Design of Micro Wind Turbine for Low Wind Speed Areas: A Review

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Abstract: ***With the increase in fossil fuel prices and the increase in demand for renewable energy sources, wind turbines play an important role in becoming the alternative technology in the generation of electricity. Since wind is clean and unbounded, wind energy is one of the best renewable sources of energy for generation of electricity. This paper presents the ideas of designing a small-sized wind turbine or micro wind turbine for low wind speed areas which can be used in many applications like homes, villages, and so on to produce electricity. A small-sized wind turbine or micro wind turbine is a type of turbine that converts the kinetic energy of wind into electrical energy and it is used to generate power for small power needs. Additionally, this type of micro wind turbine can be used in rural areas, requiring a very low cost for installation.***

Keywords: Renewable Energy, Micro Wind Turbine, HAWT, VAWT.

1. Introduction

In recent years, the importance of renewable sources of energy in power generation has been growing day by day around the world. Also, due to the lack of fossil fuel resources, utilization of renewable sources of energy has become even more important. Large wind farms, either in the countryside, offshore, mountains or at the seaside have already been invested by many countries around the world. Since wind speed and direction are well known and there are only a few factors that will influence them, the energy gathered from these wind farms can easily be predicted and calculated. However, in a city environment, wind speed and wind direction cannot be predicted because they are easily led in different ways or influenced by all kind of obstacles such as skyscrapers, apartment blocks, etc. As a result, large size wind turbines cannot work effectively and efficiently. So, to overcome these problems, micro wind turbines are used [1,2].

Apart from all the renewable energy resources, cleaner energy systems such as micro wind turbines played a key role in the renewable electricity generation. A micro wind turbine is used to produce or generate power of low DC voltage. In wind turbines, some mechanical and electrical aspects of the turbines are necessary to study in details so that the turbine can achieve its electrical output efficiency [1,2].

Micro wind turbines can also be used as alternative sources of energy in locomotives, especially in passenger trains in which it can generate enough power to support the hotel load requirements including light, fan and AC and so on. Since, it is very cheap, affordable reliable and almost maintenance free it gives more benefits than the large wind turbines [3,4].

For large wind turbines, people used mostly VAWTs (Vertical Axis Wind Turbines) over HAWTs (Horizontal Axis Wind Turbines) for low wind speed areas, especially in buildup areas. VAWTS have lower wind startup as compared to HAWTS. However, for micro wind turbines, people used either micro VAWTS or micro HAWTS for power generation in low wind speed areas. Since in rural areas, electricity crisis is the main problems, they are used mainly in rural and remote applications or areas where wind speed is low [4,6].

Moreover, research on the design and development of the turbine blades has been studied so that it becomes beneficial to use in areas where wind speed is low. However, studies also show that in a low wind speed areas, a practical wind booster can also be used so that it can generate power satisfactorily [9,10].

In case of variable wind speed conditions, a controller is designed to maximize the energy output and this modified turbine controller is also used to examine the provision of frequency support from wind turbines under changing wind conditions [12,15].

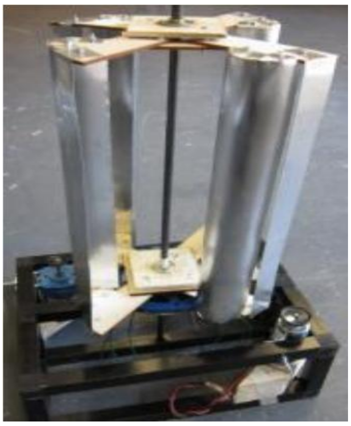

Figure 1: Vertical Axis Wind Turbine- Savonius type [1]

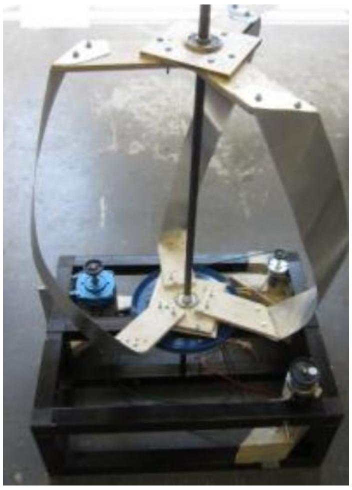

Figure 2: Vertical Axis Wind Turbine- Darrieus type [1]

Figure 3: Horizontal Axis Wind Turbine [5]

Implementation of variable wind speed turbines also has been done enables the turbines to get maximum efficiency as the wind varies. Similarly, under varying wind conditions, control strategies are obtained for operating a variable wind speed turbine and the determination of the increase in energy can be achieved using these strategies [13].

Micro wind turbines can be designed using PVC blades as it can give better power capacity and less costly. It can be used in areas where the velocity of wind is low, that is, as low as 2 m/s, like a plateau or hilly region or in places where large wind turbine does not give a good result. Because of low cost and being of economical, it can be installed in residential areas over the houses for power generation. Moreover, utilization of small wind turbines for the household would result in fewer burdens on the grid and also plays a vital role in reducing utilization of conventional energy and mobility to utilize the power [17].

These micro wind turbines can be used where wind velocity is low like hilly regions or especially rooftops of building and they are less costly, easier to install and can power electrical devices like the LED sign, Cell phones, lighting a lamp, etc. [20].

2. Micro Wind Turbines versus Large Wind Turbines

A Micro wind turbine is set up in the location where wind power has to be consumed. It is not necessary that the design of micro wind turbine will depend on the location where the wind power is the best. Micro wind turbines help to provide energy in the locations where unavailable of other sources of electric energy are not available. Micro wind turbines are designed to operate with low wind speed even in places where the wind speed is as low as 2 m/s. Moreover, micro wind turbines do not require large areas of land. Due to their small size and modular construction, a micro wind turbine can be installed in smaller places like apartment balconies, building-terraces,the rooftop of a building and of course in small farmhouses. Based on the available space and the power output required, the size of micro wind turbines can be adapted. The design is very simple, the components required to set up the installation are easily available and maintenance is very easy. Consequently, simple designs lead to low manufacturing cost. Similarly, because of their light weight, small size, and flexible configuration they can be installed in both urban and rural environments, for individual or corporate use. Some applications, like charging the batteries on sailboats and recreational vehicles, micro wind turbines with very low capacities can be used and implemented. Such micro wind turbines with output lesser than 100W are practically used and can be utilized for charging batteries with minimum cost and minimum complexity. Such types of micro wind turbines can be used to charge automobile batteries and power security lighting systems in remote locations or urban areas [6,21].

Common types of large wind turbines require large areas of land because they are designed for a large amount of electricity production. Largely sized wind turbines are used for commercial energy production and they are very costly. They are usually connected to a power grid and installed in locations where wind speed and direction are suitable for wind turbines. These large wind turbines cannot operate in low wind speed areas or places where the wind speed is below 10 m/s. Regular wind turbines can only operate at wind speed between 10 m/s and 25 m/s [6,21].

3. Design Parameters of a Micro Wind Turbine

Following are the key parameters required to be considered while designing micro wind turbines:

1) Wind speed -It is very important for the productivity of a windmill.The output of micro wind turbine mostly depends on the wind. Therefore, the more is the wind speed, the greater is the amount of power the wind turbine generates. Different regions have different wind speeds. As a result, determination of the value of the wind speed for a particular region is necessary.Whether to design a Vertical Axis Wind Turbine (VAWT) or Horizontal Axis Wind Turbine (HAWT) is determined based on wind speed.

2) Sites Selection (Location) - By determining the direction of the wind in the selected areas, the site is considered suitable. It can be observed during wind storms, that is, by looking at the trees near the site. To determine a good indication of prevailing wind speed and direction, it can be done by identifying the trees that are all leaning in the same direction and that have branches mostly on one side of the trunk. This information can sometimes be provided by the local airports and weather stations also.

3) Height - Due to various atmospheric factors, places or region of higher altitudes experience more wind because there is less obstruction from the surrounding hills, trees and building in places of higher altitudes. As a result, a micro wind turbine should be placed at least 30 feet above the ground without any disturbances within 300 feet in any direction. Use of short towers will reduce power output, and cause physical stresses on the turbine and tower.

4) No. of Blades and Blade Length – A micro wind turbine performance can be affected by the number of blades that make up a rotor and the total area they cover. Blade length depends on the design of the power output. The space between blades should be great enough to avoid turbulence so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it. Therefore, because of this requirement, most micro wind turbines have only two or three blades on their rotors.

5) Tip Speed Ratio - The tip-speed ratio is the ratio of the rotational speed of the blade to the wind speed. This ratio is directly proportional to the rotation of the micro wind turbine rotor, that is, larger is the ratio, the faster is the rotation of the micro wind turbine rotor at a given wind speed. High rotational speed is required for electricity generation.

6) Generators - The generator converts the mechanical energy of the turbine or the turning motion of a microwind turbine's blades to electrical energy (electricity). There are different generator designs which can produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The rating or size of a generator is dependent on the length of the wind turbine's blades because longer blades capture more energy. Therefore, it is important to select the right type of generator for intended use. Most home and office appliances operate with 50 cycles AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be run on DC. Storage systems using batteries store DC and usually operate at voltages of between 12 volts and 120 volts.

7) Towers - The tower is a structure where the micro wind turbine is mounted and the turbine is mounted on a tower because wind speeds increase with height. Consequently, the higher the tower, the more power the micro wind turbine can produce. However it is not just a support structure, but it plays a very important role in raising the micro wind turbine so that its blades safely clear the ground and at higher elevations, the turbine can reach stronger winds. The height of the tower can be determined based on the cost involved versus the value of the increase in energy production resulting from their use. The towers that will be installed should be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of the micro wind turbine.

4. Energy Output Calculations of a Micro Wind Turbine

Kinetic energy in (Joules) is given by,

$$K.E = \frac{1}{2}.m.V^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where,
m = mass (kg)
V = velocity (m/s)

Since, Energy = Power × Time

And to express the mass of flowing, air density is a more convenient way to consider; the kinetic energy equation can be converted into a flow equation.

Power in the area swept by the micro wind turbine rotor is given by,

$$P = \frac{1}{2}.\rho.A\,V^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

where,

P = power in watts (746 watts = 1 hp and 1000 watts =1 kilowatt),
ρ= air density (about 1.225 kg/m^3 at sea level, less higher up),
A = rotor swept area (m^2),
V = wind speed in m/s.

Micro Wind Turbine Power is calculated [17]as–

$$P = \frac{1}{2}.\rho.A.C_p.V^3.N_G.N_B \;\; \ldots\ldots\ldots \text{(3)}$$

where,

P = power in watts (746 watts = 1 hp and 1000 watts = 1 kilowatt),
ρ = air density (about 1.225 kg/m^3 at sea level, less higher up),
A = rotor swept area (m^2),
C_p = Coefficient of performance (0.59 {Betz limit} is the maximum, 0.35 for a good design)
V = wind speed in m/s,
N_G = generator efficiency (50% for car alternator, 80% or more for a permanent magnet generator or grid-connected induction generator),
N_B = gearbox or bearings efficiency (if good it could be as high as 95%).

Tip Speed ratio for a micro wind turbine is also defined as the ratio between the tangential speed of the tip of a blade and the actual velocity of the wind.

$$\lambda = \frac{r.\omega}{v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

where,

λ = Tip speed ratio
r = Radius of a rotor
v = wind velocity

Wind velocity at different places can be measured by anemometer and Turbine velocity with the help of Non-contact type Tachometer [17].

5. Vertical Axis Wind Turbine versus Horizontal Axis Wind Turbine

Wind turbines are designed both as Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT), depending on the wind speed, power output required and efficiency.

Vertical Axis Wind Turbine (VAWT):

Generally, there are two kinds of VAWTs, namely, the Savonius and the Darrieus. The functions of Savonius are similar to a water wheel whereas the Darrieus makes use of blades similar to the blades used on HAWTS. VAWTs commonly function closer or nearer to the ground level and not in the nacelle, and has the benefit of enabling placement of heavy equipment, such as the gearbox and generator. However, near ground level the winds are lower; hence a less amount of power is generated. Similarly, among the vertical axis wind turbines, the Darrieus rotor is the more efficient than the Savonius rotor, but the main limitation of the Darrieus rotor is that it cannot be self-start. The efficiency of the Savonius rotor is much less as compared to the Darrieus rotor even though its rotor is simple and cheap. VAWTs give many advantages when compared to horizontal axis wind turbines (HAWTs). They are much more compact and can be placed on building rooftops and other urban locations whereas, the tall tower and long blades of HAWTs work well only in wide-open spaces. Similarly, they do not need much wind in order to produce power and hence allowing them to be nearer to the ground where the speed of the wind is lower. Since they are closer to the ground, they can be easily controlled and implemented on tall structures [22].

Horizontal Axis Wind Turbine (HAWT):

Since a nacelle is installed perpendicular to the turbine tower and horizontal in terms of the ground, hence, they are called as the horizontal axis wind turbine. These Horizontal Axis Wind Turbines should always be pointed in the right direction, that is, into the wind, or away from the wind, based on the type so that they can achieve maximum efficiency. Currently, because of their good aerodynamic efficiency, high-speed propeller wind turbines are commonly used as horizontal axis turbines. The core components of a horizontal wind turbine consist of the main rotor shaft, the electrical generator, the gearbox to increase the rotation speed of the blades and the Turbine blades.

HAWTS has also some of its advantages. They use the variable pitch of blades to collect the maximum amount of energy from the wind. HAWTs have higher efficiency as it has blades in perpendicular to the direction of the wind. Similarly, the designs of HAWTs allow easy installation as well as easy maintenance [22].

6. Conclusion

This paper presents an exclusive review of the design of micro wind turbines for low wind speed areas. Small or micro wind turbines are more suitable in regions where wind speed is low and also in urban areas. The energy output calculations are included for the benefit of designers. Also, a comparison between Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) has been done, with regard to their efficiency. This will enable the designers to select a particular design and a type for low wind speed areas.

References

[1] D. M. Bui and W. J. C. Melis, "Micro wind Turbine for Energy Gathering in buildup areas", *International Journal of Sustainable Energy Development (IJSED)*, Vol. 2, Issue No. 2, December 2013, pp. 105-114. Retrieved from http://infonomics-society.org/wp-content/uploads/ijsed/published-papers/volume-2-2013/Micro-Wind-Turbines-for-Energy-Gathering-in-Build-Up-Areas.pdf

[2] Z. Li, F. Boyle and A. Reynolds, "Domestic Application of Micro wind Turbines in Ireland: Investigation of their economic viability", *Renewable Energy*, Vol. 41, May 2012, pp. 64-74.Doi: https://doi.org/10.1016/j.renene.2011.10.001

[3] J. K. Sahu and M. Sahu, "Micro Wind Turbine Technology: To Enhance Self Generative System in Passenger Train", *International Research Journal of Engineering and Technology (IRJET)*, Vol. 3, Issue No. 11, November 2016, pp. 629-634. Retrieved from https://www.irjet.net/archives/V3/i11/IRJET-V3I11110.pdf

[4] A. R. Sengupta, A. Biswas and R. Gupta, "Vertical Axis Wind Turbines in the Built Environment: A Review", *ISESCO Journal of Science and Technology*, Vol. 12, Issue No. 22, pp. 11-16. Retrieved from https://www.researchgate.net/publication/313740546

[5] A. Deo, J. N. Goundar, S. Narayan and N. Chettiar, "Design and Performance Analysis of Micro Wind Turbines for Fiji", *International Journal of Information and Electronics Engineering*, Vol. 6, Issue No. 1, January 2016, pp. 37-40. Retrieved from http://www.ijiee.org/vol6/590-SE307.pdf

[6] N. N. Sorte and S. M. Shiekh, "Design and Development of Micro Vertical Axis wind turbine for Rural Application", *International Journal of Engineering and Computer Science*, Vol. 3, Issue No. 7, July 2014.

[7] J. Zhang, Z. Zhou and Y. Lei, "Design and research of high-performance low-speed wind turbines blades", *2009 World Non-Grid-Connected Wind Power and Energy Conference (WNWEC 2009)*, Nanjing, 24-26 Sept., 2009, pp. 1-5.Doi: https://doi.org/10.1109/WNWEC.2009.5335818

[8] M. Mohammadi, A. Mohammadi, M. Mohammadi and H. N. Minaei, "Optimization of small-scale wind turbine blades for low-speed conditions", *Journal of Clean Energy Technologies*, Vol. 4, Issue No. 2, March 2016, pp. 140-143.Doi: 10.7763/JOCET.2016.V4.268

[9] N. Prasad E., Janakiram S., Prabu T. and Sivasubramaniam S., "Design and development of Horizontal small turbine blade for low wind speed", *International Journal of Engineering Science & Advanced Technology (IJESAT)*, Vol. 4, Issue No. 1, 2014, pp. 75-84. Retrieved from http://ijesat.org/Volumes/2014_Vol_04_Iss_01/IJESAT_2014_01_01_14.pdf

[10] N. Korprasertsak and T. Leephakpreeda, "Analysis and optimal design of wind boosters for Vertical Axis Wind Turbines (VAWTs) at low wind speed", *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 159, Dec. 2016, pp. 9-18.Doi: https://doi.org/10.1016/j.jweia.2016.10.007

[11] Y. Vidal, L. Acho, N. Luo, M. Zapateiro and F. Pozo, "Power control design for variable speed wind turbines", *Energies*, Vol. 5, Issue No. 8, Aug. 2012, pp.3033-3050.Doi: http://dx.doi.org/10.3390/en5083033

[12] S. Rajendran and D. Jena, "Control of variable speed variable pitch wind turbine at

above and below-rated wind speed", *Journal of Wind Energy*, Vol. 2014, Oct. 2014, Article ID 709128. Retrieved from http://downloads.hindawi.com/journals/jwe/2014/709128.pdf

[13] A. Mclver, D. G. Holmes and P. Freeze, "Optimal control of Variable speed wind turbine under dynamic wind conditions", *Proceedings of Industry Applications Conference, 1996. Thirty-First IAS Annual Meeting, IAS '96., Conference Record of the 1996 IEEE*, San Diego, CA, Vol. 3, 6-7 Oct. 1996, pp. 1692-1698. Doi: https://doi.org/10.1109/IAS.1996.559297

[14] M. Izadbakhsh, A. Rezvani, M. Gandomkar and S. Mirsaeidi, "Dynamic analysis of PMSG wind turbine under variable wind speeds and load conditions in the grid-connected mode", *Indian Journal of Science and Technology*, Vol. 8, Issue No. 14, July 2015. Doi: 10.17485/ijst/2015/v8i14/51864

[15] L. Wu and D. Enfield, "Investigation on the interaction between inertial response and droop control from variable speed wind turbines under changing wind conditions", *Proceedings of 2012 47th International Universities Power Engineering Conference (UPEC)*, London, 4-7 Sept. 2012, pp. 1-6. Doi: https://doi.org/10.1109/UPEC.2012.6398429

[16] Abubakkar A., T. Ravisankar and M. Makeshkumar, "Design and fabrication of micro wind turbine", *International Journal of Science, Engineering and Technology Research (IJSETR)*, Vol. 5, Issue No. 5, May 2016, pp. 1785-1787. Retrieved from http://ijsetr.org/wp-content/uploads/2016/05/IJSETR-VOL-5-ISSUE-5-1785-1787.pdf

[17] V. K. Rathod and S. Y. Kamdi, "Design and Fabrication of PVC bladed inexpensive wind turbine", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, Vol. 11, Issue No. 4, Ver. II, Aug. 2014. pp. 114-119.

[18] A. Dhote and V.Bankar, "Design, analysis, and fabrication of Savonius Vertical axis wind turbine", *International Research Journal of Engineering and Technology (IRJET)*, Vol. 2, Issue No. 3, June 2015. pp. 2048-2054.

[19] M. Kumari and H. K. Singh, "Small Scale Wind Turbines: As alternative Energy system", *International Journal of Science and Research (IJSR)*, Vol. 3, Issue No. 6, June 2014, pp. 1607-1609.

[20] D. P. Drumheller, G. C. D'Antonio, B. A. Chapman, C. P. Allison and O.Pierrakos, "Design of a micro wind turbine for implementation in low wind speed environment", *Proceedings of 2015 Systems and Information Engineering Design Symposium*, Charlottesville, VA, 24 April 2015, pp. 125-130.Doi: https://doi.org/10.1109/SIEDS.2015.7116959

[21] A. Suresh and S. Rajakumar, "Design and experimental investigation of a micro wind turbine", *International Journal of Advances in Engineering Research (IJAER)*, Vol. 10, Issue No. VI, December 2015, pp. 216-224. Retrieved from http://www.irapub.com/images/short_pdf/1454220602_A_Suresh_22.pdf

[22] M. M. M. Saad and N.Asmuin, "Comparison of Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines", *IOSR Journal of Engineering (IOSRJEN)*, Vol. 4, Issue No. 8, V2, August 2014. pp. 27-30. Retrieved from http://www.iosrjen.org/Papers/vol4_issue8%20(part-2)/E04822730.pdf

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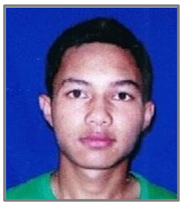

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