the greatest power coefficient from the wake of a passing car compared to the Darrieus and Savonius rotor. Therefore, the

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

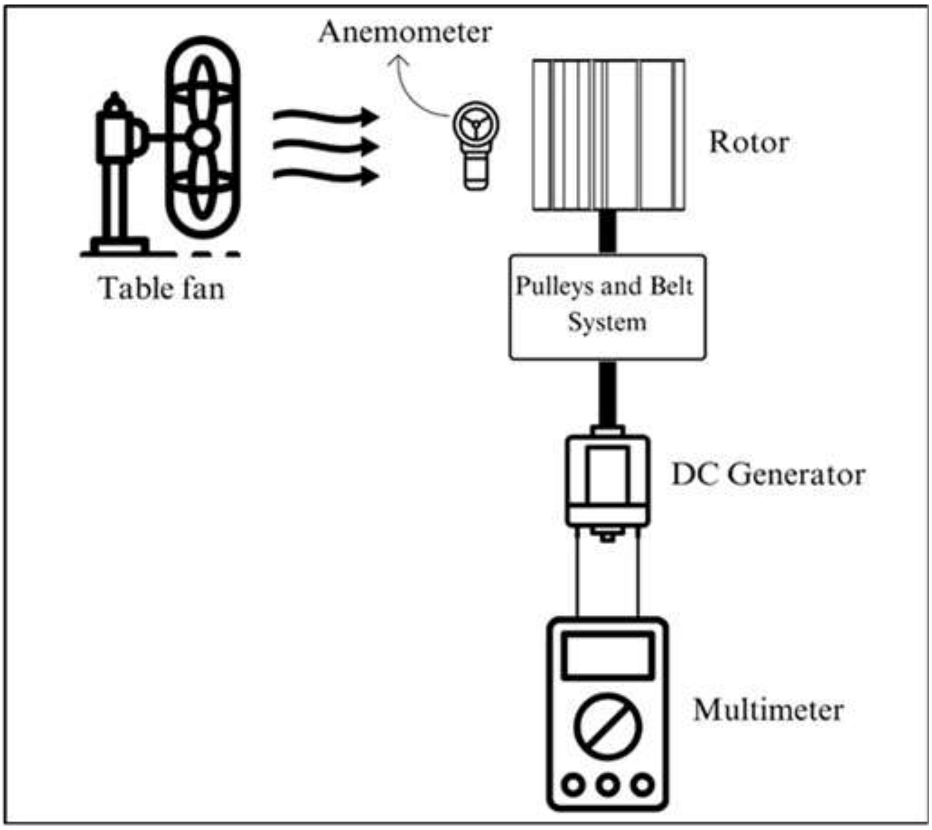
comparison of performance in generating electricity between the Savonius rotor and Banki rotor will be done in this project to find out which configuration is better for harnessing wind energy from moving vehicles. The inclusion of two distinct rotor types allows students to perform comparative analysis, a key skill in engineering critical thinking. The blades of the Banki and Savonius rotors were made of PLA while the base frame and rotor shaft were made of steel and aluminium hollow cylinder respectively. The system consists of DC motor, bearing, pulley, shaft connector and blades. The overall components of VAWT with Savonius rotor is shown in Figure 3. In this case, the same base frame will be used for the Banki rotor. It can be said that the system is suitable as an educational aid for students since the rotor's shaft can be removed and attached to the base frame. Therefore, students can fabricate any kind of blade design and attached to the base frame in order to measure its voltage output and power generated.

Figure 3: VAWT with Savonius rotor



Experimental setup

Figure 4: Schematic diagram of the wind turbine system



To facilitate classroom-level data collection, a standardized testing rig was developed. The schematic diagram of the system is shown in Figure 4. The wind speed is measured by an anemometer at an elevation of 0.5 m, 1.0

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

m and 1.5 m from the ground. This is the optimum height of the VAWT's rotor from the ground to ensure optimum wind speed can be captured. Next, a digital multimeter is connected directly to the DC motor to measure the voltage and current values in unit volt (V) and milliampere (mA), respectively. This setup provides immediate visual feedback to students, reinforcing the relationship between wind velocity and power generation. Those values and wind speed are measured simultaneously for one (1) minute. Then, three (3) readings are taken within 20 seconds time intervals to determine the average value for accuracy. The steps are repeated for the other desired wind speed by varying the wind that is supplied to the rotor. The recorded values are then used to calculate the wind turbine's power output.

RESULTS AND DISCUSSION

Data of Wind Speed Produced by the Moving Vehicles

Table 1 shows the wind speed measurement data from moving vehicles on the highway, where three (3) instantaneous wind speeds are recorded for three (3) different heights. At an elevation of 1.0 m from the ground, the wind speed recorded by the anemometer is the highest at about 4.8 m/s. This could be due to the higher intensity of turbulence kinetic energy occurring around 1.0 m from the moving vehicles' side region (Al-Aqel et al., 2017). Therefore, elevation 1.0 m from the ground will be selected for measuring power output for both Savonius and banki rotor VAWT. A range of possible instantaneous wind on the highway will be set from 3.0 m/s to 5.0 m/s based on the data from Table 1. A table fan will be used to supply the speeds as a safety factor.

Power Output from Savonius Rotor VAWT

Several wind speeds have been selected to analyse the power output from the VAWT, and the selection is made by considering the wind turbine's cut-in speed and the range of possible optimum wind speeds that can be achieved on the highway. Table 2 below shows experimental data involving voltage (V), current (mA), and power output from VAWT with Savonius rotor. A range of possible instantaneous wind on the highway at speeds of 3.0, 3.5, 4.0, 4.5 and 5.0 m/s are supplied by the table fan straight to the rotor.

There are some fluctuations in the values of output voltage and current measured by the multimeter. Due to that, three (3) values of voltage and current for each wind speed are taken into the average for better accuracy. The result from Table 2 shows that the highest value of voltage and current, which are 5.16 V and 15.9 mA, respectively, is recorded at a wind speed of 5.0 m/s. Due to that, the power extracted by the wind turbine is also higher than the other wind speed, which is 0.08204 W. The lowest amount of power extracted is 0.01686 W when the 3.0 m/s wind speed is supplied by the fan. The value of the average voltage and current recorded for this condition are 2.72 V and 6.2 mA, respectively. The power can be calculated by multiplying the voltage and current. This is the basic equation that can be learned by the students from this project.

Table 1: Data of Wind Speed

Elevation from Ground (m)	Reading	Wind Speed (m/s)
0.5	1	2.4
	2	3.0
	3	2.8
1	1	4.1
	2	4.4
	3	4.8
1.5	1	3.3
	2	4.2
	3	3.8

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

Table 2: Experimental data for VAWT with Savonius rotor

Experimental Data for VAWT with Savonius Rotor						
No.	**Wind Speed (m/s)**	**Voltage Output (V)**	**Average Voltage (V)**	**Current Output (mA)**	**Average Current (mA)**	**Power (W)**
1	3.0	2.87	2.72	5.9	6.2	0.01686
		2.62		6.4		
		2.67		6.2		
2	3.5	3.15	3.16	8.0	7.9	0.02496
		3.07		8.4		
		3.27		7.2		
3	4.0	3.81	3.87	10.6	10.1	0.03909
		4.01		9.2		
		3.79		10.7		
4	4.5	4.67	4.66	13.4	13.3	0.06198
		4.75		13.6		
		4.56		12.9		
5	5.0	5.16	5.16	15.7	15.9	0.08204
		5.18		15.8		
		5.13		16.1		

Power Output from Banki Rotor VAWT

Same as the Savonius rotor, the value of voltage and current is taken in average count due to fluctuation of reading from the multimeter during the experiment. As can be seen in Table 3, the value of average voltage and current directly increase as the wind speed increase, and the same goes for power output. The maximum power output generated is at a wind speed of 5.0 m/s which is 0.27225 W, with average voltage and current values of 8.25 V and 33.0 mA, respectively. On the other hand, the minimum power output generated is 0.06603 W, recorded at 3.0 m/s wind speed, where the average voltage and current are 4.26 V and 15.5 mA, respectively.

Table 3: Experimental data for VAWT with Banki rotor

Experimental Data for VAWT with Banki Rotor						
No.	**Wind Speed (m/s)**	**Voltage Output (V)**	**Average Voltage (V)**	**Current Output (mA)**	**Average Current (mA)**	**Power (W)**
1	3.0	4.25	4.26	15.4	15.5	0.06603
		4.20		16.0		
		4.33		15.1		
2	3.5	5.76	5.66	19.7	19.9	0.11263
		5.60		19.5		
		5.62		20.4		
3	4.0	6.50	6.39	22.9	22.6	0.14441

		6.36		22.1		
		6.30		22.8		
4	4.5	6.93	6.93	25.5	25.3	0.17533
		6.91		26.6		
		6.95		24.4		
5	5.0	8.32	8.25	33.1	33.0	0.27225
		8.28		32.6		
		8.79		33.2		

CONCLUSION

This study successfully demonstrates that a 3D-printed VAWT prototype is a potential teaching aid for renewable energy education. By comparing the Savonius and Banki rotors, students can observe firsthand how mechanical design choices directly impact the voltage and power output. The use of vehicle-induced wind as a theoretical source connects engineering principles to everyday life, fostering a deeper interest in sustainable technology. The voltage and power output of other rotors can be measured using the same base frame for the next project.

ACKNOWLEDGEMENT

The authors would like to thank Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka for the technical support.

REFERENCES

1. Al-Aqel, A. A., Lim, B. K., Noor, E. E. M., Yap, T. C., & Alkaff, S. A. (2017, March 6). Potentiality of small wind turbines along highway in Malaysia. Proceedings of 2016 International Conference on Robotics, Automation and Sciences, ICORAS 2016. https://doi.org/10.1109/ICORAS.2016.7872634
2. Banihani, E., Sedaghat, A., Al-Shemmary, M., Hussain, A., Alshaieb, A., & Kakoli, H. (2018). Feasibility of Highway Energy Harvesting Using a Vertical Axis Wind Turbine Open jet wind tunnel testing View project Emulsions and Microemulsions View project. https://www.researchgate.net/publication/323279889
3. Dragomirescu, A. (2011). Performance assessment of a small wind turbine with cross flow runner by numerical simulations. Renewable Energy, 36(3), 957–965. https://doi.org/10.1016/j.renene.2010.07.028
4. Gordon, M., Staebler, R. M., Liggio, J., Makar, P., Li, S.-M., Wentzell, J., Lu, G., Lee, P., & Brook, J. R. (2012). Measurements of Enhanced Turbulent Mixing near Highways. https://doi.org/10.1175/JAMC-D
5. Islam, M. R., Mekhilef, S., & Saidur, R. (2013). Progress and recent trends of wind energy technology. In Renewable and Sustainable Energy Reviews (Vol. 21, pp. 456–468). Elsevier Ltd. https://doi.org/10.1016/j.rser.2013.01.007
6. Johari, M. K., Jalil, M. A. A., & Shariff, M. F. M. (2018). Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). International Journal of Engineering and Technology(UAE), 7(4), 74–80. https://doi.org/10.14419/ijet.v7i4.13.21333
7. Magedi Moh. M. Saad & Norzelawati Asmuin. (2014). Comparison of Horizontal Axis Wind Turbines and Vertical Axis Wind Turbine. IOSR Journal of Engineering (IOSRJEN), 4, 27-30. https://doi.org/10.9790/3021-04822730
8. Qusai, S., Esraa, S., & Aseel, R. (2021, April 14). Polycarbonate Bladed Highway Wind Turbine: A Case Study. 2021 12th International Renewable Engineering Conference, IREC 2021. https://doi.org/10.1109/IREC51415.2021.9427820

9. Saqr, K. M., & Musa, M. N. (2011). A perspective of the Malaysian highway energy consumption and future power supply. Energy Policy, 39(6), 3873–3877. https://doi.org/10.1016/j.enpol.2011.03.034
10. Tian, W., Song, B., & Mao, Z. (2020). Numerical investigation of wind turbines and turbine arrays on highways. Renewable Energy, 147, 384–398. https://doi.org/10.1016/j.renene.2019.08.123
11. Wenlong, T., Baowei, S., & Zhaoyong, M. (2014). A numerical study on the improvement of the performance of a banki wind turbine. Wind Engineering, 38(1), 109–116. https://doi.org/10.1260/0309-524X.38.1.109
12. Zarkesh, A., & Heidari, M. (2013). Developing a new application for wind generators in highways. Proceedings - 5th International Conference on Computational Intelligence, Communication Systems, and Networks, CICSyN 2013, 279–282. https://doi.org/10.1109/CICSYN.2013.39
13. Zhixin, W., Chuanwen, J., Qian, A., & Chengmin, W. (2009). The key technology of offshore wind farm and its new development in China. In Renewable and Sustainable Energy Reviews (Vol. 13, Issue 1, pp. 216–222). https://doi.org/10.1016/j.rser.2007.07.004
14. Z. Hameed, Y.S. Hong, Y.M. Cho, S.H. Ahn, C.K. Song (2009). Condition monitoring and fault detection of wind turbines and related algorithms: A review. Renewable and Sustainable Energy Reviews Volume 13, Issue 1, January 2009, Pages 1-39. https://doi.org/10.1016/j.rser.2007.05.008