Emerging trend in Horizontal Axis Wind Turbines to Exploit Low Wind Resource

Albert John Varghese[1], Rejo Roy[1], S.R. Awasthi[2]
[1]Research Scholar, Dept of Electrical & Electronics Engineering, RNTU, Bhopal (M.P.) India
[2]Professor, RNTU, Bhopal (M.P.) India

ABSTRACT
Renewable energy is finding increasing adoption in generation of electrical energy. One of the most widely used forms of renewable energy is wind; but utility scale WECS need a minimum average wind speed which is not available in most of the areas in India. Hence, traditional WECS is unlikely to be economically viable due to inadequate power generation. Avante Garde has developed a small efficient horizontal wind turbine system with very low cut-in speed of 1.9 m/s and made it commercially available at a reasonable price. This paper discusses the horizontal axis WECS with permanent magnet synchronous generator and electronic convertor system for extracting the maximum power at a constant voltage and constant frequency. The WECS is simulated for a standalone application and its performance evaluated for Bhilai, Chhattisgarh.

Keywords: Low Wind Speed WECS, TSR based Duty ratio Control, TSR MPPT, HAWT based WECS

I INTRODUCTION

Avante Garde has developed an efficient small wind turbine "AVATAR" suitable for low wind speed horizontal axis wind turbine with a start-up wind speed of 1.4 m/s and cut-in wind speed of 1.9 m/s. AVATAR is available for the price of a smart phone which can power homes, farms and offices. In 2015 the first prototype of "AVATAR" was chosen as one of the top 20 cleantech innovations in India. The new "AVATAR" small wind turbine was showcased by UN as one of the top 20 innovations at the UN Innovation Summit held in September 2019 in India. It has paved the way for exploration of vast low speed wind resource in India (Fig No. 1) with the well established technology of horizontal axis wind turbines (HAWT).

Electrical Energy is one of the most utilized forms of energy worldwide. It is widely preferred as it can be easily converted to other forms like light, heat, motion etc. Electrical energy is mostly generated using coal based thermal power plants, nuclear power plants, hydel power plants and renewable energy sources. India has a total installed power capacity of 3,71,054 MW comprising of fossil fuel based 2,30,906 MW, nuclear based 6,780 MW, Hydro based 45,699 MW and renewable energy based capacity of 87,669 MW as of June 2020 [1]. The share of fossil fuel based capacity is 62.29% which contributes largely to the green house gases emissions leading to global warming. In order to counter this, a rapid shift towards renewable energy has become inevitable. Wind Energy plays an important role in the mission to minimise dependence on renewable energy by any nation and helps in the sustainable development. Wind is the movement of air caused by temperature differences, pressure difference or altitude difference. Wind energy can be simply stated as the conversion of energy in the motion of air (kinetic energy) to electrical energy. Wind is one of the oldest power sources to be utilised by humanity to grind grains, as sail in boat, draw water etc.

Standalone WECS (Wind Energy Conversion Systems) used for power generation will have a turbine, power electronic converter, generator and a controller. The interest in small HAWT WECS system will increase rapidly with the development of innovative cost effective and efficient wind turbines for low wind speeds. It would pave the way for utilization of huge low wind speed resource of India which is not viable with the conventional WECS [2].

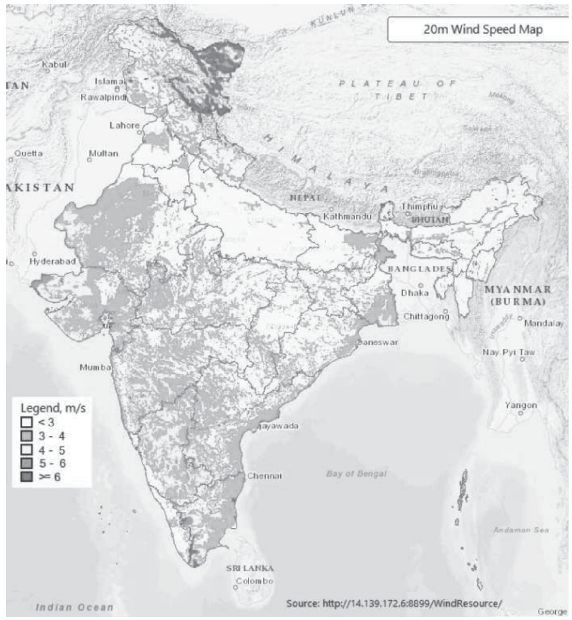

Fig.1: Wind Speed Map of India at 20m agl

When talking about Low Wind Speed WECS it has the potential to enhance the wind energy production [6] and penetration in India. Some factors to be considered in the selection of site and wind turbine are given below:

(a) Increasing the number of blades in case of VAWT increases power output, but in case of HAWT using 2 or 3 blades give the maximum power output [4]. Further, HAWT proves to be more advantageous than VAWT based on power output [5][7][8][13] while in terms of portability[7], VAWT is better in handling the turbulence [9].
(b) The surroundings to be free from obstacles for laminar wind flow [16].
(c) The provision of MPPT techniques to optimize the usage of wind resource to enhance power generation [3][14]. The MPPT can be achieved by:
  (i) Pitch control of blades to maximize output up to rated wind speed [17].
  (ii) PWM control for power electronic switches helps in achieving constant voltage and constant frequency above the rated wind speed [17].
(d) Power Electronics life also plays a role in reducing the maintenance and improving performance of a WECS. The life of power electronics was found to be more for HAWT [10].
(e) PMSG is preferred for low speed wind power generation system [15] starting time can be reduced by reducing the resistive torque of generators [12] which will result in small decline in power output.

The Utilisation Factor for a low speed wind turbine lies between 19% and 21% of rated capacity for a three bladed HAWT. The efficiency decreases above rated wind speeds [11]. The provision of a tail fin offers alternative to pitch control in small HAWT [16]. The use of VAWT or HAWT depends on the wind speed, place where it is to be installed and its application [13].

Based on the literature review it was noted that WECS generally uses Horizontal Axis Wind Turbine (HAWT) in conjunction with a Permanent Magnet Synchronous Generator (PMSG). It consists of a tip speed ratio based Maximum Power Point Tracking (MPPT) coupled to a Proportional Integral (PI) Controller and a Power Electronic circuitry consisting of a Rectifier-DC link-inverter set-up. The duty ratio of switches can be controlled as per the MPPT algorithm.

In this paper, the methodology adopted is described in Section II whereas section III deals with the application of the developed methodology. The results and discussion are provided in Section IV. Finally, the conclusion drawn from the work is given.

II METHODOLOGY

The objective of this work is to assess the performance of a WECS for Bhilai. The paper showcases a MATLAB/Simulink based performance assessment for a WECS which can operate in lower average annual wind speed.

The steps involved in the process of simulating a WECS which can work in lower wind speeds:

(a) Selection of wind speed range for which WECS is to be used.
(b) Selection of a Wind Turbine Generator based on the wind speed and performance desired
(c) Selection of Converters to transfer power from the machine to the load (Uncontrolled Rectifier – Boost Chopper – Three Phase Inverter, so that a constant voltage, constant frequency AC supply can be fed to the load)
(d) Selection of a power extraction scheme (Tip Speed Ratio based MPPT which is used for duty ratio control of the converter)

(e) Selection of Load (As a standalone system is considered AC Load is used here)

For simulating the Wind Energy Conversion system for performance assessment MATLAB/Simulink may be used. Simulink is one of the many tools provided by MATLAB. Simulink is a graphical environment which can be used for modelling, analyzing and simulating a system. Simulink helps make simulations easier to achieve using blocks available in the Library Browser. This helps to produce results which may be used for further analysis. Using Simulink, the system may be studied economically.

III APPLICATION OF THE DEVELOPED METHODOLOGY

The developed methodology is applicable for Bhilai, Chhattisgarh which has an annual average wind speed of 3.61m/s. Block diagram shown in Fig. No.2 is prepared to visualise the ideas of the proposed Low Wind Speed WECS and components.

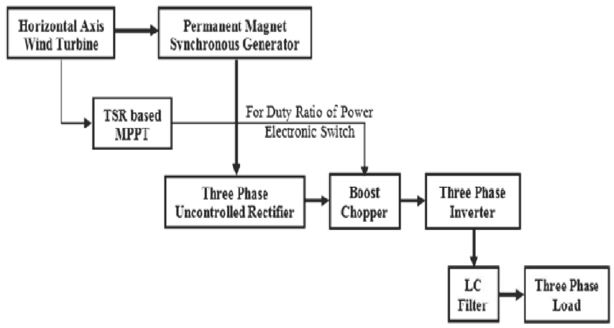

Fig. 2 Block Diagram for Proposed Low Wind WECS

The components to be used are selected based on the literature review and their availability in the market.

A 1 kW wind turbine model e300i of E-Hands Energy Pvt. Ltd. [18] with directly coupled PMSG has been selected for simulation on MATLAB 2016a. It avoids the need of a gearbox which reduces complexity, losses/problems in gearbox and cost. Fig No.3 shows the simulation of these connections in MATLAB/Simulink,

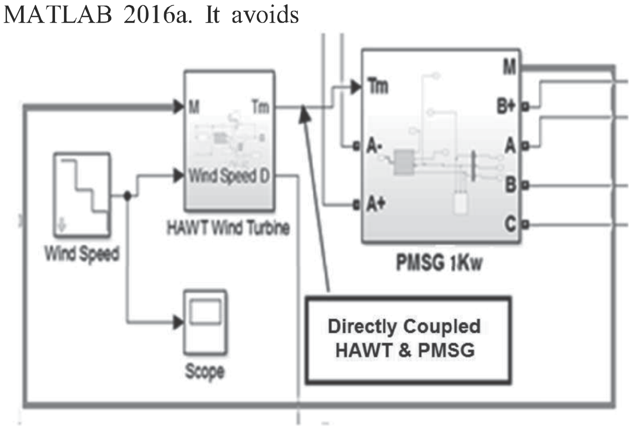

Fig. 3 Simulation Diagram of Directly Coupled HAWT

The broad specifications of wind turbine generator are given in Table No. 1.

Table 1
Specifications of Wind Turbine Generator[18]

Parameter	Value
Type	HAWT
No. of Blades	3 (Fibre Glass)
Rotor Diameter	3.0 m
Cut in Wind Speed	2.5 m/s
Rated Wind Speed	10.5 m/s
Type	Off Grid
Capacity	1000 Watts
Generator Type	PMSG (Axial Flux)
Rated Voltage	415VAC, 3-phase

MPPT normally either changes the pitch angle or controls the duty ratio. Implementing pitch control again means increasing the complexity and cost as wind measurement devices and pitch control motors are also to be provided. Here duty ratio is changed for the power electronic switches.

Wind turbines must be designed with optimal Tip Speed Ratio (TSR) to extract the maximum power from wind. Here a TSR based MPPT is considered to regulate the output of generator in order to maintain an optimum value at which power is extracted. A PI Controller is used which controls the actual rotor speed to the desired value by varying the duty ratio using PWM scheme. The scheme of tip speed ratio MPPT is shown in Fig No.4. The TSR based MPPT is used for manipulating the switching of power electronic switches using a PI Controller.

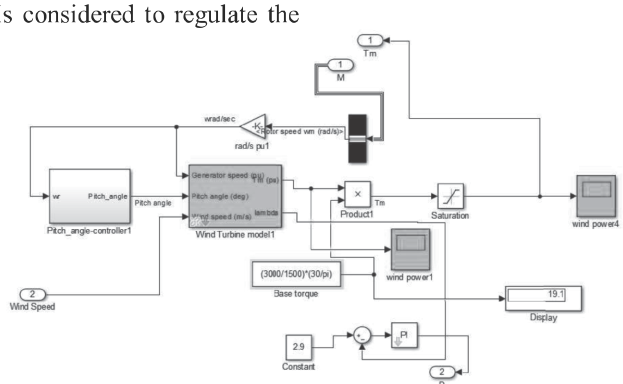

Fig.4 Simulation Diagram of MPPT

The Uncontrolled Rectifier gets input from PMSG which converts AC output to DC. The boost chopper increases the level of DC from the rectifier to desired level boosted DC output and the switching scheme used here is pulse width modulation (PWM). The duty ratio of switch is controlled based on signals from PI Controller which is controlled by TSR based MPPT. The Inverter uses space vector pulse width modulation (SVPWM) technique and converts the boosted DC output to a suitable AC output, at constant voltage and constant frequency. This output is given to the load so that there are no power quality issues at the load side due to variation in the output due to fluctuating wind, the implementation of power electronic converter is illustrated in Fig No.5.

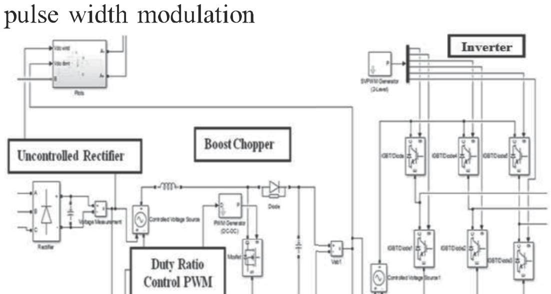

Fig.5: Simulation Diagram of Power Electronic Converter (Uncontrolled Rectifier-Boost Chopper-Three Phase Inverter)

The output from the Power Electronic Converter is fed to a LC filter to smoothen out any ripples and then it can be connected to load directly as a standalone system is simulated. The connection of load to the output is shown in Fig No.6.

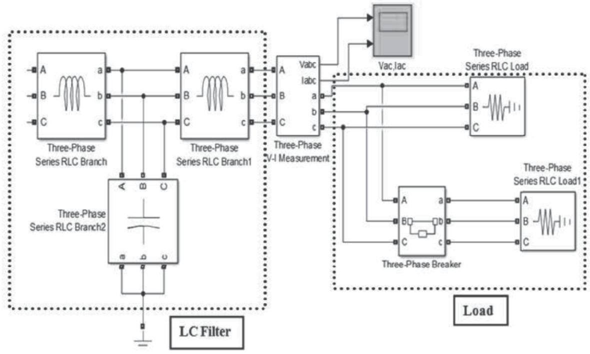

Fig. 6: LC Filter and Load

IV RESULTS AND DISCUSSION

MATLAB 2016a has been used for running the simulation. The input wind speed data is fed to the HAWT and based on these values the system operates. The input wind speeds used in the simulation of the WECS are shown in Fig. No.7.

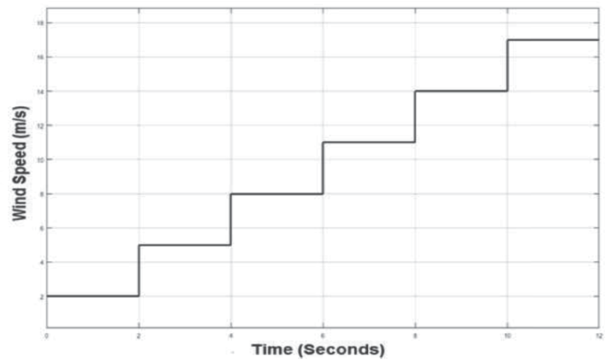

Fig.7: Wind Speed vs. Time

The PMSG starts producing power after 3m/s and reaches rated power at wind speeds near 10.5 m/s. During the simulation 1004 Watt was power output at a wind speed of 10.5 m/s.

The output voltage and current generated by the PMSG generator are shown in Fig No.8 and generated power is shown in Fig No.9.

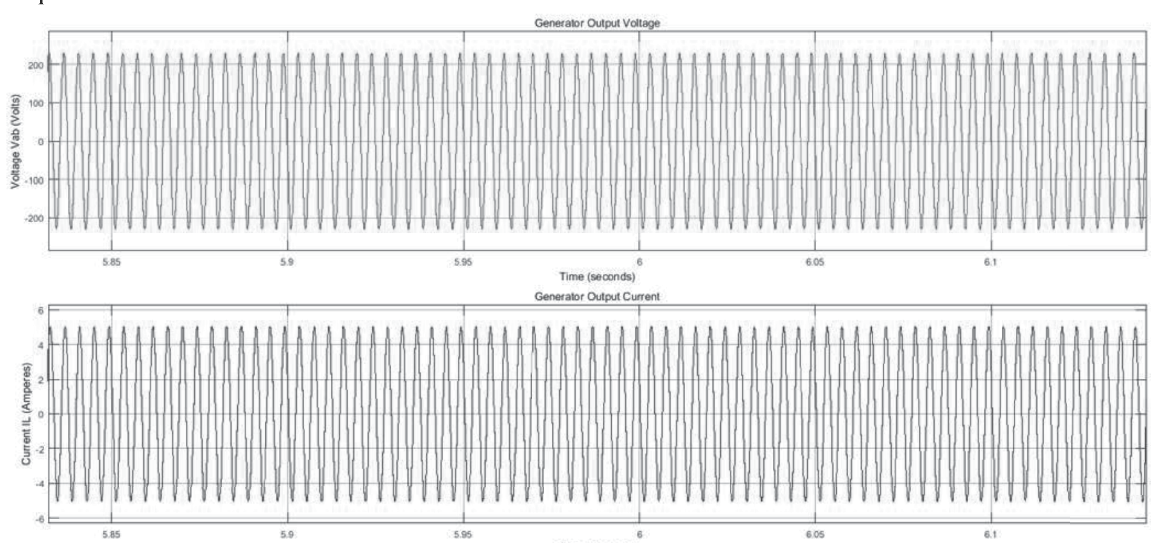

Fig.8: Voltage and Current Waveforms of PMSG

It can be seen from the Fig No.9, that the power output of PMSG used in WECS takes some time to reach the peak power production, but once it reaches the peak the MPPT kicks in and helps in maintaining the power delivered to the load even when input wind speeds drop slightly.

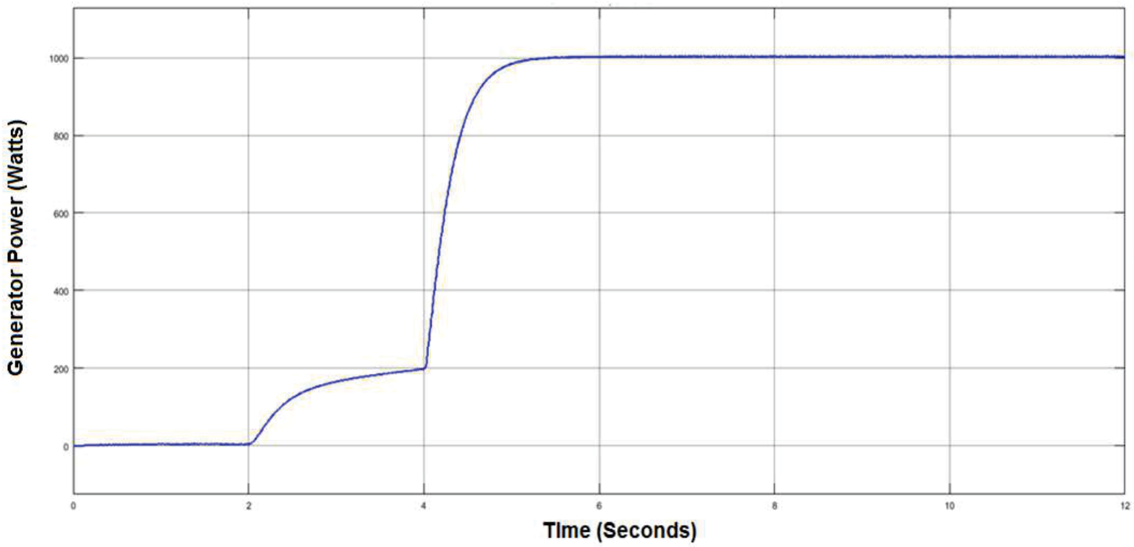

Fig.9: Power Output of PMSG

The system simulation has shown that it can operate in lower wind speed regions. Table No.2 gives the maximum values and time of their occurrence after running the simulation of WECS. These values were found using the peak finder function in the graph window.

Table 2
PMSG Output Parameters

Stages of WECS	Maximum Value
Generator Phase Voltage (V_a)	230.3 V @ 10.18 s
Generator Phase Current (I_a)	5.032 A @ 10.74 s
Generator Power	1004 W @ 9.8 s

V CONCLUSION

HAWT based WECS simulated operates well in low wind speed range of 3 m/s to 17 m/s. The WECS generated a peak power of 1004 Watt at a wind speed of 10.5 m/s. The TSR MPPT and electronic converters proved to be helpful in extracting maximum power at constant voltage and frequency for the low wind speed range and enhancing performance of the WECS. A series of wind turbines developed by Avante Garde Innovations under trade name, 'AVATAR' rated 1, 3 and 5 kW are commercially available. With the further research and policy support, such wind turbines have potential to emerge as a viable option to venture in large low wind regions spread over India.

REFERENCES

[1] Executive summary on power sector for May 2020, *Central Electricity Authority*, http://www.cea.nic.in/reports/monthly/executivesummary/2020/exe_summary-05.pdf

[2] Wind Speed Map by Envitrans Pvt. Ltd., https://www.envitrans.com/windrose.php

[3] Xiaolian Zhang, Yangfei Zhang, Sipeng Hao, Lei Wu and Wei Wei, (2019), An improved maximum power point tracking method based on decreasing torque gain for large scale wind turbines at low wind sites, *Electric Power Systems Research 176 (Elsevier),* Pg. No.1-10

[4] Langlang Gumilar, Muhammad Afnan Habibi, Dwi Prihanto, Hendro Wicaksono, Achmad Gunaman and Jade Rosida Larasati, (2019), Maximum Power of Horizontal and Vertical Wind Turbine to Changes on Wind Speed and Number of Blade, *International Conference on Electrical, Electronics and Information Engineering (IEEE),* Pg. No. 27-31

[5] Anjana Jain, Shankar S. and Vanitha V., (2018), Power Generation Using Permanent Magnet Synchronous Generator (PMSG) Based Variable Speed Wind Energy Conversion System (WECS): An Overview, (Vol.-7, Issue-4) *Journal of Green Engineering*, Pg. No. 477–504

[6] Anil Patel, Albert John Varghese and Soma Rajwade, (2017), Evaluate Yearly based Forecasting Model of Wind Energy Production Capacities in India using NARX Neural Network, (VOl-5, Issue-1) *International Journal of Recent Trends in Electrical & Electronics Engineering,* Pg.No.1-12

[7] Apurb Das, Chimonyo K.B., Rohith Kumar, Gourishankar T. and Rani C, (2017), Vertical Axis and Horizontal Axis Wind Turbine- A Comprehensive Review, *International Conference on Energy, Communication, Data Analytics and Soft Computing (IEEE)* , Pg.No.2660-2669

[8] Jazuli Fadil, Soedibyo and Mochamad Ashari (2017), Performance Comparison of Vertical Axis and Horizontal Axis Wind Turbines to Get Optimum Power Output, *International Conference on Quality in Research (IEEE),* Pg.No.429-433

[9] Winslow Andrew R., (2017), Urban Wind Generation: Comparing Horizontal and Vertical Axis Wind Turbines at Clark University in Worcester, Massachusetts, *International Development, Community and Environment (IDCE)*,127(Master's Papers)

[10] Max Alexander Parker, Conaill Soraghan and Alex Giles, (2016), Comparison of power electronics lifetime betwen vertical- and horizontal-axis wind turbines, (Vol.-10, Issue-5), *IET Renewable Power Generation*, Pg. No.- 679–686

[11] Ravi Anant Kishore, Anthony Marin, and Shashank Priya, (2014), Efficient Direct-Drive Small-Scale Low-Speed Wind Turbine, *Energy Harvesting and Systems*, Pg. No. 27–43

[12] Abolfazl Pourrajabian, Reza Ebrahimi and Masoud Mirzaei, (2014), Applying micro scales of horizontal axis wind turbines for operation in low wind speed regions, *Energy Conversion and Management(Elsevier)*, Pg. No. 119-127

[13] Magedi Moh, Saad M. and Norzelawati Asmuin, (2014), Comparison of Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines, (Vol.-04, Issue-08) *IOSR Journal of Engineering*, Pg. No. 27-30

[14] Yun Yang, Kwan-Tat Mok, Siew-Chong Tan and S. Y. R. Hui, (2013), Nonlinear Dynamic Power Tracking of Low-Power Wind Energy Conversion System, *IEEE Transactions on Power Electronics*

[15] Zhuoran Zhang, Yangguang Yan, and Yangyang Tao, (2012), A New Topology of Low Speed Doubly Salient Brushless DC Generator for Wind Power Generation, (VOL.-48, NO.-3) *IEEE Transactions on Magnetics,* Pg. No. 1227-1233

[16] David Wood, (2011), Small Wind Turbines, *Advances in Wind Energy Conversion Technology, Environmental Science and Engineering*, Pg. No. 195-211

[17] Wang Fengxiang, Hou Qingming, Bo Jianlong and Pan Jian, (2005), Study on Control System of Low Speed PM Generator Direct Driven by Wind Turbine, *International Conference on Electrical Machines and Systems*, Pg. No. 1009-1012

[18] Small Wind Energy, Directory Indian Wind Power-2019, Pg. No.10-12. Consolidated Energy Consultants Limited, Bhopal.