I J C T A, 9(6), 2016, pp. 2827-2833 ISSN: 0974-5572

Cost Effective Design Fabrication of a Low Voltage Vertical Axis Wind Turbine

Shahrukh Adnan K.[1], Rajprasad K.R.[2], Aravind C.V.[3] and Wong Y.W.[4]

ABSTRACT

This paper applied Weight to Power Ratio into two different Permanent Magnet Synchronous Generator based Vertical Axis Wind Turbines and found out the relative cost-efficient model. Both the models were developed in Matlab Simulink under various parameters and were in low voltage range.Before sending the cost-effective design out of the two Simulink model, the chosen design was implemented and a prototype version of it was built in the lab to make sure the turbine produces enough torque and falls in to the low voltage open circuit region. After getting satisfactory result, the design was sent for fabrication. Upon arrival, the turbine was set-up in the laboratory and was performed open circuit analysis and comparison was made between the manufactured design and the prototype. It was found out at the high wind speed range, error estimated was also high. Reason was found out and suggestion was made to develop the model further.

***Keywords**:* Cost-efficiency, Vertical Axis Wind Turbine, Weight to Power Ratio, Permanent Magnet Synchronous Generator, Low Voltage, Prototype

1. INTRODUCTION

Recent revolutionary advances in technology are creating better future for countries with low wind speeds like Malaysia and also changing the face in wind technology. The first known specific windmill, Pneumatics, was said to be found in the 1st century BC by Hero of Alexandria [1-2]. Time goes even earlier to 500 B.C. when People first used wind power to propel the boats in Nile opposite to river current [3-4]. Wind power technology has been developing since then and each era brings us closer to perfection. Coming back to 21st century, numerous projects regarding this sector have been funded and many a researcher are getting interested to develop the wind power technology to further extension. The low speed kind, Vertical Axis Wind Turbine (VAWT) with its ability to function from multi directional wind angle is getting popular with low average speed countries like Malaysia [5]. Government as well as private companies are coming forward to sponsor these low speed turbines. In order to bring a project in the industry-efficiency, environment friendliness and cost-efficiency are one of the most important factors to cover. But these has been a lack of finding a cost-effective technique that can compare the newly invented current model to the old ones. This paper finds a solution to this problem by applying a relative comparison and finding out the relative cost-efficient model from the two products. It took one comparative old model of Permanent Magnet Synchronous Generator (PMSG) based VAWT which was experimented in 2013[6] and it was compared with another simulated model. The comparatively cost-efficient model was built as a prototype which was later sent for fabrication after getting satisfactory open circuit voltage result.

1 Research Assistant (PhD), Dept. of Electrical & Electronic, Faculty of Engineering, University of Nottingham, 43500 UNMC, Jalan Broga, Semenyih, Selangor, Malaysia, *Email: kecx1msa@nottingham.edu.my*

2 Associate Professor, Dept. of Electrical & Electronic, Faculty of Engineering, University of Nottingham, 43500 UNMC, Jalan Broga, Semenyih Selangor, Malaysia, *Email: Rajprasad.Rajkumar@nottingham.edu.my*

3 Senior Lecturer, School of Engineering, Taylor's University, Selangor, Malaysia Taylor's, Selangor, Malaysia, *Email: aravindcv@ieee.org*

4 Assistant Professor, Dept. of Electrical & Electronic, Faculty of Engineering, University of Nottingham, 43500 UNMC, Jalan Broga, Semenyih Selangor, Malaysia, *Email: YeeWan.Wong@nottingham.edu.my*

2. COST EFFICIENCY COMPARSION-WPR

This section discussed the two system configuration in brief and came up with a low cost system which was then sent for fabrication.A simple but effective "Weight to Power Ratio" (WPR) technique was used here. "Weight to Power Ratio" is commonly applied to power sources in order to find out the relative cost effective but yet efficient unit or design being compared to a second unit or design. It simultaneously represents efficiency and cost-effectiveness together and indicates which design is better in terms of percentage. [7][8].It is important to note that this model tells a relative cost effective scenario in terms of "Kg/W" or "m^2/s^3". It is a measurement of relative cost-effective performance of any engine, motor, generator or power source. It is also used as a measurement of efficiency of a system as a whole, in here, which is the weight (m) of the entire system (PMSG adopted to VAWT) being divided by the PMSG rated output power (P). It is noteworthy to mention that in "Weight to Power Ratio", "Weight" in this context means "Mass" (m). Weight is the colloquial term often used instead of mass and since then "Weight to Power Ratio" has been conventionally used. [7-10]

2.1. Physical Interpretation

$$WPR = \frac{m}{P} \tag{1}$$

$$\sim \frac{m}{\left(\frac{W}{t}\right)} = \frac{m}{\left(\frac{FS}{t}\right)} = \frac{m}{\left(\frac{ma.\,S}{t}\right)} = \frac{m.t}{m.a.s} = \frac{m.t}{\left(m.\frac{v}{t}.S\right)}$$

$$= \frac{m.t^2}{m.v.S} = \frac{m.t^2}{\left(m.\frac{S}{t}.S\right)} = \frac{t^3}{S^2}$$

$$\sim \frac{kg}{W} = mnt^3 / m^2$$

Efficiency, $$\eta = \frac{WPR_1 - WPR_2}{WPR_1} x\ 100\%$$

After applying the cost effective technique in the two configurations achieved from the simulation, the better model, in terms of low costing, was sent for fabrication. An earlier work in 2013 [6][11], a 1.5KW 20 Pole PMSG based maglev 3-bladed VAWT was analysed for low wind speed. The configuration of the system from previous work was compared with the current model for relative cost-efficiency. The current system was developed under Matlab Simulation under various wind parameters and described previously in the same year of 2016 [12]. Following are the configuration details.

Table 2.2 illustrates the "Weight to Power Ratio of the two design configuration. It is clear that the smaller design version is 20% cost effective relative to the first design due to its small weight scale. Also, this 200W, 12V 9 bladed rated system much compact comparing to the 1.5kW, 220V, 3 bladed turbine. As far as low wind and low torque concern, the voltage and power output will also be very low as per the simulation data. Therefore it was decided to send current configuration for fabrication.

3. PROTOTYPE CONFIGURATION AND FIELD TESTING

A Chinese Company namely "JN Wind Power Technology Development Co LTD" was chosen for design fabrication. The company was requested to put Maglev in the system. They had also been asked to

Table 1
System Design Configuration

VAWT			*Current System*	*Previous system*
	Height	:	60 cm	2.6m
	Radius	:	14.5 cm	1m
	Number of Blade	:	9	3
	Pitch Angle	:	0	0
	Power Co-efficient	:	0.4412	0.44
PMSG				
	Phase	:	3-Phase	3-Phase
	Type	:	Axial Flux	Axial Flux
	Rated Power	:	200W	1500W
	Rated Voltage	:	12V	220V
	Pole Pair	:	8	10
	Diameter	:	16cm	55.5cm
Top net weight				
		:	12.5kg	75kg

Table 2
Weight to Power Ratio

Weight to Power Ratio 1, WPR_1	:	0.05 Kg/W
Weight to Power Ratio 2, WPR_2	:	0.0625 Kg/W
Cost Efficiency,	:	20%

provide a data sheet for the system but generally data sheets were to be provided only after fabrication, not before that. Therefore, before ordering from the Chinese Company, in order to be assured that the design would work well in low wind speed, a lab prototype was built similar to the current design configuration. The ideas was to go for fabrication only if the lab prototype indicated good pattern of result.

3.1. VAWT & PMSG Design and Set-up

The design of VAWT included eight blades as aerofoil (1). The length of the blade, that was also the height of the turbine, was 60cm, the aerofoil chord diameter was 6.5cm and the radius of the turbine was 14.5cm matching the current configuration which was being investigated. The PMSG used was taken from the fan motor. The only difference between prototype and current simulation model was the pole number. Unlike the current 8 pole pairs, the prototype PMSG was made with 4 pole pair.

Figure 2 shows the laboratory set-up where the prototype was experimented with external fans and open circuit voltage was measured by a multimeter.

3.2. Prototype Field Testing

Figure 3 focuses the generator open circuit voltage at null pitch angle. Furthermore, at the lowest wind speed of 4m/s, the generator was still able to produce an open circuit voltage of 7V (figure 3). It was not possible to make a 16 pole configuration for the prototype but even with 8 pole configuration it showed good result overall. Therefore, it was decided that the prototype system made was good enough to produce low voltage at lower wind speeds.

(a) (b)

Figure 1: Hardware Architecture-Design of VAWT and PMSG

Figure 2: Prototype Set-up

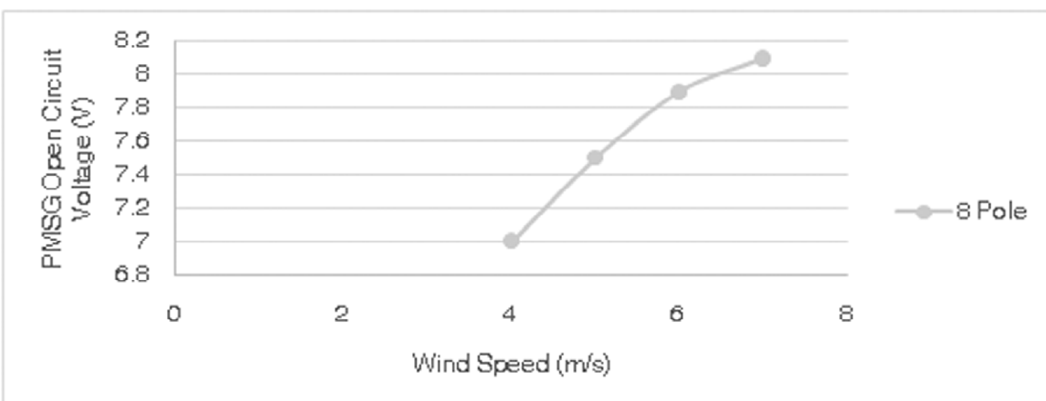

Figure 3: Prototype 3-phase 8 Pole PMSG Open Circuit Voltage for various wind speeds

4. FABRICATION AND FIELD RESULT

The design was then sent for fabrication and upon arrival, it was set-up in the lab and tested for open circuit voltage. Figure 4 shows the fabricated PMSG based VAWT with the cost-effective optimal design parameters.

The system was tested at the Research Building of the Engineering faculty of University of Nottingham Malaysia Campus. The open circuit voltage found was recorded and compared with the prototype design. The wind speeds were varied in the same range as the prototype and the findings are shown in figure 5. It was found that the developed design performed significantly better, particularly at high wind speed. At low wind such as 4m/s, the open circuit voltage different was only 0.5V and estimated error was only 7.7%. But it can be observed that with the increase amount of wind speed, error started to increase as well. At maximum wind speed of 7m/s, 26% error was estimated. After analysis, it was clear that the difference was due to the pole pair number. The manufactured model basically had 8 pole pairs whereas the prototype built only had 4. Therefore, the factory made design showed better performance at high wind speed.

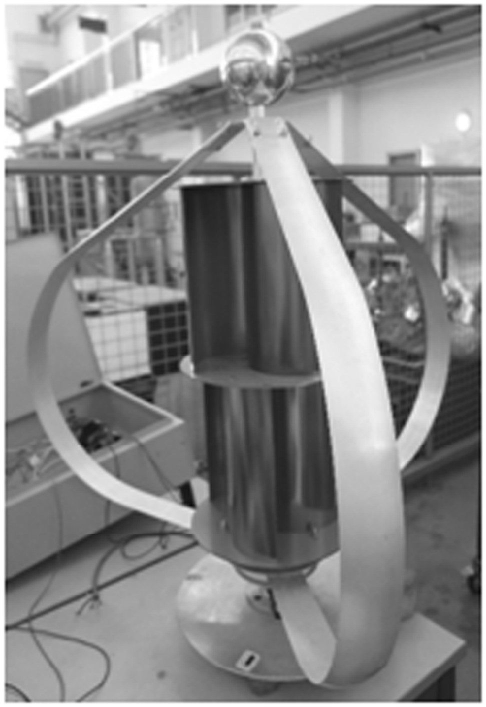

Figure 4: VAWT upon arrival

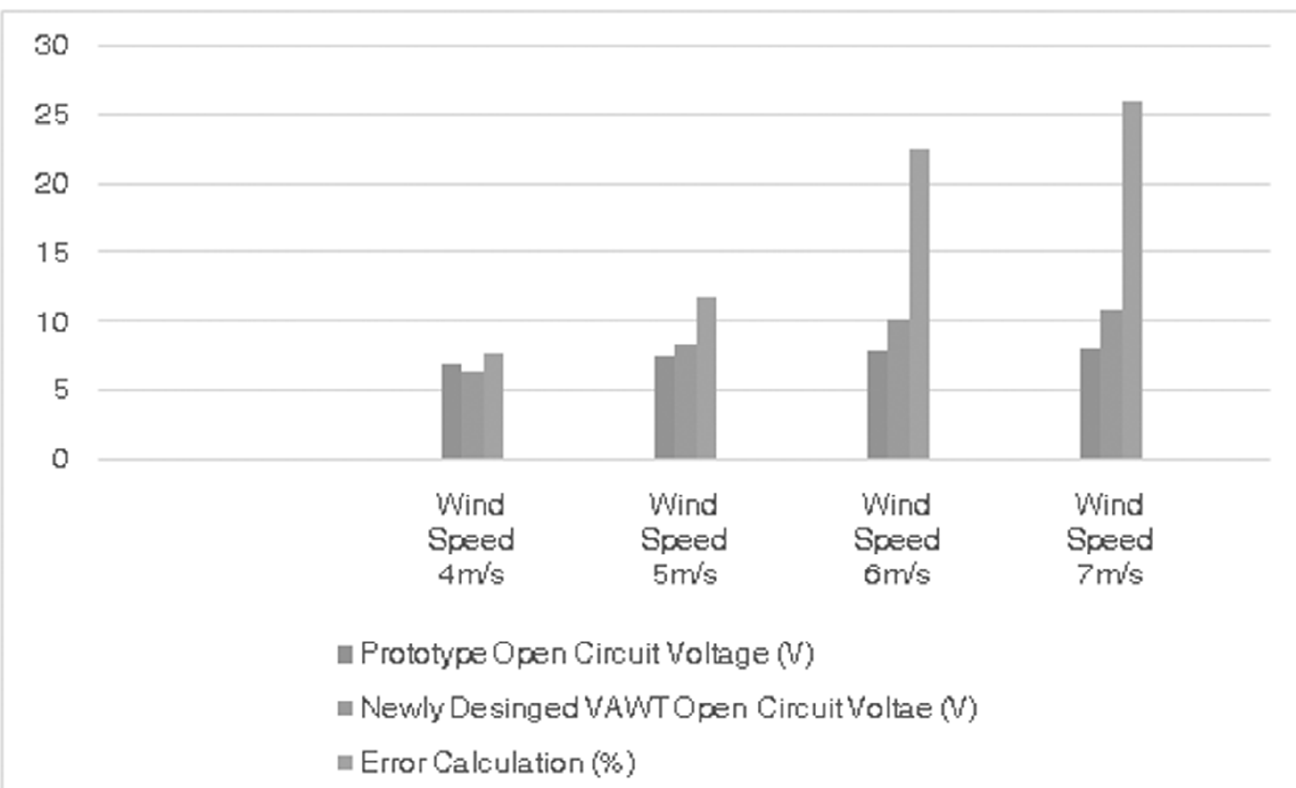

Figure 5: Open Circuit Voltage Comparison and Error Estimation

Wind Speed (m/s)	*Prototype Open Circuit Voltage (V)*	*Newly Designed VAWT Open Circuit Voltage (V)*	*Estimation of Error(%)*
4	7	6.5	7.7
5	7.5	8.5	11.8
6	7.9	10.2	22.6
7	8.1	11	26

5. CONCLUSION

To recapitulate, the paper contributed a new approach towards measuring relative cost-efficiency of different wind power models. One earlier model of 1.5KW PMSG based 3-bladed VAWT was taken for evaluation and it was compared with another model of 200W PMSG based hybrid VAWT. Both model was tested and developed in Matlab Simulink. After comparison by applying Weight to Power Ratio, the newer and smaller version of VAWT was found to be cost-effective. Afterwards, a laboratory prototype of the developed smaller version of VAWT was built to test the open circuit performance in order to confirm low voltage performance. Having accomplished satisfactory performance, the model was sent for fabrication and upon arrival tested for error calculation. Lastly, analysis was done and it was found out the prototype voltage performance error was significantly high at higher wind speed. It was found out due to the limitation of matching the high number of pole, the prototype was built with 8 poles only whereas the proposed system consisted of 16. Due to the insufficient amount of pole number, the prototype was unable to produce enough voltage compared to the manufactured model and thereby causing the estimated error to be high. In short, method used in this paper could be useful to further research model and could give us a relative idea in cost-efficiency.

REFERENCE

[1] A.L. Rogers J.F. Manwell, J.G. McGowan. Wind Energy Explained – Theory, Design and Application. John Wiley and Sons Ltd., second edition, 2009.

[2] World Wind Energy Association, “New Record in Worldwide Wind Installation,” 5 February 2015. [Online]. Available: http://www.wwindea.org/new-record-in-worldwide-windinstallations/. [Accessed 15 March 2015].

[3] S.M. Muyeen, Junji Tamura, T. Murata, Stability Augmentation of a Grid-connected Wind Farm, Springer-Verlag London Limited, 2009.

[4] MD Shahrukh A. khan, R. Rajkumar, Rajparthiban K., CV Aravind, “Optimization of Multi-Pole Permanent Magnet Synchronous Generator based 8 Blade Magnetically Levitated Variable Pitch Low Speed Vertical Axis Wind Turbine”, Applied Mechanics and Materials, Vol. 492, pp. 113-117, 2014.

[5] K. A. MdShahrukh, R. K. Rajprasad, R.K. Rajparthiban., C. Aravind, “A Comparative Analysis of Three-phase, Multi-phase and Dual Stator Axial Flux Permanent Magnet Synchronous Generator for Vertical Axis Wind Turbine”, Applied Mechanics and Materials Vols. 446-447 (2014) pp. 709-715.

[6] MdShahrukh A. Khan, Rajprasad K. R., C. Aravind, “Performance analysis of 20 Pole 1.5 KW Three Phase Permanent Magnet Synchronous Generator for low Speed Vertical Axis Wind Turbine”, Energy and Power Engineering, (2013), pp. 423-428.

[7] NASA, “Priorities in Space Science Enabled by Nuclear Power and Propulsion,” National Academies Press, 2008, ISBN: 0309100119

[8] Mollenhauer, Klaus, Tschöke, Helmut, “Handbook of Digital Engines,” Springer, 2010.

[9] K. Yazawa, A. Shakouri, “Cost-effective waste heat recovery using thermoelectric system”, Birck and NCN Publications, 2012, p. 1199.

[10] Aravind C. V., M. Norhisam, M. H. Marhaban, and I. Aris, “Analytical design of double rotor switched reluctance motor using optimal pole arc values,” International Review in Electrical and Electronics, Vol. 7, No. 1, 3314-3324, Feb. 2012.

[11] MD Shahrukh A. khan, R. Rajkumar, Rajparthiban K., CV Aravind, “Optimization of Multi-pole Three Phase Permanent Magnet Synchronous Generator for low speed Vertical Axis Wind Turbine”, Applied Mechanics and Materials, Vol. 446-447, pp. 704-708, 2014.

[12] MD Shahrukh A. khan, R. Rajkumar, CV Aravind, Wong. Y.W, “A Novel Approach towards Introducing Supercapacitor based Battery Charging Circuit in Energy Harvesting for an off-grid low voltage Maglev Vertical Axis Wind Turbine”, International Journal of Control Theory and Applications, Vol. 9, pp. 369-375.