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Design and performance evaluation of vertical axis wind turbine for wind energy harvesting at railway

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Abstract

Purpose – This paper aims to design an optimum vertical axis wind turbine (VAWT) and assess its techno-economic performance for wind energy harvesting at high-speed railway in Malaysia.

Design/methodology/approach – This project adopted AutoCAD and ANSYS modeling tools to design and optimize the blade of the turbine. The site selected has a railway of 30 km with six stops. The vertical turbines are placed 1 m apart from each other considering the optimum tip speed ratio. The power produced and net present value had been analyzed to evaluate its techno-economic viability.

Findings – Computational fluid dynamics (CFD) analysis of National Advisory Committee for Aeronautics (NACA) 0020 blade has been carried out. For a turbine with wind speed of 50 m/s and swept area of 8 m^2, the power generated is 245 kW. For eight trains that operate for 19 h/day with an interval of 30 min in nonpeak hours and 15 min in peak hours, total energy generated is 66 MWh/day. The average cost saved by the train stations is RM 16.7 mil/year with battery charging capacity of 12 h/day.

Originality/value – Wind energy harvesting is not commonly used in Malaysia due to its low wind speed ranging from 1.5 to 4.5 m/s. Conventional wind turbine requires a minimum cut-in wind speed of 11 m/s to overcome the inertia and starts generating power. Hence, this paper proposes an optimum design of VAWT to harvest an unconventional untapped wind sources from railway. The research finding complements the alternate energy harvesting technologies which can serve as reference for countries which experienced similar geographic constraints.

Keywords Techno-economic, Optimization, Alternate energy, Tip speed ratio

Paper type Research paper

1. Introduction

Wind energy is one of the emerging clean technologies in the world. The global installed capacity has increased significantly in the past few decades including onshore and offshore installation. More than 83 countries in the worldwide rely on wind energy for electricity generation. The Paris Agreement, tax incentive and large-scale manufacturing of wind turbine accelerate the growth of wind energy and affordable levelized cost of electricity. In a developing country like Malaysia, energy requirement is increasing tremendously for daily consumption in all walks of life. The energy resources in our modern fast-paced world are depleting; hence, it is indispensable and crucial that we keep discovering new approach in generation energy which is both self-sustaining as well as easily manageable. All human activities require energy right from how we require food to sustain ourselves and enable our mobility, gasoline and fuels for our automobiles and transportation as well as electricity for our lights, heating and air conditioning. Sources and quantum fossil energy are dwindling each day and getting exhausted day by day rapidly and will at the end create crises in this century. It is also beyond doubt that the current energy trends and unreasonable use of the

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planet's resources are putting the planet in great danger. The desired unlimited growth based on limited resources of fossil fuels is not only unrealistic but as well detrimental to the fragile system on earth. As ice keeps melting, global temperatures keep rising; the consequences due to human activities are already felt across the globe. Global warming challenges along the depletion of the natural resources have brought up the attention of researchers to the renewable and green energy resources in recent years. Most experts conclude that divestment from fossil fuel-related business or a dramatic reduction in electric usage could help in preventing climate change.

Switching to a more sustainable option is the best way to halt or lessen the impact of power generation on climate change at the same time to satisfy our ever-increasing energy demand. Clean energy sources are not the only means to limit the fossil fuel reserve but are also an alternate to help mitigate the damage caused by human activity. The researchers around the globe are investigating and innovating cheaper, renewable and more reliable energy sources. Solar and wind energy are the two most common renewable resources and have the most active research going on. With the sun and wind being practically an inexhaustible power source, the ability to convert this energy to electricity is probably the best approach to overcome the increasing need of energy. For the past years, there has been an exponential growth in the utilization of small-scale green energy technologies. This further stresses the need of innovation within this field, specifically for small-scale applications. Therefore, the field of renewable energies is not only environmentally attractive but also politically and economically.

Among the sources of renewable energy (RE), wind energy is the fastest growing energy technology in terms of percentage of annual installed capacity per technology source (Akdağ and Güler, 2010; Bhattacharjee *et al.*, 2018). To build up wind farm, it is necessary to carry out a general assessment of the wind energy potential nationwide. Studies have found that the annual average speed of wind in Malaysia is rather low with only 1.8 m/s below the minimum required average annual wind speed which is 2 m/s. Generally, strong wind in Malaysia is blown from the Indian Ocean and the South China Sea with a monthly mean wind speed between 1.5 m/s and 4.5 m/s. Higher altitude areas can harness between 9 and 11 m/s of wind power. Mersing, Johor and Kuala Terengganu have been identified as high wind areas within Peninsular Malaysia, while in East Malaysia, Kudat and Sabah are the highest wind potential areas. Installation onshore wind power in Malaysia could reach up to 1.5 MW (Mohammad Rafiqul, 2011).

In the approach to accelerate the growth of RE in Malaysia, the mechanism of feed-in-tariff (FiT) was implemented. More researchers and studies were supposed to explore new resources of RE to have more diverse energy generating mix as stated in Malaysia's Eleventh Plan (2016–2020), which includes sources from wind energy, geothermal and energy from ocean. The national wind mapping process which has been done in 2016 has helped to improve the wind energy feasibility (Economic Planning Unit, 2015). Until today, the assessment of potentiality of onshore wind energy is ongoing to decide the possibility of including wind energy in FiT mechanism with other RE resources. The two unsuccessful wind energy projects were in small Perhentian Island and Swallow Reef; these failures showed that it was hard to directly install wind turbines in Malaysia without sufficiently comprehensive studies (Ho, 2016).

According to the global average of the wind speed at a level of 80 m/s above the ground, Malaysia has low average wind speed with some other countries such as Congo, Indonesia, Gabon and wide area in Brazil (3TIER, 2011). The average annual speed of the wind in Malaysia is 1.8 m/s at a level of 2.0 m height from the ground (Teh, 2013). Therefore, the incentives and support from the government is crucial at the initial stage of deployment of wind power in Malaysia to be included in the FiT mechanism. For instance, at this point of time, the absence of wind power technology in the FiT categories makes it difficult to achieve project viability. This exacerbates the issue of low wind for Malaysia. Suitable technology for low wind speed conditions should be explored in Malaysia to harness the untapped potential wind power.

2. Energy harvesting methods and technologies

2.1 Vibration-based approach

The idea of generating energy from vibration has become a promising research field over the past 10 years. The motivation to venture into tapping vibration as a source of energy generation is to power small electronic components which now require less power. Several researchers have reported their work on modeling and applications of vibration-based energy harvesting using electromagnetic, electrostatic, piezoelectric and magnetostrictive transduction mechanism.

The working principle of an electromagnetic vibration energy harvester is Faraday's law of electromagnetic induction. The induction of electromotive force is produced in the circuit, when there is a change in the magnetic flux which passes through the closed loop. Induced voltage is produced when the ambient-specific vibration helps to vibrate the magnet along the axial direction of the coil and causes changes in the magnetic flux which passes through the coil. When there is a load connected to the closed loop, current will be generated in the circuit (Tan *et al.*, 2016). Micro electromagnetic vibration energy has become popular as it is known to have high output (current and power) with the use of a low load resistance. Most times, the frequency of the vibration in the ambient environment is below 100 Hz which is considered low frequency. To accommodate this situation, it is crucial to reduce the natural frequency of the device to match the frequency of the environment to ensure that the collection of the environmental vibration is done efficiently.

An electrostatic vibration energy harvester normally comprises an electrically polarized capacitor, that is, has a capacitance that is modified to receive vibration inputs. The electronic circuit of this harvester is rather complicated from the view of power conversion as there is a need for an external voltage source. This elimination is a setback that causes loss in efficiency of the harvester (Ma and Zhang, 2017). Based on the direction of the movement of the capacitor plates, the electrostatic converters can be segregated to three types which are in-plane overlap converter, in-plane gap closing converter and out-of-plane gap closing converter. Based on extensive research, the out-of-plane gap closing converter is proven to have the biggest potential of maximum capacitance. Although the capacitance is high, it also has the largest mechanical damping (Wei and Jing, 2017).

Piezoelectric energy harvesting has gained the most attention due to its large power density and ease of application. Unless it is used as a surface patch, a piezo-stack or a cymbal arrangement, typically a piezoelectric energy harvester is a cantilever with piezoceramic layers, and it is located on a vibrating host structure for electrical power generation from bending vibrations under resonance excitation. Such a design that operates effectively only at its linear resonance frequency is called a resonant energy harvester. Mechanical strain can be changes to electrical charge with the use of piezoelectric transducers. This is called a direct piezoelectric effect. Ambient vibration around the power harvesting device is normally the cause of mechanical strain. Piezoelectric transducers are also capable of converting electrical energy to mechanical strain also known as the converse (Wang *et al.*, 2017) piezoelectric effect (Wei and Jing, 2017). A study conducted by Wang *et al.* (2017) studied piezoelectric energy harvester with two-stage force magnification. With the consideration of the force of magnification, the energy transmission ratio and the maximum stress, simultaneously it can design the flexure force amplification frames optimally (Wang *et al.*, 2017).

A very vital disadvantage of the commonly used resonant harvester is that the power generation performance of the device is very dependent on resonance excitation. If the frequency of excitation experiences the slightest change, it can cause the electrical power output to be reduced by orders of magnitude. In order to overcome the bandwidth issue of the conventional cantilever configuration, researchers have considered utilizing some of the phenomena peculiar to nonlinear dynamical systems (Erturk and Inman, 2011). Hardening stiffness in the monostable Duffing oscillator is used for increasing the frequency of the bandwidth (Burrow *et al.*, 2008). More recently, the monostable Duffing oscillator with hardening stiffness was theoretically investigated by Daqaq (2010) for random forcing. An important aspect of the bi-stable Duffing oscillator has been pointed out for piezoelectric energy harvesting using the well-known magnetoelastic structure. Large-amplitude periodic oscillations on high-energy orbits of the bi-stable configuration have been shown to increase the open-circuit voltage output by a factor of three at several frequencies (Erturk *et al.*, 2009).

Piezoelectric technology has been suggested to be used to make piezo-smart roads. The property of piezoelectric materials to produce electricity on compression is employed to harness energy of vehicles moving on roads by making the roads piezo-smart. This revolutionary new surface uses piezoelectric crystals embedded in the asphalt to generate up to 400 kW of energy from a 1 km stretch, a design devised by Haim Abramovich, a developer at the Technion-Israel Institute of Technology in Haifa, Israel, enough to run eight electric cars (Kumar, 2013). A kilo-meter of piezo-smart road could generate enough power for 40 houses and progress in the technology could generate enough electricity to feed the national power grid. This concept can be adapted to rail roads as well, installing piezoelectric adapters onto the tracks to harness as much as energy possible. Studies have shown that the fuel used in vehicles is only partially used to move the vehicle and the rest is lost to engine inefficiencies. Therefore, implanting piezoelectric technology could reduce energy wastage and promise a more sustainable future.

Another example of the application of piezoelectric is to monitor pressures in tires (TPMS). The flourishment of this technology is driven by the regulations on fuel efficiency and safety in the USA, Europe and Asia. Energy harvesters have a high potential of absorbing energy from rolling tires (Yang *et al.*, 2018). The material of piezoelectric exudes an inherent electric polarization. The polarization will cause a mechanical deformation and electrical charge can be generated with the inverse piezoelectric effect. This will generate an alternating current. The energy density of a piezoelectric converter is strongly dependent on the coupling coefficient and the mechanical strength of the material (Bowen and Arafa, 2015).

Electromagnetic energy harvesting can be divided into three types of generators, namely resonant, rotational and hybrid. Resonant generators operate in an oscillating mode. They usually utilize the relatively small displacements between a permanent magnet (PM) and a coil to harness power from environmental vibrations. In contrast, rotational generators operate in the same way as the operation of large-scale magnetic generators. They have been designed to operate using rotational power from small turbines or heat engines, which can provide continuous rotational motion under a steady driving torque. Lastly, hybrid devices convert linear motion into rotational motion using an imbalanced rotor. Based on different operating conditions, the power generated by rotation from these devices may be continuous, resonant or chaotic (Khaligh *et al.*, 2009).

Resonant generators usually operate at relatively low electrical frequencies and, hence, low power densities. The basic resonant generator consists of a mass mounted on a spring, which vibrates relative to the housing when driven by an external vibration force. The mechanical energy of the moving mass is transformed to electrical energy by having the mass move a magnet relative to a coil. To achieve maximum power generation in these types of generators, the input vibration frequency should match the mechanical resonant frequency. In comparison with resonant generators, rotational generators rely on a steady source of rotational mechanical energy (e.g. from a fluid-powered turbine or heat engine). Because of their relatively smaller size, they often operate at higher rotational speeds and, hence, higher electrical frequencies compared with resonant generators. These higher speeds enable the generators to meet or exceed the power density of their large-scale counterparts (Khaligh *et al.*, 2009).

To create maximum power generation, the resonant generators are operated at only one specific frequency and, therefore, are not suitable for a time-varying frequency vibration. Nonresonant generator technologies are required in order to use linear vibrations over a wide frequency spectrum. This can be achieved using an imbalanced rotor, which will rotate under forced acceleration of the turning point. Those types of devices are called hybrid generators because they respond to resonant mechanical motion but generate power via rotary machines. A study conducted by He *et al.* (2018) proposed a hybrid nanogenerator that consists of the triboelectric-piezoelectric-electromagnetic that is capable of harvesting energy via supplemental conversion mechanism. Acrylonitrile butadiene styrene (ABS) copolymers were used to build the shell of the device with 3D printing technology. The key movable component of this device is a circular magnet which is suspended by three cylindrical magnets. This structure can oscillate around a balance point in response to small mechanical disturbance in the environment, i.e. the vibration from slapping a desk and the vibration from a moving car. This device has high sensitivity and therefore is more suitable for small-scale vibration harvesting. Mechanical fatigue or damage can be avoided. The hybridized generator can drive the wireless sensor system, which can acquire the temperature and vibration signal and send them to the control computer with an interactive interface.

2.2 Wind belt-based approach

The wind belt is a power generating device invented by Shawn Frayn in 2004 for converting wind power to electricity. It consists of a flexible polymer ribbon stretched between supports transverse to the wind direction, with magnets glued to it. When the wind blows across it, the ribbon vibrates due to aero elastic flutter, like the action of an Aeolian harp. The vibrating movement of the magnets induces current in nearby pick coils by electrostatic induction (Bhattacharjee *et al.*, 2018). Wind belt is an innovation which is based around the two main principles of (1) aeroelastic flutter, (2) electromagnetic induction, (3) vibrations due to air flow and (4) use of torsion belt. The first principle (1) is based on aeroelastic flutter which involves aerodynamic forces acting on a structure to result in a self-feeding high energy oscillation. Flutter has the potential to occur in any object subject to wind. If there is positive feedback in the structure between the aerodynamic forces and its natural vibration, flutter will occur. This means that the vibrational oscillation of the object, coupled with wind, will drive the object to move farther or faster. The second principle (2) behind the wind belts design is Michael Faraday's electromagnetic induction. Electromagnetic induction is the production of voltage across a conductor in a changing magnetic field. Faraday found and stated that the induced electromotive force or EMF in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit. Faraday's law is shown in (1):

$$\varepsilon = -N \times \Delta Ø / \Delta t \tag{1}$$

where N = the number of loops of a conductive coil and $\Delta Ø$ = the change of electromagnetic flux.

In practice, a changing magnetic field applied through a conductive wire in a closed circuit will generate electricity. The current produced in the wind belt is an alternating current, with a frequency typically between 20 and 30 Hz depending on the wind speed and construction dimensions for the unit. The third principle (3) is using vibrations that deal with behavior of bodies under the influence of oscillatory forces. These forces are caused frequently by dynamically unbalanced masses in rotating machines or by the motion of the body itself. Vibrations can be used the way wind, say, we use for making the belt flutter. In our case, as we are trying to harness energy from vibration, high amplitudes will be beneficial. Higher the amplitude, more the belt will flutter and more will be the output of the system. The fourth principle (4) is using the bending and torsion motion of the belt for generation of the electricity. The coil wounded on the cylindrical core facilitates only the production of the electricity by using the bending effect. For utilizing the torsion, the arrangement is similar to the moving coil galvanometer. In moving coil galvanometer, the coil swivels in the radial magnetic field generated by using the magnets with cylindrically concave poles.

The two-step process of vibrational energy conversion involves a main concept for the wind fluttering energy harvester by converting vibration to useable electrical output, known as current. In terms of relative motion, a mass spring system acts as an energy storage aiding the motion of two elements. The energy is then channeled into mechanical to electrical converter. The known converter utilized electromagnetic, piezoelectric and electrostatic methods. Comparison of strength and weakness among the converters was conducted on a seven-factor basis and electromagnetic method was chosen for further design (Vinayan *et al.*, 2019). An effect known as aeroelastic flutter utilizes the wind energy by capturing its kinetic energy causing vibration to its elastic structure when in the direction of wind flow (Arroyo *et al.*, 2014). A change in the magnetic field occurs due to this relative movement, otherwise known as magnetic flux, producing current. An omni-directional wind harvester was designed to harvest energy from low-speed wind coming from all directions (Arroyo *et al.*, 2014). While another study suggested to power up wireless sensors and devices of small scale by wind belt (Aquino *et al.*, 2017). On the other hand, Pimentel *et al.* researched the belt tension and attack angle that affects the Humdingers wind belt in wind tunnels. The optimal results for the tensions are 8.1 N at 3.6 m/s and 36 N at 7 m/s, the cut in attack angle is 40° at 3.6 m/s and 4 m/s to 55° at 10 m/s (Pimentel *et al.*, 2010). The stiffness of belt was investigated by Chen *et al.*, 2016. Theoretical structure for the stiffness and flexible materials for the flutter was developed. The frequency of flutter is independent of the velocity of wind in the stiff material, whereas for the flexible material, the flutter frequency is proportional to wind speed (Chen *et al.*, 2016). The piezoelectric wind belt parameters were optimized by Fernandez *et al.* (2018). Parameters examined including belt length, material and exposed length of the transducers. A finalized optimum measurement was of 0.75 m latex rubber with frame length of 0.86 m and the exposure of transducer being 75% for a recorded wind speed of 3 m/s (Fernandez *et al.*, 2018). The vibration aspect of the harvester was studied by Ahmad and Khan (2018). Multiple modes and nonlinear behavior were studied in electromagnetic energy harvester. By altering the design and mass of magnet, the device can be tuned as desired (Ahmad and Khan, 2018). Atrah *et al.* (2017) mentioned that by adding a cylinder in front of the wind belt, Karmen vortex can be created to improve the wind belt performance. Materials, dimensions, tension of the wind belt are some design parameters that might affect performance. However, their relationship is not widely researched.

2.3 Aeroelastic-based approach

When a structure is subjected to flow loads, the structure may undergo various responses including nonlinear undesirable dynamic phenomena such as divergence also known as static aeroelastic phenomenon, flutter that is dynamic aerodynamic phenomenon, vortex – included vibration – unsteady aerodynamic phenomenon known as buffeting or limit cycle oscillations (Lee *et al.*, 1999). Piezoelectric materials and other actuators have been mostly used as active and semi-passive controllers to modify aeroelastic behavior of wings. Piezoelectric actuators were also used for morphing wings. Aeroelastic flutter involves aerodynamic forces acting on a structure to result in a self-feeding high energy oscillation. Flutter had the potential to occur in any object subject to wind. If there is positive feedback in the structure between the aerodynamic forces and its natural vibration, flutter will occur

(Fei and Li, 2009). The vibrational oscillations of the object will couple with wind that dives the object to move faster. Aeroelastic flutter results in "self-exciting oscillations" and will build up until the aerodynamic or mechanical damping of the system matches the energy input. At this point, large amplitudes are occurring which can cause rapid failure in structure. In other words, aerodynamic force acting on a surface are divided in two parts: the component that supports the structural motion of the body and the other that resists the movement; when the aerodynamic and structure loads are in balance, it will produce harmonic oscillations. Above the critical flow speed, there is an unbalance of energy flowing to the structure that cannot be dissipated and as the consequence, the oscillations grow divergently. Flutter occurs as result of interactions between aerodynamics, stiffness and inertial forces on a structure. Aerodynamic force acting on a surface is divided in two parts: the component that supports the structural motion of the body and the other that resists the movement. When the aerodynamic and structure loads are in balance, it will produce harmonic oscillations. Above the critical flow speed, there is an unbalance of energy flowing to the structure that cannot be dissipated and as the consequence, the oscillations grow divergently.

Transverse galloping is another possible phenomenon of aeroelastic energy harvester; the phenomenon uses a quasi-steady-state hypothesis in describing the aerodynamic forces. In a well-defined lift and drag coefficient, a development of criterion for galloping phenomenon takes place (Hartog, 1984). Transverse galloping occurs when the wind speed exceeds a critical value at which an instability is initiated and the prismatic structure starts to oscillate on the elastic bluff bodies. The phenomenon is well known for causing large oscillations amplitudes which benefit to generate voltage from amplitude of oscillation by using piezoelectric transducer. A numerical analysis on the maximum potential energy harvested power from galloping-based piezoelectric with an analysis of wind energy causing transverse vibration on a nonlinear model of galloping cantilever beam, thus giving mechanical energy of vibration to be converted into electrical charge using the piezoelectric transducer (Abdollahzadeh Jamalabadi *et al.*, 2020). The mechanical limit of the system has shown a disallowance of anticipated values in the theory with feasibility values 2–3 orders of magnitude lower than prediction values.

Nonlinearity model of structure and aerodynamics can lead to persistent oscillation in an aeroelastic system which can be utilized through conversion of mechanical energy into electrical power. Analysis of a nonlinear model induced with flow structure interaction of an energy harvester has been done with a laminated beam integrated with a piezoelectric sensor (dos Santos *et al.*, 2021). A finite element approach of the cantilever beam and piezoelectric lamina model has been approached with an unsteady aerodynamic effect which allows arbitrary nonlinear life characteristic. The fluttering beam of the electro-aeroelastic model undergoes broad range of flow speeds and presents an angle of incident for validation using the wind tunnel test. Result of the investigation has shown that the model and experiment has demonstrated an appropriate modeling of flow and dynamic structure which is crucial in accurately describing the complex physics involved in the phenomena. In the experiment of the study, the limit cycle oscillation can be achieved in the post-flutter behavior of the beam and power can be harvested for wind speed of 7 and 10 m/s, despite not able to been done through computational through numerical and finite element simulation.

Aeroelastic energy harvester enhancement can be done through modification of the harvester; an addition of beam stiffener to harvester would increase the electromechanical coupling, thus modifying the mode shape of the harvester. Theoretical models of the aeroelastic energy harvester, including the electromechanical model based on the Euler-Bernoulli beam theory and Kirchhoff laws that represents the coupling effect of the structure with the electrical component and the aerodynamic model in calculating the aerodynamic force because of the specific aeroelastic phenomenon. An experiment with wind tunnel of the galloping-based harvester prototype at both different lengths of the beam stiffener and wind speeds. Nonlinear numerical analysis has been conducted to identify the effect of beam stiffener length and wind speed on the harvested power as well as the transverse displacement and efficiency of flow power conversion. As a result, the galloping-based harvester does produce a significant higher value of output power than conventional harvester; meanwhile, the flutter-based harvester has the highest efficiency and the vortex-induced vibration (VIV)-based harvester is lock-in region to be broadened. In conclusion, inclusion of addition beam is an effective and practical method to enhance the aeroelastic energy harvesting devices in producing output power than the conventional harvester (Abdelkefi, 2016).

2.4 Movement from high-speed train

Clean and green energy is emerging as the future of power generation. Nonrenewable energy resources are depleting fast, and they are harmful to the environment. We have relied upon wind energy from early days of sailing and presently use turbines to harvest wind energy. There are still unexplored areas where we could potentially harvest wind energy. One such example is the vast amount of wind energy produced by trains traveling in tunnels. This high velocity wind energy can be used to generate power by placing vertical axis wind turbines (VAWTs) alongside the trains. The alternate form of wind energy produced by train is unique as it does not depend on any natural energy resources. In the process of capturing and routing wind induced by train, optimum electricity may be generated if the wind is properly directed toward the wind turbine blades. In this project, the availability of wind energy for generation of electricity through small turbines is a key factor which decides the efficiency of the entire project. Therefore, complete analysis of the routing schedule of all trains within the railway systems is crucial in determining the installation process of the turbines in such a manner that they are exposed to the most suitable windy conditions around the railway tracks (Joshi *et al.*, 2012).

Besides, a compact fluorescent lamp requires a standard of 20–30 W of power, and a led module requires only 3 W of power at 12 V. A single proposed wind turbine can quickly produce 400–600 W of power, and we can light up about 200 units of LED module and 20 units of CFLs at a time. An installation of different design and shale along the railway with train which runs at an average speed of 30 to 55 kmph is enough for proposed wind turbines to produce electricity to light up the railway stations and the surplus can be transmitted to nearby areas. It is also suggested that the wind turbines should be installed where the trains tend to stop or decelerate because while stopping, there is no fuel loss and the gust produced will be used to rotate these turbines to generate electricity and power (Kumar *et al.*, 2015).

Furthermore, the fixed wind power generation system is used up till, but it depends on the wind force and wind direction. All time throughout the year, the wind is not available at all places. Therefore, the need for a system generating the electricity through wind induced by moving train, which is available at all places and with wind force. A fast-moving train generates the wind on the front of it and pushes the wind on the wind turbine blades. The kinetic energy is used to rotate the wind turbine and generate electricity by using a direct generator (DC) generator. The generator is used to convert mechanical energy into electrical energy. The turbine blades transfer the kinetic energy from the wind into rotational energy, and the wind turbine is used to the exaction of the generator. With the help of a turbine, the exaction generator generates electrical power. The wind turbine is coupled with a generator. This power is generated using a generator. Moreover, this power is stored in a DC battery. Furthermore, this generated power is used to run electrical equipment inside the train (Sagar *et al.*, 2015).

It is also known that during the train movement, the air vacuum will be produced at the sides and the back of the wagon. Therefore, air with speed equal to the moving vehicle's velocity will rush to these vacuums to fill that vacuum. The kinetic energy of that air can be used for the generation of electricity. In other words, the wind's energy will be transformed into mechanical energy of the blades of the wind turbine and further, by connecting the rotor of the turbine to the generator shaft, transferred into electrical energy according to the principle of electromagnetic induction. In this case, Nurmanova *et al.* (2018) proposed that wind energy is harvested from installing wind turbine on the roof of a high-speed train. The train's rooftop was chosen for the installation point due to higher wind speed and fewer obstacles. Moreover, the top area is sufficient to locate all components of the system, including wind turbines, gearboxes and generators and consequently decreasing the necessity of long wiring.

In modern times, wind power technology has been growing widely. With the incorporation of wind turbines together with the electrical grid, the system operators must know the behavior of wind turbine under all the many operational areas of interest in the power system such as calculation of wind speed, modeling, control and stability analysis of the wind system connected with electric grids are of importance in the modern power system. The problem related to the various effects of wind energy when integrated with the power system on the system's stability is gaining more interest of researchers because of increasing its penetration level. There may be an argument relating to the installation of windmills along railway tracks or mounted on the rooftop of the train, but for a proper understanding of the pros and cons, we need to implement this idea on a small scale first and then move ahead with implementing it.

For this project also, railways where rail traffic is high and the number of operating trains are more are much likely to provide positive results since more the frequency of trains, more will be the generation of air currents due to them. The disturbance in air produced by the moving vehicle can lead to production of substantial amount of power if tapped efficiently over a duration. The moving vehicles could be railway train which is running on railway track. As train runs over railroad tracks, the alternate form of wind energy produced by train is very unique as it does not depend on any natural energy resource. If the wind is properly directed toward the wind turbine blades, optimum electricity may be generated. The desired direction of wind is obtained by a means for channeling wind, in the direction of the wind turbine. Channeling of wind in a desired direction may be obtained by at least one truncated cone- or pyramid-shaped housing or a pair of planar members converging toward the blades of the wind turbine (Prasanth and Sudheshnan, 2011).

2.5 Related research work and research gap

Table 1 provides related work and the key findings in wind energy harvesting technologies. Masdari *et al.* (2020) studied the effect of gurney flap on National Advisory Committee for Aeronautics (NACA) 0012 airfoil of middle range Reynolds. ANSYS is used to simulate the condition with and without gurney flaps to understand the flow of wind. The pitching function is used on the airfoil when studying the oscillation of the blade. The effects of the gurney flap's height and mounting angle are studied. Normally, the flow on the upside of the airfoil is accelerated and the flow pressure is decreased when a gurney flap consists of two counter-rotating vortexes. Based on the study, it was proven that with a height of 3.2% of chord and with no mounting angle, the best aerodynamic performance can be attained (Masdari *et al.*, 2020).

Tien and Goo (2010) discussed the use of piezoelectric on windmills to harvest the wasted energy produced to be later used. The paper proposes a design that uses piezo-composite generating element (PCGE) to generate electricity. A multilayer PCGE was introduced to improve the efficiency of piezoceramic as it is known to be susceptible to breakage under pressure. The PCGE structure encompasses of piezoceramic, glass or epoxy and epoxy or carbon. The layers are done as such to segregate the generating segment apart from the

Paper name	Author	Year	Key finding
Design of aeroelastic wind belt for low-energy wind harvesting	V A Vinayan, T C Yap and Y I Go	2019	(1) The peak output voltage and power recorded whilst the four coils are connected in parallel are about 21.00 V, generating 346.08 mW at 12 m/s wind speed: 1.224 N belt tension (2) The peak power recorded in parallel connection at lower wind speed are 81.02 mW at 6 m/s with a belt tension of 0.816 N and 24.54 mW at 4 m/s with belt tension of 0.612 N
Maximum obtainable energy harvesting power from galloping-based piezoelectrics	Mohammad Yaghoub *et al.*	2020	(1) The nonlinear model of the galloping cantilever beam used for piezoelectric energy harvesting is simulated numerically with respect to the failure criteria as a limit of the maximum obtainable power (2) Maximum obtainable average power in a standard RC circuit as a function of deflection limit and synchronized charge extraction is obtained
Wind power generation system using railway – a prototype model	Sagar Ingle *et al.*	2015	(1) The wind energy produced by train is unique as it does not depend on any natural source. Generated wind is directed toward the wind turbine and generates electricity. At list one, pyramid-shaped housing toward the blades of the wind turbine (2) The turbine is placed on top of the train and turbine coupled with generator has no any gear arrangement for rotating the generator. Turbine and generator are directly coupled to each other
Wind energy in Malaysia: past, present and future	Lip-Wah Ho	2016	(1) Review on global wind energy development found successful installation of wind power capacity depends very much on robust regulatory support and strong political will, something that Malaysia is still lacking and uncertain (2) Wind speed data from or near airports should not be used for wind power potential analyses, particularly if the data come from low wind speed regions

(continued)

Table 1.
Summary of literature review

Paper name	Author	Year	Key finding
Design optimization of low power wind belt electric generator using piezoelectric transducer	Fernandez *et al.*	2018	(1) The length of the frame to which the belt was elongated to for the aeroelastic flutter to occur that produces the highest induced voltage on the piezoelectric transducer was also determined to be about 0.86 m (2) The best material for the belt was identified to be latex rubber and its optimum length was obtained experimentally to be 0.75 m
Design and performance evaluation of vertical axis wind turbine for wind energy harvesting at railway	This paper	2020	(1) To identify the suitable material and NACA number for the turbine blades (2) Simple economic evaluation of wind turbine installation at KLIA transit (3) Carry out ANSYS to identify the direction of wind and its highest potential

Table 1.

flexural neutral surface to ensure the generator can produce high output voltage and power. The PCGE is vibrated and produces electricity when it is bent or there is a deformation. The rotation of the fan blade is transferred to the rotary disk via the center rod. The PCGE is excited by the exciter teeth which are attached to the frame. This technology has been proven to be able to produce power from wind energy vibration; the PCGE was able to produce 6.1 and 8.5 MW of power with interface lengths of 1 and 1.5 mm, respectively. The PCGE technology can be further improved to be used to harvest energy from machine vibrations, wind, ocean and body motion (Tien and Goo, 2010).

Hulio and Jiang (2020) studied the effect of wind speed on the performance and the cost of wind energy generation. The wind characteristics of the wind farm was measured and analyzed with the Weibull k and c parameters. The performance of the wind turbine is evaluated based on the performance model. To study the effect of wind speed on the behavior and failure of the wind turbine, the wind correlation was evaluated based on changing wind speed. The power curve of the wind turbine is also assessed. Based on the records of the wind farm, it was proven that when the wind speed increases, there was network failure including electrical and mechanical failure. The wind farm has an efficient performance when operated below the rated wind speed of 11.5 m/s. The energy loss model shows that the main portion of energy time is lost because of network, voltage dip, electrical and mechanical components failures (Hulio and Jiang, 2020).

The effect of global warming on wind energy was studied by Gungor (2015). The Weibull distribution was is an accepted and recommended literature used to evaluate wind speed frequency and estimate wind energy. This study uses wind data of 35 years to investigate the effect of global warming on wind energy, and it was proven to be negative. There were no significant changes in the Weibull scale parameters, but there are changes in the Weibull shape parameter. For the past 35 years, the intensity of wind power has halved and proves that it has become a serious matter. After 1980, there has been large drop in the potential of wind energy. In the power density from the years 1980–1995, there were serious fluctuations of average power density; after the year 1995, the average power density was about 15 W/m2. The study proves that global warming has substantial effect on wind power production (Gungor, 2015).

Wind energy harvesting is not commonly used in Malaysia due to its low wind speed ranging from 1.5 to 4.5 m/s. Conventional wind turbine requires a minimum cut-in wind speed of 11 m/s to overcome the inertia and starts generating power. Hence, this paper proposes an optimum design of VAWT to harvest an unconventional untapped wind sources form railway. The research finding complements the alternate energy harvesting technologies which can serve as reference for countries which experienced similar geographic constraints. The research gap addressed in this project is the harvesting of wasted wind energy from moving trains to be implemented in Malaysia as Malaysia is heading to a greener, carbon neutral environment.

3. Research methodology

3.1 Site selection

In this study, KLIA Transit railway has been chosen with a track length of 57 km. A section from the track has been identified for simulation and power generation calculation. Figure 1 shows a 30 km of the KLIA Transit track being taken as the installation site for the wind turbine; the track from Putrajaya Central to KLIA is taken for as the study site. The wind turbine would be installed along the 30 km track which will be placed between the two railway tracks; the south bound and the north bound which are being used to utilize drag air from both trains which are coming from an opposite side. Figure 1 shows the installation of wind turbine which will be placed between two tracks. Track length of 30 km is used in the simulation. The distance between each turbine is 1 km. This indicates a total number of 30 turbines to be installed in this case. KLIA Transit would have eight train sets which would carry 32 cars which would be in service; meanwhile, there are another two train sets which can carry eight cars being standby as an additional train for the peak hour time. The rolling stocks would travel at a 160 km/hr speed along KLIA Transit, which would take only 48 min to travel from Putrajaya Central to KLIA 2; the drag air which is found to be 33.3 m/s would be utilized to generate power and stored in a battery storage which will be used to power up the KLIA Transit Station, specifically for the Putrajaya Central and KLIA Station.

Operating hour for the KLIA Transit would be 20 h, which will be divided into 11 h of normal operation hour and 9 h of peak operation hour. In the normal operating hours, eight

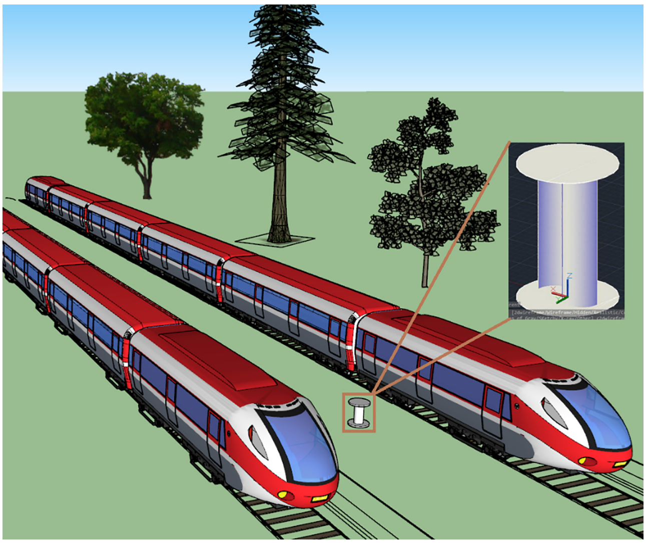

Figure 1.
Wind turbine placement

train sets which carry 32 cars would be us for the operation; meanwhile, during peak hour, an additional two train sets with eight cars would be added; therefore, a total of ten train sets with 40 cars would be operating during the peak hour. In the operation of the train, the time interval of each train during the normal operation would be 30 min; meanwhile, during the peak hours, it will be 20 min. Table 2 indicates the site data that will be used for the calculation and design of the wind turbine as well as power storage for the battery to power up the station. The data consist of site distance and the number of turbines that will be installed along track with the distance interval. Table 2 includes the operation hour of the wind turbine which is similar to the peak hour of the train in order to find the maximum possible power produced during peak time as there are a greater number of trains and less time interval between the trains. Figure 2 presents the methodological stages of the work with key work packages and design parameters.

3.2 Main components of the system

Rotating blade is a one of the important components of the proposed system which converts kinetic energy into mechanical energy. Blade is designed aerodynamically to work on the principle of lift and drag to convert kinetic energy of wind into mechanical energy through shaft. There are two important reasons why wind turbine blades can spin in the wind: Newton's third law and the Bernoulli effect. Newton's third law states that for every action, there is an equal and opposite reaction. In the case of a wind turbine blade, the action of the wind pushing air against the blade causes the reaction of the blade being deflected or pushed. If the blade has no pitch, the blade will simply be pushed backwards (downwind). Since wind turbine blades are set at an angle, the wind is deflected at opposite angle, pushing the blades away from the deflected wind. This phenomenon can be viewed on a simple, flat blade set at an angle.

The Bernoulli effect tells us that faster moving air has lower pressure. Wind turbine blades are shaped so that the air molecules moving around the blade travel faster on the downwind side of the blade than those moving across the upwind side of the blade. This shape, known as an aero foil, is like an uneven teardrop. The downwind side of the blade has a large curve, while the upwind side is relatively flat. Since the air is moving faster on the curved, downwind side of the blade, there is less pressure on this side of the blade. This difference in pressure on the opposite sides of the blade causes the blade to be lifted toward the curve of the aero foil (Tupe *et al.*, 2016). Generator is another unit of wind turbine that converts mechanical energy into electrical energy. Generator is the next state in the supply of energy from the wind turbine to the electrical grid. Wind turbine may be connected to an electricity generator. The generated electricity may be stored in batteries, from which energy may be used as per application. Figure 3 shows the process of wind energy conversion.

3.3 Selection, design and analysis of vertical axis wind turbine

In this work, Savonius wind turbine has been chosen due to its simplicity to construct and its decent starting torque. In this turbine, it adopts drag concept to operate, which is independent of the wind direction. It does not need an additional force to get it going and has a relatively

Study site (train service)	Putrajaya Central to KLIA (KLIA Transit)
Study length (total length)	30 km (57 km)
The number of turbines (Turbine/km)	30 (1/km)
Drag wind speed V_{avg}	33.3 m/s
Operation hour, Hr	9 h
Train time interval	20 min

Table 2.
Site data and specifications

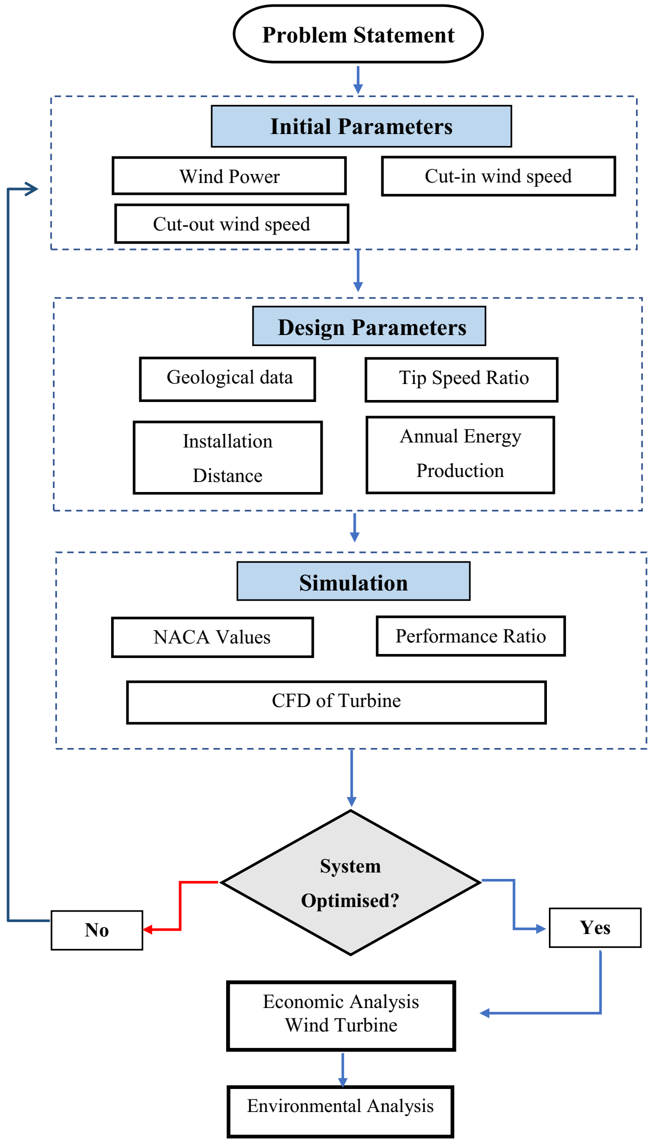

Figure 2.
Flowchart of methodology

low emission and noise. Sigurd Johannes Savonius of Finland invented the Savonius wind turbine in 1925 (Spera, 2009). His invention was patented in 1929. Savonius wind turbine is a VAWT as its rotating axis is vertical or perpendicular to the ground (Kishore, 2010). The conventional Savonius wind turbine rotor blades design consists of two to three scoops. The scoops are generally semi-cylindrical in shape, and it is one of the simplest wind turbine designs. Top view cross section of two scoops resembles an *S* shape (Torresi *et al.*, 2014).

Curvature of the Savonius wind turbine's scoops is designed to experience the drag forces from the wind (Deshmukh *et al.*, 2015). Savonius wind turbine is a self-starting turbine since it

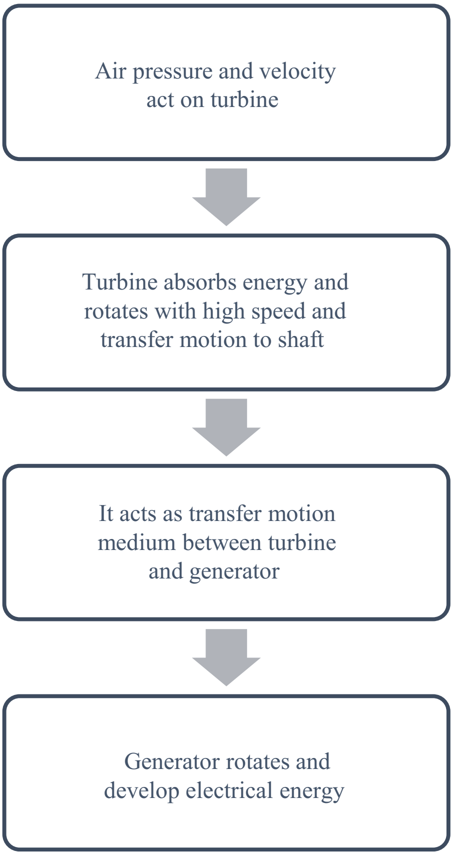

Figure 3.
Wind energy conversion process

has a high starting torque. The turbine adapts to multiple wind direction where no additional control mechanism is required. It is observed that when the turbine is moving at lower speeds, it produces low noise level. The turbine can be operated at lower elevation because the electrical component could be placed at ground level (Widodo *et al.*, 2012). The turbine also functions better at a low-speed wind. Thus, strong supporting tower is not needed, and this makes Savonius wind turbine low in production cost, easy to be installed and easy to be transported from one place to another. As a result, less maintenance is necessary (Devi and Singh, 2014). The Savonius wind turbine does not stick out very far, making it a compact-sized wind turbine; thus, it is suitable to be installed in urban areas such as rooftop of a building (Ali, 2013). Considering all these factors, this work has identified the key design parameters of the air foil as described in the following section:

3.3.1 Design variables: thickness. The thickness should be chosen to give enough structural strength with respect to the loads on the blades. A thicker air foil of 20% can be an option. The advantage of higher thickness is increase of the drag bucket and increase of structural strength. The disadvantages of higher thickness are higher drag coefficient at lower angles of attack and a chance of "overshooting" the maximum, past a certain unknown point more thickness will result in a lower efficiency. The optimum of the thickness is difficult to find. In older VAWT, less thick air foils were used of 12% or 15%. The 18% thick air foils also produce very good results. The question is how much the thickness can be increased without performance loss. From the figure below, the increase of thickness from 9% to 15% results in a wider drag bucket. The minimum thickness with respect to structural demands is 18%. If thickness can be added, it would be a great benefit. This would result in more structural strength and effectively a larger operating envelope; in this project, we have opted for 20% thickness.

3.3.2 Design variables: camber. Until now in almost all VAWTs, only symmetrical air foils have been applied (mostly NACA 0015 and NACA 0018). From a physical point, the velocity at the upwind side of the turbine will be higher than that at the downwind side as the blade extracts energy from the air at the first passage. The lower airspeeds result in lower angles of attack at the downwind side as these two parameters are directly related. The power extraction from the wind is a function of V^3. Only a small variation in wind speed gives a large difference in possible power extraction. Therefore, an optimal power extraction at the upwind side is preferable. This will have a negative result, that is, the velocity and therefore, the extracted power at the downwind side will decrease even more. To increase the efficiency of the turbine, camber can be added to the profile. In this case, the profile will be more efficient at the upwind side. Even more energy will be extracted from the wind, and the angle of attack at the downwind side will be even lower. This is very important because the efficiency at the downwind side will be much lower (Claessens, 2006).

3.3.3 Design variables: noise. Not much research is performed on the noise emission of the VAWT. From Iida *et al.* (2004), the aerodynamic sound of a VAWT is numerically modeled using discreet vortex methods. The complicated wake structure can be captured using this method. It shows that the VAWT produces less sound than a horizontal axis wind turbine with the same power coefficient at normal operating speed. The simulated sound against the tip speed ratio is given below in the figure. The operating tip speed ratio is 3, which results in a produced aerodynamic noise of 60 dB. The design that has been deduced that will be suitable for the proposed idea is NACA 0020. The thickness and the air foil design of this NACA specification fit the wind speed and the need of the project proposed (Claessens, 2006).

3.4 Power obtained from wind turbine

Power of an ideal turbine rotor, thrust of the wind on the ideal rotor and the effect of the rotor operation on the local wind field can be determined by Betz principle (Manwell *et al.*, 2010). The linear momentum theory is the concept of this model. The controlled variable in this analysis is the volume, in which the control volume boundaries are the surface of a stream tube and two cross-sections of the stream tube. The only flow is across the ends of the stream tube. The turbine is represented by a uniform "actuator disk," which creates a discontinuity of pressure in the stream tube of air flowing through it. This analysis applies to all types of wind turbine. The net force on the contents of the control volume can be determined by applying the conservation of linear momentum to the control volume enclosing the whole system. That force is equal and opposite to the thrust, T, which is the force of the wind on the wind turbine. From the conservation of linear momentum for a one-dimensional, incompressible, time-invariant flow, the thrust is equal and opposite to the change in momentum of air stream (2):

$$T = V_1(\rho A V)_1 - V_4(\rho A V)_4 \tag{2}$$

where ρ is the air density, A is the cross-sectional area and V is the air velocity.

Steady state flow means $(\rho A V)_4$ = mass flow rate ($\dot{m}$). Therefore, shown in (3):

$$T = \dot{m}(V_1 - V_4) \tag{3}$$

The free stream velocity V_1 is higher than the velocity behind the rotor V_4 because the thrust is positive. There is no work done on either side of the rotor. Therefore, Bernoulli equation (4) for the upstream of the disk is given by

$$P_1 + \frac{1}{2}(\rho v_1^2) = P_1 + \frac{1}{2}(\rho v_2^2) \tag{4}$$

And for downstream of the disk (5) is given by

$$P_1 + \frac{1}{2}(\rho v_3^2) = P_1 + \frac{1}{2}(\rho v_4^2) \tag{5}$$

In this case, the pressures upstream and downstream is considered equal ($P_1 = P_4$). The velocities across the disk are equal ($V_2 = V_3$). Thrust can also be expressed as the net sum of the forces on each side of the actuator disc (6) as

$$T = A_2(P_2 - P_3) \tag{6}$$

Figures 4a and b show the position of the turbines that can be placed along the train tracks to generate electricity.

4. Results and discussion

4.1 Wind power

Wind power is the use of wind energy which is converted to mechanical and then to electrical power. Wind power can be defined as the multiplication of mass flow rate and potential

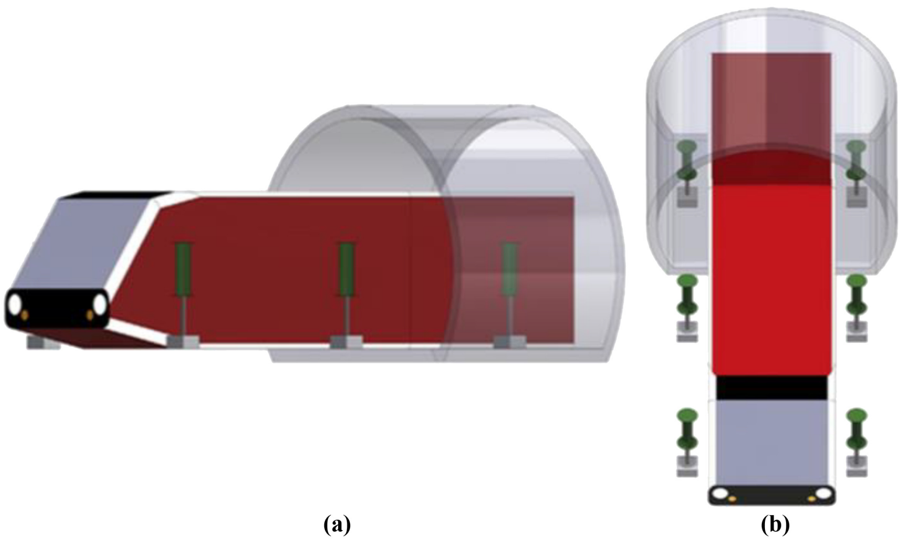

Figure 4.
(a) Front 3/4 view of the proposed system, (b) isometric top view of the proposed system (Bethi *et al.*, 2019)

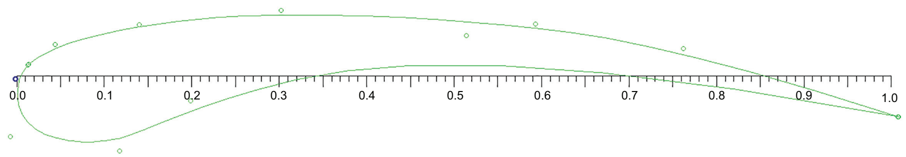

Figure 5.
NACA 0020 blade design

energy per unit mass. The wind power can be denoted by mathematic equations (7)–(9) as follows:

$$P_w = \frac{1}{2} \times \dot{m} \times v^2 = \frac{1}{2} x\ (\rho \times A \times v)v^2 = \frac{1}{2} \times \rho \times A\ v^3 \tag{7}$$

$$\text{Where, mass flow is } \dot{m} = \rho \times A \times v \tag{8}$$

$$\text{Kinetic Energy} = \frac{1}{2} \times v^2 \tag{9}$$

The wind power equation is based on the ideal case for the Savonius wind turbine as in a real-life case, loss would present for the conversion of mechanical to electrical from the gearbox, blade, bearing and transmission. The maximum power coefficient for Savonius wind turbine is found to be 0.45, which is taken into the calculation (10) for the design of the wind turbine.

$$P_w = 0.225 \ \left(\rho \times A \times v^3\right) \tag{10}$$

The use of vertical wind turbine for the project would have a calculation of swept area (11) as

$$\text{Area} = \text{Rotor Diameter}\ (m) \times \text{RotorHeight}\ (m) \tag{11}$$

The swept area would represent the area of the wind which would cause the turbine to spin for power generation. A larger swept area would give a larger power output, but it is limited to the cost and space of the turbine placement.

4.2 Wind speed

In the calculation of wind power, the wind velocity is the major significant component that influences the amount of power output that can be produced from the wind turbine. The wind speed parameter of this experiment is divided into three which is cut-in, rated and cut-out speed. The wind speed can be expressed according to Jain (2011) and is as follows (12), (13), (14):

$$V_{\text{cut-in}} = 0.5\ V_{\text{avg}} \tag{12}$$

$$V_{\text{rated}} = 1.5\ V_{\text{avg}} \tag{13}$$

$$V_{\text{cut-out}} = 3.0\ V_{\text{avg}} \tag{14}$$

The wind speed parameters are dependent on the average wind speed from the drag wind of the train which is 33.33 m/s. Table 3 shows the calculated value of the three wind speeds. The rated speed was taken in account for the design and calculations of the wind turbine power generated as the value of rated wind speed would produce the highest amount of electricity from the wind turbine.

4.3 Aspect ratio

Aspect ratio of the turbine was also taken into consideration in the design of the wind turbine to ensure the aerodynamic performance of the turbine would be enough for the power

Parameter	Equation	Calculation
Cut-in speed	$V_{\text{cut-in}} = 0.5\ V_{\text{avg}}$	17 m/s
Rated speed	$V_{\text{rated}} = 1.5\ V_{\text{avg}}$	50 m/s
Cut-out speed	$V_{\text{cut-out}} = 3.0\ V_{\text{avg}}$	100 m/s

Table 3. Wind speed specifications

generation; therefore, a calculation is conducted according to the equation X. Johnson (1998) recommended for Savonius rotor, the design would have a height which is twice the rotor diameter to ensure the turbine would be aerodynamic enough for power production (15):

$$A.R = \frac{\text{Height of Rotor (m)}}{\text{Diameter of Rotor (m)}} \tag{15}$$

4.4 Tip speed ratio

A higher value of tip speed ratio, λ would improve the efficiency and the performance of the wind turbine (Manwell *et al.*, 2010). Therefore, the value of tip speed ratio was calculated using the following formula (16):

$$\lambda = \frac{\omega \times d}{V} \tag{16}$$

where ω = angular velocity

d = chord diameter

V = velocity of wind

4.5 Solidity

The solidity σ of the turbine blade for Savonius would be defined as the ratio of blade area of area as according to Musgrove (2010). The solidity would have a relation with the tip speed ratio (17); therefore, the solidity of the wind turbine can be calculated as

$$\sigma = \frac{n \times d}{R} \tag{17}$$

where n = the number of blades

d = chord diameter

R = radius of wind turbine

The result from calculation for the design parameter of the wind turbine can be seen according to Table 4, where 245 kW would be generated by the power of the wind with a swept area of the turbine to be 8 m^2 and 50 m/s of wind speed. The wind turbine design would be seen according to Figure 4. A detailed design parameter as shown in Table 4 was used to design the turbine. The blade of the turbine was designed according to NACA 0020 as shown in Figure 5; the blade was designed to ensure enough drag air would be utilized to turn the turbine. Figures 6a and b show the final design of the wind turbine from AutoCAD, the drawing shows the wireframe and the solid shape of the wind turbine.

4.6 Computational fluid dynamics (CFD) analysis

The wind turbine was developed and simulated with ANSYS software to provide a computational fluid dynamic (CFD) study for the designed turbine. The study could give us an understanding of the air flow and pressure exerted on the turbine determined through the simulation. Figure 7a shows the bounded turbine as a boundary condition. The boundary was made to simulate a wind tunnel as the wind turbine is being rotated by an external flow which is flowing over a body. After enclosing the wind turbine model, the model enters meshing where a wireframe view of the turbine and the enclosed box can be seen in Figure 7b, where the wind turbine has a denser wireframe than the box which shows the fluid flow

Parameter	Value
Power generated	245 kw
Swept area	8 m^2
Rated wind speed	50 m/s
Diameter – height	2–4 m
The number of blades	2
Aspect ratio	2
Tip speed ratio	0.4
Solidity	0.77
Swept area, *A*	8 m^2
Rotor diameter, *D*	2 m
Rotor height, *H*	4 m
Chord length, *d*	1.08 m
Overlap distance, *e*	0.16 m
Blade thickness, *t*	10 mm
Mass density	2,700 kg/m^3
Tensile strength	68,935 kN/m^2
Yield strength	2.76 kN/m^2
Poisson's ratio	0.33

Table 4. Design parameter and specifications

separation as the fluid moves externally from the wind turbine. Figure 7c shows the wind flowing inside the bounded turbine, the flow shows how the rotation of the can be developed from the wind that enters from the left side of the boundary box.

CFD analysis of the wind turbine with ANSYS software can simulate the velocity toward the wind turbine. The simulated result can help understand the fluid dynamics and air flow exerted to the wind turbine. Figure 8 shows different air flow velocity that was flowing within the generated wind tunnel for the wind turbine analysis. Figure 9 shows the magnitude velocity that was acting on the turbine. The simulated velocity magnitude values could be used to calculate the power generated by the wind turbine from the power generated.

4.7 Power production

A circuit connected from the wind turbine to the battery can be seen from Figure 10. The connection of the wind turbine circuit would be connected to each station. The wind turbine installed along the 30 km railway track between the Putrajaya Central and KLIA Station would generate 7.3 MW of electrical power and would generate 66.15 MWh of energy in 9 h of operation due to transmission loss from the movement of the electrical energy which is assumed to be 15%; meanwhile, the loss due to time interval of the train which is to be assumed 25%; therefore, the finalized energy is calculated to be 39.69 MWh; meanwhile, the power that would be produced after all the loss calculation will be 4.41 MW. The 4.41 MW of power was equally shared among the two stations, where one battery is being installed in each station for station lights power up, where each station would receive 2.2 MW of power to charge the 10 MW battery at each station. The battery then will discharge to station to power up the light at the station during the night operation. A detailed explanation of each components of the diagram block can be seen from Table 5 below:

Table 6 shows the economic analysis of the project (Ayodele *et al.*, 2016). The price of the turbines and the cost of storing the energy have been listed. The maintenance cost has been identified accordingly. The CAPEX of the project is RM 35,300. Battery power of 10 MW placed in two stations. Average that can be saved when 10 MW batteries are discharged = 43,800 MWh. Average cost that can be saved from power discharging battery = RM 16.7 mill if batteries are discharged daily for a year for 12 h.

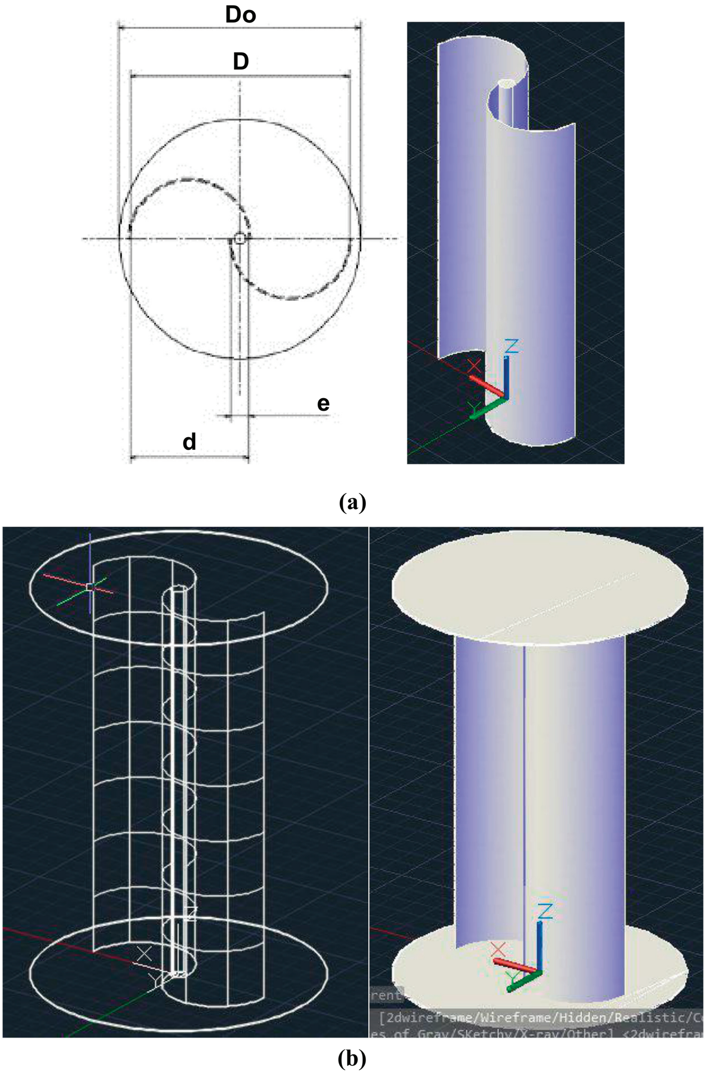

Figure 6.
(a) Top view, (b) final design using wireframe and solid configuration from CAD

4.8 Assistive scheme and related policies

In recent years, the government has attempted to enhance the development of RE which improves the conservation of the nonrenewable resources from depleting and to ensure the sustainability of energy supply. RE is included in the Fifth Fuel Policy which was implemented under the 8th and 9th Malaysia Plan as the fifth component along with hydro, coal, gas and oil. Currently, the recognized sources of RE in Malaysia are biogas, biomass, small hydropower and solar photo-voltaic (PV). Unlike the RE mentioned above, wind energy has yet to be approved as an RE source of the country.

The responsibility of the regulatory framework development for wind energy in Malaysia is under the Sustainable Energy Development Authority (SEDA), which was formed under

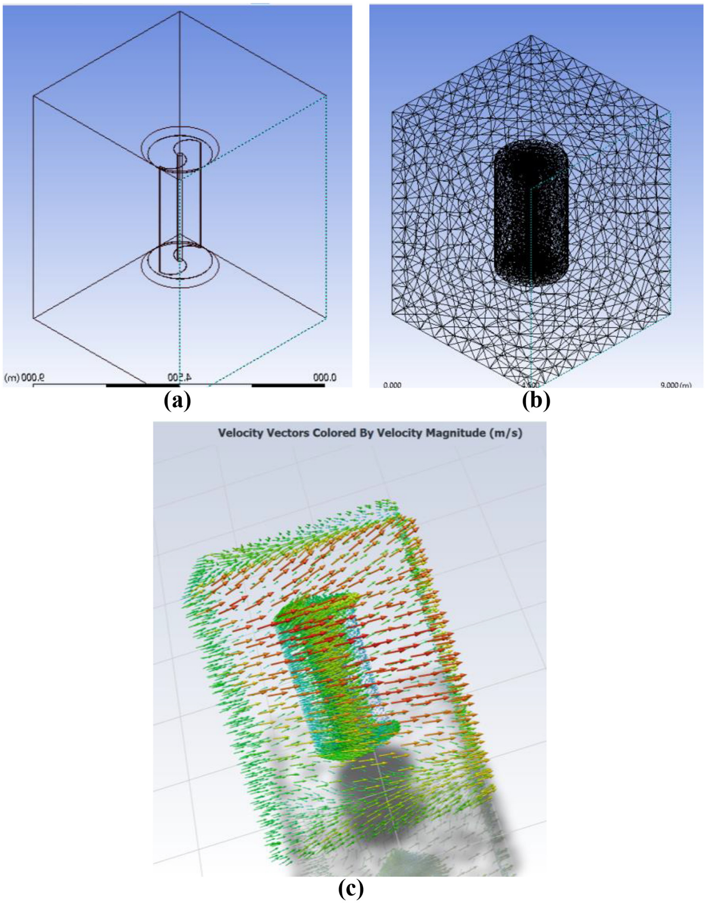

Figure 7.
(a) Enclosed wind turbine, (b) mesh of wind turbine model (c) wind flow

the Sustainable Energy Development Authority Act 2011 with key responsibilities for the promotion and implementation of RE and the implementation and management of FiT scheme which is mandated under the Renewable Energy Act 2011. Main legislation that governs the legal framework for RE in Malaysia is Renewable Energy Act 2011 (REA). However, as previously mentioned, wind energy is an RE resource that has yet to attain recognition as an eligible RE under the REA. It is observed from the first column of the schedule of the REA that wind does not fall within the category of renewable resources under the REA. The schedule only recognizes biogas, biomass, small hydropower and solar PV as renewable resources. The deliberateness of wind energy development in Malaysia may be caused by various factors including lack of robust regulatory framework and the location of Malaysia which is situated in a low wind speed region.

5. Conclusion

In today's world, wind energy has become a prominent source to generate electricity. Malaysia may not have the enough wind speed to carter for a large windmill, but it has the potential of harvesting wind energy from moving vehicles. This study focuses on the design

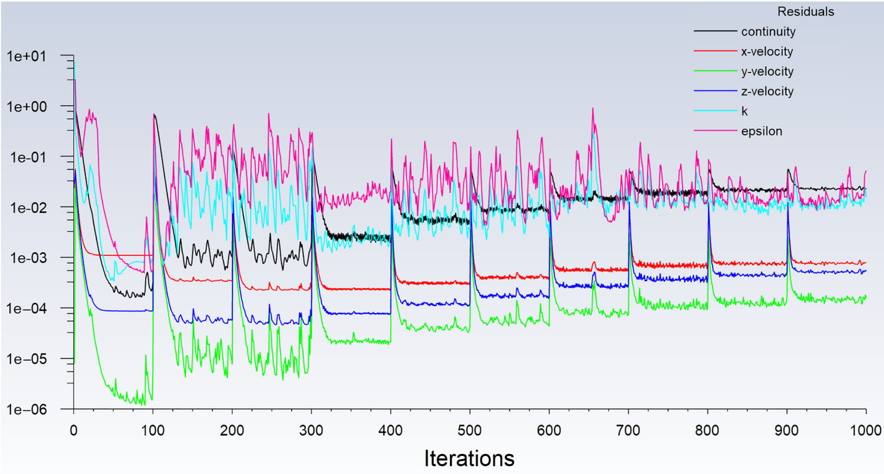

Figure 8.
Different air flow velocity that was flowing within the generated wind tunnel for the wind turbine analysis

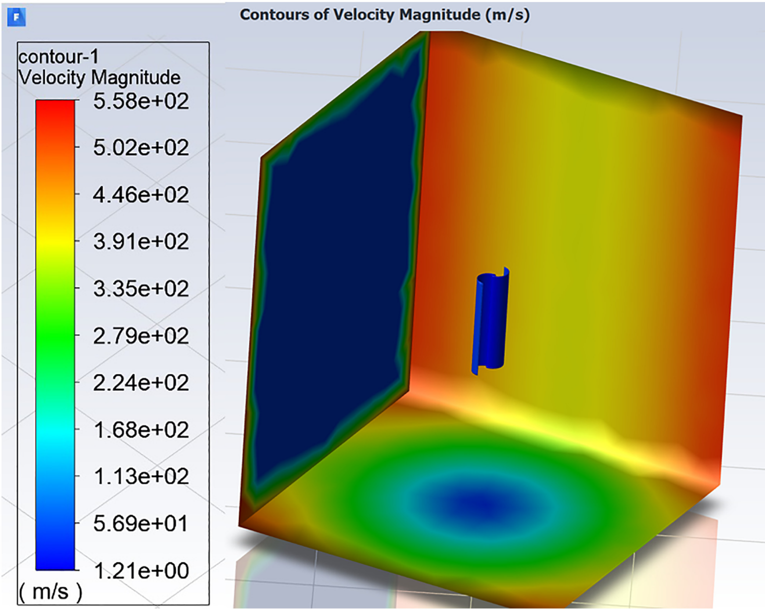

Figure 9.
Magnitude velocity that was acting on the turbine

parameters of the vertical wind turbine to fit the wind speed caused by the moving train. An engineering simulation and 3D design software tool was used to simulate the design of the vertical turbine and the blade design. The blade design that suited the wind energy produced from the moving trains was concluded to be NACA 0020. The total estimated energy generated is 66 MWh/day with eight trains operating for 19 h per day with an interval of 15 min during peak hours and 30 min during nonpeak hours. The power generated from the wind turbines is 245 kW per turbine, where the wind speed is 50 m/s and a swept area of 8 m^2. The average cost saved by the train stations is RM 16.7 mil/year with battery charging

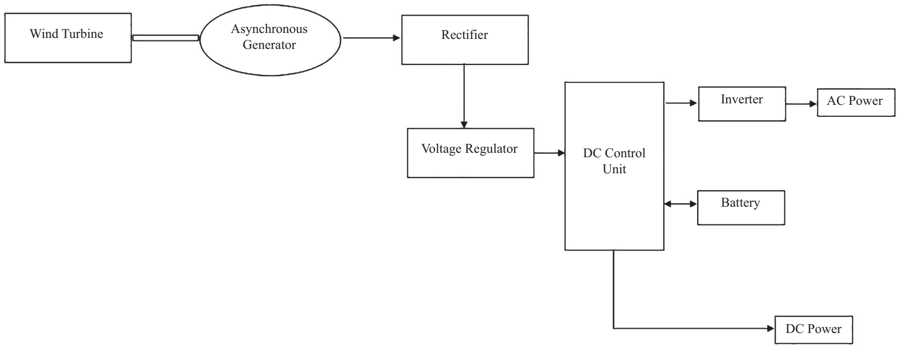

Figure 10. Overall system block diagram

Table 5. Main components of the system and descriptions

Components	Functions
Wind turbine	Converted the wind energy to mechanical energy for electrical energy production
Asynchronous generator	Generating alternating current using the principle of induction motors to produce electricity
Rectifier	The rectifier would change the alternating current to a direct current
Voltage regulator	Regulating the voltage level while traveling to the battery
Inverter	Changes alternating current to direct current
Battery	To store the electrical energy that can been converted

Table 6. Economic evaluation

Parameters	No. of units	Cost per unit (RM)	Cost (RM)
Turbines + blades cost	30	1,000	30,000
Storage cost	2 (1 in each station)	6,000	1,200
Maintenance cost	32 (all units)	(120 × 30) + (250 × 2)	4,100
CAPEX			35,300

capacity of 12 h/day. The energy power is stored in batteries to be used during an emergency in the train stations. The implementation of this technology will be a good advantage to the authorities. The wasted energy from the trains is made to good use and can also save the cost of electricity on affected authorities.

Malaysia is actively progressing toward transitioning into RE. However, the regulatory support for RE in Malaysia is at an early stage, particularly for the wind energy sector since the FiT scheme for wind energy is yet to be included and recognized as one of the RE resources. Therefore, the incentives and support from the government are crucial at the initial stage of deployment of wind power in Malaysia to be included in the FiT mechanism. For instance, at this point of time, the absence of wind power technology in the FiT categories makes it difficult to achieve project viability. This exacerbates the issue of low wind for Malaysia. Suitable technology for low wind speed conditions should be explored in Malaysia to harness the untapped potential wind power.

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