# A Review of Performance & Power Generation using Vertical Axis Wind Turbines.

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## Abstract

Wind energy is a renewable energy source that is considered to be the key to promoting sustainability, as society is planning to move away from fossil fuels and minimise greenhouse emissions. This paper presents a concise overview on wind energy, types of turbines, performance, challenges, and affordability. Wind turbines are classified into: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). The majority of the commercial market is captured by HAWTs, which are employed in various countries for medium-to-large-scale energy demands. Whereas in urban areas with a turbulent nature of wind, HAWTs are not seen as a feasible option for energy generation, VAWTs can be recognised as a better alternative. VAWTs are preferred for urban areas due to their better performance in weak and unsteady wind, omni-directional, no-yaw system, no noise, and safety issues. It was concluded that VAWTs are more promising and in development, and further additional research is yet to be done in order to make VAWTs feasible, economical, and dependable for application.

***Keywords***- Horizontal Axis Wind Turbine (HAWT), Vertical Axis Wind Turbine (VAWT), Small Vertical Axis Wind Turbine (SVAWT), Operation & Maintenance (O&M), Coriolis effect, Turbulence.

## 1. Introduction

Most of the problems, consisting global warming, energy scarcity, and rapid depletion of natural resources like petroleum, coal and natural gas were occurring as a result of increase in population. The opportunity for widespread adoption of renewable energy technology has substantially expanded as a result of rising demand in several emerging economies, including India [1]. Not only we must depend completely on solar energy, but wind energy is also crucial. Wind energy is most relevant source of energy that can be produced in safe and environmentally friendly manner by conversion of wind energy into the electrical energy. Wind energy which is the result of variations in the air pressure caused by unequal heating of the earth surface and the Coriolis effect of the Earth's rotation, has played a vital role in advancing human civilisation.

Wind energy is freely available in urban locations, with potential for powers in road dividers, along railway tracks, and multistorey of a specific height. By establishing an effective wind energy source to fulfil the requirements of household power consumption, we can reduce the load of existing power supplies while minimum use of diesel/oil-based energy generation. Developing a small efficient wind turbines is a potential power source for incorporating sustainability [2,3]. Horizontal axis wind turbines (HAWT) are proved to be ineffective and face local opposition owing to noise pollution, less predictable wind patterns of urban sectors, more chaotic with greater turbulence, making HAWT (Horizontal axis wind turbines) ineffective [4,5]. The VAWT (Vertical axis wind turbine) offer greater unsteady wind adaptive qualities with low environmental effect. These turbines are simple to integrate with urban structures because of their basic design and the ability to generate electricity from multiple directions in low cut wind speeds. The working of VAWT is based on the principle that the rotors of the turbine will spin around the vertical shaft using vertically aligned blades. As a result, they create energy using wind power. The wind drives the rotor that is attached to generator, and the generator transforms mechanical energy into electrical energy. The components of VAWT have blade, shaft, bearing, frame, and blade support.

An efficient alternative for horizontal axis wind turbine is vertical axis wind turbine as an effective solution for operation of VAWT in urban as well as semi urban areas. As told earlier also the VAWTs have the ability of producing energy at low cut wind speeds, a yaw system (to move blades according to wind direction), and a self-starting mechanism (except for Darrius turbines) making then more effective in unsteady wind conditions of urban localities. The vertical axis wind turbine was developed through detailed study, research, and development, and the most recent trend in technological art is gaining popularity in installation and testing the same vertical axis wind turbine because of its light weight and compactness. Vertical axis wind turbine can be easily installed into residential as well as commercial buildings as a non-renewable energy source or power generation due to their low weight and compactness.

This paper mainly focuses on accessibility, cost, easy operation of SVAWT (Small vertical axis wind turbine) over those locations where HAWT cannot be placed, VAWT can be used as an alternative for many purposes like, energy generation for households, power the street lights in roads and highways, used for charging station for electric vehicles that can increase their driving range for long distances.

# 2. Types of wind turbines

The orientation of the axis of rotation, the drag or lift forces acting on the blade surface, and power output of turbines are the various ways nowadays modern wind turbines can be classified. There are two varieties of wind turbines based on axis of rotation that is HAWT and VAWT [6]. At present, the most popular type of wind turbine is HAWT or Horizontal axis wind turbine. HAWT can be characterised as turbine in which rotor shafts are pointing towards the wind direction. Aerodynamic blades are utilised in these turbines and are coupled to a rotor by placing downwind or upwind and can be founded in two or three bladed designs. These turbines are installed mostly on hilly areas away from the cities and due to their large and heavy design they are difficult to transport and are not preferred for the urban environment due to several factors like chaotic character of wind, high value of the cut in wind speed, noise pollution and public’s perspective of these large machines [7]. Instead, VAWT are the turbines where rotor shafts are placed transverse to the wind direction. There construction is simple are there is no additional requirement of any yaw system to move blades according to wind direction and a self-starting mechanism. VAWT are better suited for the urban environments due to having a relatively low cut-in wind speed allowing them to function when surrounded by structures like buildings and infrastructure unknown of the wind directions. Also, the gearbox, generators and other components are located on the ground level that makes O&M (Operation and Maintenance) much easier [6].

On another way wind turbines are classified on the basis of drag and lift force acting on surface of blade. The aerodynamic force in drag-based wind turbine is parallel to the air flow direction, whereas perpendicular to the air flow direction in lift type. Horizontal axis wind turbines are lift based devices; Vertical axis wind turbines are drag force based. Despite of having simple design, drag based turbines are less efficient, lift based turbine are more complex but generates more energy on area swept basis [8].

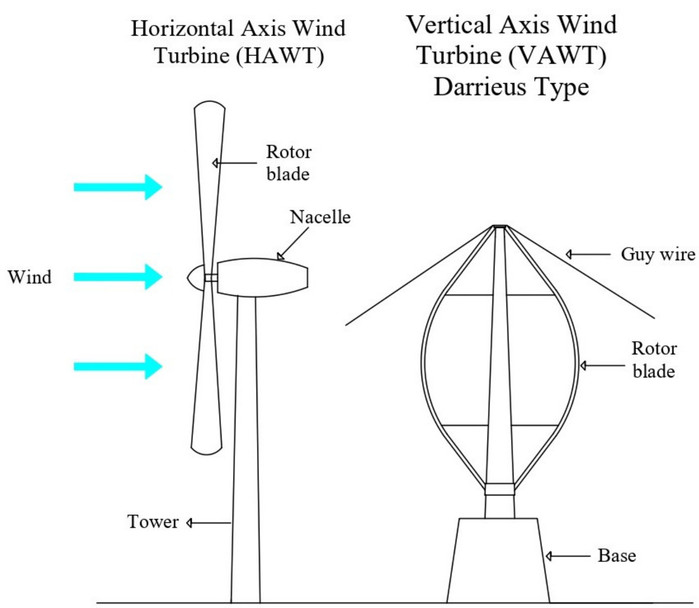


**Figure 1:** Types of Wind Turbine

In recent years, we can see huge acceptance in the hybrid designs of VAWT in wind turbine markets. For example, to overcome the shortcomings of Darrieus and Savonius turbine, both designs were merged into a single hybrid design that can be driven by both drag and lift forces, resulting in better efficiency and self-starting capability [9]. An experiment was conducted in which an SVAWT was installed on the rooftop of building that was 27 m tall, facing uneven terrain and obstacles. The DS-3000 model a Class III turbine by Hi-VAWT Technology Corp, from Taiwan was used, with rated power of 3 kW, three bladed combining Savonius and Darrieus turbines. [10].

## 2.1 Horizontal axis wind turbines (HAWT)

These are the most widely preferred wind turbines in wind energy market with numerous designs available, ranging from 55 W to 4.5 MW. Horizontal axis wind turbine (HAWT) are the turbines where the shaft of rotor is placed in the direction of wind and parallel to the ground. Majority of them consist of a gearbox that converts the rotor's slow spin into a rapid rotation to provide appropriate power to run an electric generator [11]. The rotor blades of this type of turbine are normally designed to fulfil the purpose to face the wind, that is why they are equipped with servo motor and a wind sensor. Wind turbines possess the threat of getting damaged by high-speed winds because of being placed at height about 80-100 m; to reduce the rotor shaft speed they are equipped with brake mechanism [12].

The most commercially used design of HAWT blades are two-and three bladed turbines [13]. Both upwind and downwind operations are possible in HAWT, among them "upwind" is more frequent because it produces less noise pollution, minimum risk of rotor fatigue in components such as tower, blades, and nacelle [11]. One to many numbers of blades are common for agricultural windmill. Two or three blades are ideal for energy generation, where fast rotating speed permits the utilization of small and less costly electric generator. Three-bladed rotor is superior in aerodynamic and mechanical balance. Small wind turbines generally consist of three blades. In farms, multiblade turbines are used to supply water by pump [14].

HAWT have tall towers, resulting in more strong wind with wind shear provides more power output to the turbine. Furthermore, they can be installed offshore, above trees in forests, or on uneven ground. They also have an impact on the aesthetics of landscape because of the wind turbine heights. Moreover, wind turbine is difficult to maintain, large structures are needed to hold the heavy blades, generators, and gearbox systems etc. Despite of the fact that wind power projects techno-economic feasibility is improving each year in terms of production cost per kW, advanced research on urban horizontal axis wind turbine will prove them a viable choice for power generation in these locations.

## 2.2 Vertical axis wind turbines (VAWT)

VAWT are small wind turbines where the shaft of rotor is placed perpendicular to the ground [15]. The advantage of the VAWTs is that they can utilize wind from every direction independently which is the main reason VAWT are well suited for urban environments to deal with the changes in wind directions. Components including generators and gearbox are base-mounted, making them easily accessible for maintenance work, so there is no requirement of tower for support. The maintenance of VAWT is simpler and quicker since they are done on ground level as compared to HAWT, which involves high risks for workers at certain height.

These are the turbines that produce less noise as compared to normal turbines, less in weight, easy and quick to install on any structures even alongside the roadways.

They are difficult to install on towers, referring to the fact that they are placed closer to the base they support, for example ground or rooftop of building [16]. The building generally directs wind over the roof when a turbine is installed on rooftop, results in the increment of the wind speed at the turbine twice times. The Rooftop installed turbine height should be 50% of the height of building for gaining minimal wind turbulence and maximum wind energy. The Vertical axis wind turbines are the most common wind turbine that houseowners install to their houses as a renewable energy source. Despite of not being used widely as the horizontal axis wind turbine, they are excellent for installation at residential sites and many locations. Darrieus (lift based) and the savonius (drag based) are the two main designs developed in VAWT [15].

### 2.2.1 What is Savonius VAWTs?

In 1922, a Finnish engineer Sigurd J. Savonius invented this turbine using drag force. It is the simplest design of wind turbine that was made using two half semi cylinders placed on the opposite direction to each other forming an S- shape [17]. Savonius wind turbines are drag-driven and works well in areas with little wind. It can rotate at low wind speed, no requirement of any yaw system, operate at wind from any directions, these are all the benefits. One of the drawbacks is low power coefficient compared to other turbines since they are drag machines operating at low tip speed ratios. They are well known for their simple design so' there is no requirement of any technical skills for fabrication. Savonius wind turbines are more suitable and appealing for utilization in less developed nations. Savonius rotors are having high degree of solidity that makes them appropriate for the purpose of water pumping because of high initial torque.

Many researches were carried out on the savonius wind turbine to determine the impact of blade numbers, aspect ratio, end plates, bucket spacing, bucket overlap, rotor stages, buckets and rotor shapes, rotor shaft and other components effect on the efficiency of savonius wind turbines [18,19].

An experiment was carried out on Ryerson University that tested all the blade shapes including curved, straight, aerofoil, and twisted [20]. In relation to the speed of wind, for each variety of blades, the rotations per minute (RPM) were recorded. Among all the four shapes, it was found that the straight blade had the lowest rotation per minute, whereas the twisted blade had the highest rotation per minute. The straight blade has been found to be less effective than other three blade configurations, because there is greater drag force acting on the straight blades that are 120° apart. For the straight blade shape less amount of torque is produced for same wind speed [20].

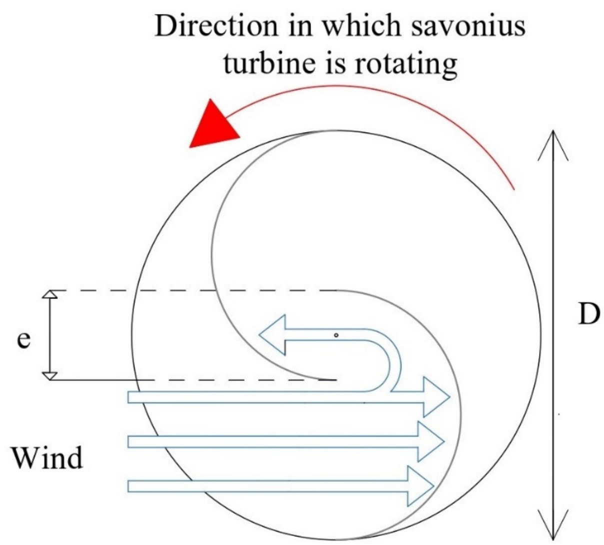


**Figure 2:** Operational mechanism of savonius wind turbine

2.2.2 What is Darrieus VAWTs?

Georges Darrieus was a French aeronautical engineer who invented the first lift based vertical axis wind turbine (that is Darrieus VAWT) in the 1920s in France. (Patented in French in 1925; Patented in US in 1931) [21]. Due to having resemblance to a massive eggbeater, Darrieus wind turbines are also called as “Eggbeater turbines”. The Darrieus vertical axis wind turbine is a lift-type and utilises the lift forces produced by the wind hitting the aerofoils to create rotation as opposite to the savonius, that collects the wind in cups and pushing the turbine around. As compared to savonius, these turbine shows better aerodynamic performance, low price, and easy design. Darrieus turbine consist of two or more arched blades. At the ends of blade, a vertical shaft is attached, hence the force produced by blade rotations is only tension. In the centre shaft, mechanical torque will generate. The generator will get mechanical energy from the shaft and utilise it to produce energy. This machine is developed in such a way that they are capable to protect the blades from bending pressure during normal operations.

One major drawback of the Darrieus wind turbines is their inability to begin rotation on their own. In order to start the rotation, they require a small motor for external starting boost. The design of Darrieus turbine occurs changes and development over timelines to overcome these shortcomings. In the current market scenarios, majority of these developed designs have more cost of energy and poor financial prospects. Darrieus vertical axis wind turbine needed large concrete foundations to operate and manufacturing is also expensive that makes them less competitive in wind energy market. Significant challenges must be overcome in order to make the Darrieus turbine self-starting and wind storm resistant.

An experimental investigation was carried out at the University of Reading in UK by Musgrove on the blade cross-section. Musgrove's work produced the straight-bladed design of Darrieus wind turbine also known as H-blade arrangement [22]. The performance of H-bladed configuration is more superior than regular designs and also the design and manufacturing process are more straightforward. Musgrove designs undergoes development in recent decades into fixed pitch straight bladed H-rotors, which comes in Tiled, Articulating and Helical H-rotor forms. However, self-starting, affordability, and dependability are the factors over which its popularity among public depends [23].

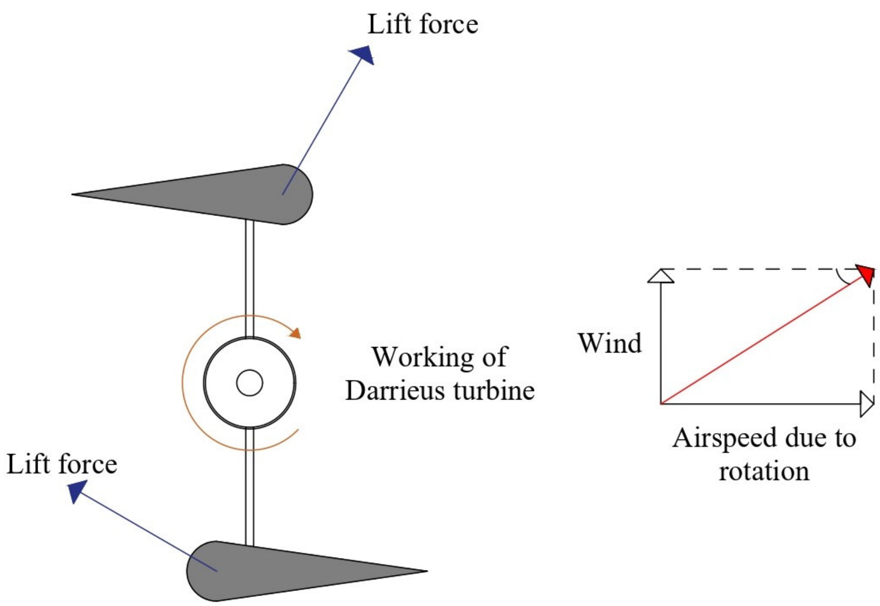


**Figure 3:** A Darrieus turbine design where the lift force is applied to the blade surface in a specific direction.

2.2.3 Application of Vertical Axis Wind Turbines

Towards the application of VAWTs, they have a wide range of applications due to their unique design and advantages that make them suitable option for urban environments. Unlike HAWTs, the VAWTs can operate in multiple direction of wind and can also be mounted on the rooftops of a buildings enabling them for decentralized power generation in cities.

Also, VAWTs are suitable for off grid applications in highways or roads, that involves the installation of the VAWTs in median separators of roads to provide clean and renewable energy for illuminating the roads. Unavailability of street lights in roads or highways can lead to poor visibility and raises the risk of accidents in night-time, this issue can be resolved by installing VAWTs in remote areas to power street lights for safe driving experience. According to the studies the average vehicle speed of vehicle on highway is a about 60 to 80km/h that will provide the turbine enough wind wake to rotate constantly.

Nowadays, there has been a huge increase in the usage of electric vehicles, indication a major shift in favour of sustainable transportation. Strategically placed VAWTs on highways or urban areas can serve as charging stations for electric vehicles. The integration of VAWTs with charging stations can use the renewable wind energy to charge the electric vehicles, and reduces the dependency of traditional charging networks. Assigning the VAWTs on highway as an additional power source for electric vehicles could extend the driving range of vehicles. Whether stationary or in motion, the VAWTs can generate wind energy to charge the batteries of the electrical vehicle, offering a clean, sustainable, and endless energy source. This can reduce the carbon footprint and promote the more usage of electric vehicles.

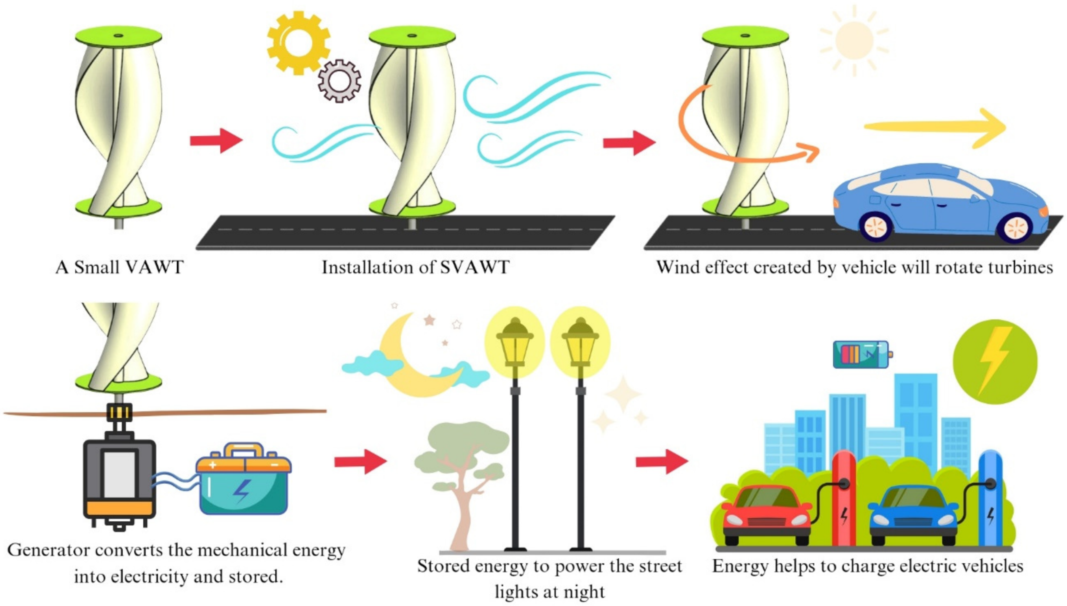


**Figure 4:** Working and Application of Vertical Axis Wind Turbines (Elements are taken from Canva: https://www.canva.com/)

2.2.4 VAWTs future scope.

To make VAWTs more efficient, many research studies have been carried out on variables including the tip speed ratio, solidity, and angle of attack. One of the major issues with the VAWTs are that it encounters very little amount of air on ground level. The current issue can be resolved by using flat plate deflector, that reduces the negative torque and improves the efficiency by directing the wind flow away from returning blades of the turbine. To carry out their research, researchers use aerodynamic profile blade of NASA and NACA (National Advisory Committee for Aeronautics). These are the self-starting blades that can increase turbine efficiency i.e., Blades profiles such as NASA 4415 and NACA 4418.

As compared to savonius type wind turbines, Darrieus wind turbines has less self-starting capacity and this can be overcome by combining them both as hybrid model (Darrieus+Savonius) to get better power output. Blades that are placed helically, their performance can reach more than 33% to roughly 42%. In future the integration of the VAWTs with the solar cells can be proved to be most productive method to generate power from the both sources.

# 3. Conclusion

The acceptance of wind energy sources has expanded in recent years. Wind turbines installed onshore and offshore also have better performance than our expectations. The utilisation of wind turbines for urban is still in growth and has only reached a limit to no acceptance, despite of having extraordinary development. Installation of vertical-axis wind turbines as a renewable energy source in urban locations like houses, buildings, roadways can be beneficial in many ways. For example, power generation, lack of transmission and distribution losses, elimination of grid electricity dependency, greenhouse gas emissions, and global warming will be substantially reduced. Additionally, VAWT can function at low wind speeds and is omni-directional. They are compact and pose the minimum threat to the lives of birds. In those urban areas where HAWT cannot be installed due to reasons like space requirements, aesthetics, noise, safety concerns, and wind turbulence, VAWT can pose a sustainable solution. As the technology develops, prices fall, and more people become aware of the potential of VAWT to lower their energy costs and carbon footprints, their acceptance will increase. It was concluded that vertical-axis wind turbines provide promising attributes for changing wind nature in urban environments. However, further developments are required to increase their effectiveness and get beyond mechanical restrictions, which might potentially provide VAWTs a bigger role in the renewable energy sector.

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References

[1] Kumar R, Raahemifar K, Fung A.“A critical review of vertical axis wind turbines for urban applications”.Renewable and Sustainable Energy Reviews 2018;89:281-91.

[2] Toja-Silva F, Colmenar-Santos A, Castro-Gil M. Urban wind energy exploitation systems: behavior under multidirectional flow conditions-opportunities and challenges. Renew Sustain Energy Rev 2013;24:364–78

[3] Allen SR, Hammond GP, McManus MC. Prospects for and barriers to domestic micro-generation: a United Kingdom perspective. Appl Energy 2008;85:528–44

[4] Groth TM, Vogt C. Residents' perceptions of wind turbines: an analysis of two townships in Michigan. Energy Policy 2014;65:251–60.

[5] Ahmed NA, Cameron M. The challenges and possible solutions of horizontal axis wind turbines as a clean energy solution for the future. Renew Sustain Energy Rev 2014;38:439–60

[6] Liu J, Lin H, Zhang J.“Review on the technical perspectives and commercial viability of vertical axis wind turbines”.Ocean Engineering 2019;182:608-26.

[7] Liu S, Ho Y. Wind energy applications for Taiwan buildings: what are the challenges and strategies for small wind energy systems exploitation? Renew Sustain Energy Rev 2016;59:39–55.

[8] Bedon G, Antonini EGA, Betta SD, Castelli MR, Benini E. Evaluation of the different aerodynamic databases for vertical axis wind turbines simulations. Renew Sustain Energy Rev 2014;40:386–99.

[9] Sharma KK, Biswas A, Gupta R. Performance measurement of a three-bladed combined Darrieus-Savonius rotor. Renew Energy Res 2013;3:4.

[10] Lee KY, Tsao SH, Tzeng CW, Lin HJ.“Influence of the vertical wind and wind direction on the power output of a small vertical-axis wind turbine installed on the rooftop of a building".Applied Energy 2017;61:495-504.

[11] Montoya LTC, Hayyani MY, Issa M, Ilinca A, Ibrahim H, Rezkallah M. Wind power plant planning and modelling. Hybrid Renewable Energy Systems and Microgrids 2021:259-312.

[12] Dincer I, Ezzat MF. Renewable Energy Production. Comprehensive energy systems 2018;3:126-207.

[13] Boulouiha HM, Allali A, Denai M. Grid Integration of Wind Energy Systems: Control Design, Stability, and Power Quality Issues. Clean Energy for Sustainable Development 2017:239-335.

[14] Islam SM, Nayar CV, Abu-Siada A, Hasan MM. Power Electronics for Renewable Energy Sources. .Power Electronics Handbook 2018:783-827.

[15] Hyams MA, Wind energy in the built environment. Metropolitan Sustainability 2012:457-499.

[16] Bhatia SC, Wind Energy. Advanced Renewable Energy Systems 2014:184-222.

[17] Mathew S, Philip GS. Wind Turbines: Evolution, Basic Principles, and Classifications. Comprehensive Renewable Energy 2012;2:93-111.

[18] Kim S, Cheong C. Development of low-noise drag-type vertical wind turbines. Renew Energy 2015;79:199–208.

[19] Akwa JV, Vielmo HA, Petry AP. A review on the performance of Savonius wind turbines. Renew Sustain Energy Rev 2012;16:3054–64.

[20] Shah, S., 2014. Small scale vertical axis wind turbine (M.Eng. thesis). Submitted to Ryerson University, Toronto, Canada, Available on: https://digital.library.ryerson.ca/islandora/object/RULA:4280 [Accessed 19 September 2018].

[21] Möllerström E, Gipe P, Beurskens J, Ottermo F. A historical review of vertical axis wind turbines rated 100 kW and above. Renewable and Sustainable Energy Reviews 2019;105:1-13.

[22] Musgrove PJ. Energy from wind in rural and urban communities. Passive Low Energy Eco Tech 1985:290–309.

[23] Musgrove PJ. Wind energy conversion: recent progress and future prospects. Sol Wind Technol 1987;4:37–49.