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Analysis of Variable Speed Micro Wind Energy Generator Using SEPIC Converter

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ABSTRACT

In today's world, most of the problems in the engineering field are foreseen and an opt solution is proposed. One such thing is reducing the usage of fossil fuels by using wind energy conversion systems to meet the consumer's demand without causing pollution but to meet small scale domestic power needs in possibly high wind regions, a micro wind energy conversion system can be used. However, when it comes to investment consideration wind or even micro wind energy conversion systems have a huge deficit, thus this paper has analyzed a low-cost variable speed micro wind energy conversion system in addition to a SEPIC converter. Unlike any other converter, SEPIC is capable of providing consistent and non-inverted output voltage regardless of the varying input voltage over a range. In terms of the system's performance, the wind turbine is sensitive to low wind speeds due to the use of the five-blade system over the common three-blade design. The converter is incorporated with closed-loop control for accurate control of the electrical parameters thereby providing the load with consistent power supply.

Key words: PI controller, SEPIC, MOSFET, Duty cycle, QBlade, MATLAB simulink.

1. INTRODUCTION

In a fast-developing world, renewable energy systems have done their part in meeting the power demands, specifically wind energy conversion systems. The biggest challenge is to convert energy with a minimum loss as possible. Sharma .S [3] has discussed a small wind energy conversion system that can be developed and implemented with low power ratings such as 100 or 200 Watts. S. Ramachandran [12] has presented the right converter that is very compact along with improved efficiency. Sharma .S [3] has also discussed some miniature models that can be taught to unemployed people in the rural area for large scale production within the region thereby increasing employability. Dixon P. Drumheller [4] has proposed the blade design for small scale wind turbines that are planned for implementation in low wind regions. This is for very low wind speeds such as 2 m/s or 7 m/s where the rotor blades can cause the necessary moment to rotate the generator shaft for better power output. As in all the energy conversion systems the output has to be manipulated and further rectified to the desired value. Alexander Bubovich [6] has proposed the Single-ended primary inductor converter as it is better than many converters for the use in renewable energy systems. Carlos Lumbreras [1] has discussed this system for high wind speed areas with the same specifications designed for low wind speed along with a protection mechanism to prevent damage to the mechanical parts of the system.

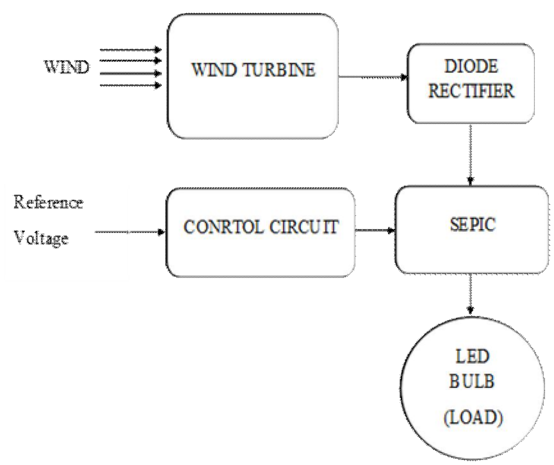

Figure 1: Micro wind energy conversion system

The growing demand for electricity, the limited supply and increasing cost of conventional fuel such as coal, fossil fuels, and petroleum has led to the need for renewable energy. With the advancement in power electronic technology, wind power generation systems have attracted more attention due to the energy crisis and environmental pollution problem. The major problems with the wind power system are, the size of an individual system is large, achieving maximum efficiency is slim and the cost per kilowatt-hour (kWh) is not competitive as compared to petroleum energy sources. A windmill is only

30% to 50% efficient yet it is more productive than solar power systems. Solar systems require larger area for instalment than wind energy systems.

This paper deals with the performance analysis of a micro wind energy system using a single-ended primary inductor converter (SEPIC). Based on the intensity of the wind, the output voltage from the windmill will fluctuate. To overcome this, SEPIC is employed. This DC-DC converter is mainly used to change the voltage levels, optimizing the losses from the obtained voltage level [7],[8],[12],[18]. The SEPIC is a boost converter followed by an inverted buck-boost converter, therefore providing a positive output, unlike other converters [14],[15],[16]. SEPIC can provide a lower output or higher output than the given input voltage.

2. DESIGN AND SIMULATION

2.1 Blade comparison using QBlade

The forthcoming simulation and analysis are done using a blade parameter calculation software called QBlade. For small wind turbines, the SG6043 foil model was found to be the best fit for the design of blades [5],[9],[11],[10] and using the same foil model the 3 blade and 5 blade designs are compared. The following figures show the SG6043 air foil and blade designs for horizontal axis small wind turbine in QBlade.

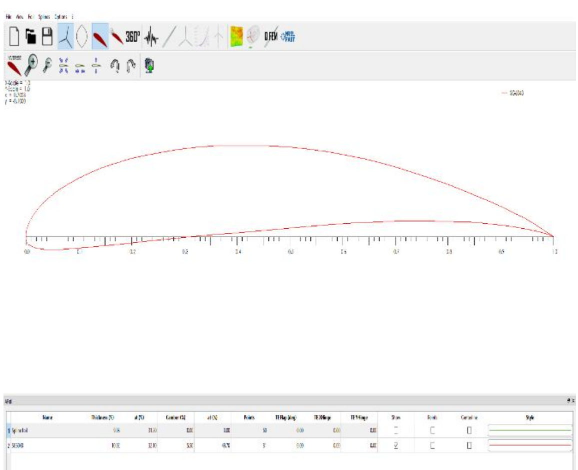

Figure 2: Air foil model

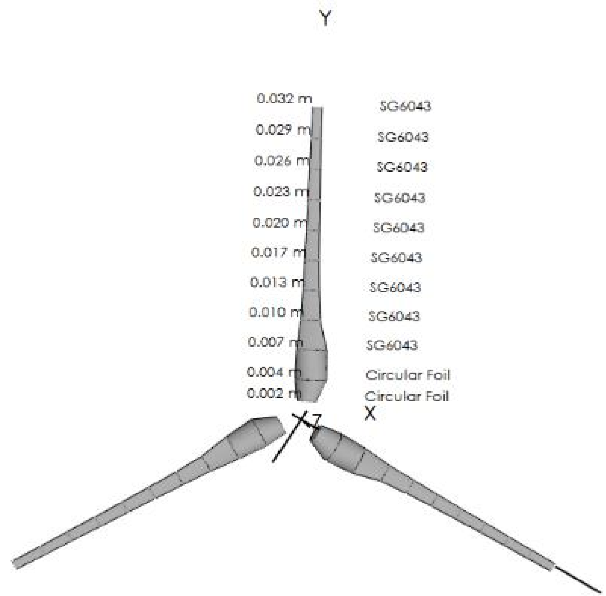

Figure 3: Three blade design

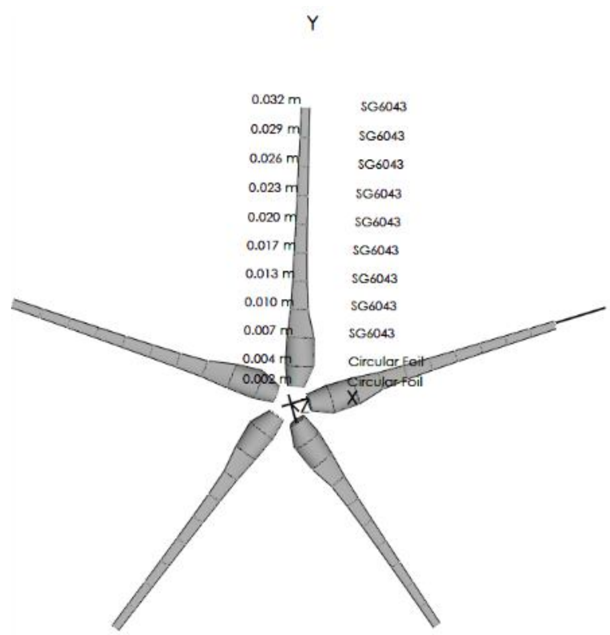

Figure 4: Five blade design

Table 1: Blade parameters

Serial no.	Position(m)	Chord(m)	Twist	Foil
1	0	0.076	0	Circular Foil
2	0.09	0.126	0	Circular Foil
3	0.21	0.118551	18.3186	SG6043
4	0.33	0.0755927	12.1912	SG6043
5	0.45	0.0625468	8.65956	SG6043
6	0.57	0.054959	6.3787	SG6043
7	0.69	0.0495343	4.78876	SG6043
8	0.81	0.0452978	3.61874	SG6043
9	0.93	0.0417521	2.72238	SG6043
10	1.05	0.0388054	2.01403	SG6043
11	1.17	0.0362923	1.44033	SG6043

Table 1 represents the values of various parameters for which the blade designs are plotted.

2.2 Design of SEPIC using MATLAB simulink

SEPIC stands for single-ended primary inductor converter. It is a combination of boost converter and buck-boost converter [13]. Based on the duty cycle, the output voltage can either be higher or lower than the given input voltage. The mode of operation and switching action of SEPIC is same as Cuk converter but SEPIC has continuous input current only where as Cuk converter has both continuous input and output currents [17]. SEPIC basic circuit diagram is same as Cuk converter but inductor is shunt connected rather than the diode. Its major advantage is the non-inverted output [6],[8],[13]. Unlike the buck-boost converter, its output has the same voltage polarity as the input. SEPIC has a series capacitor to couple energy from the input to the output. Therefore, it can respond smoothly to a short-circuit output. SEPIC reciprocates the energy between the capacitors and inductors to change from one voltage to another. This process is controlled by the switch.

SEPIC has both continuous mode and discontinuous mode of operations. It is in continuous mode when the current through the inductor L1 is not allowed to fall to zero and it is in discontinuous mode when the current through the inductor L2 goes to zero. The efficiency of SEPIC is subjected to change based on the resistance values of the capacitors and inductors used. The switching time and change in voltage levels across the diode can also affect the converter's efficiency [2].

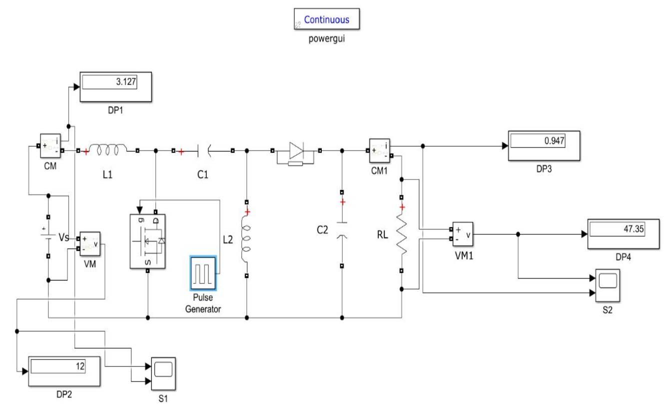

Figure 5: Open-loop control method of SEPIC

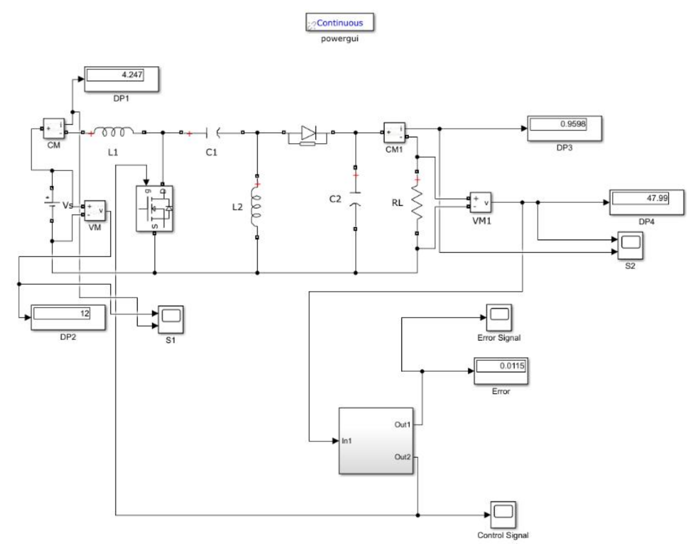

Figure 6: Closed-loop control method of SEPIC

Figure 5 represents the open-loop circuit of SEPIC [7]. This circuit has been modelled using MATLAB simulink. The SEPIC consists of a controlled switch (MOSFET), a pair of inductors, a pair of capacitors and a diode. The switch is controlled by the pulse generator. The pulse generator is used to generate the gate pulse for the switch. The resistive load is connected in parallel to the output capacitor. In open-loop control, the duty cycle is varied directly to get the required output. Figure 6 represents the closed-loop control of SEPIC. Here, the pulse generator is replaced by a control circuit where a PI controller is used to control the gate pulse of the SEPIC [7],[12]. In closed-loop control, the output voltage is obtained based on the set value. This method is more accurate when compared with the open-loop control method.

3. RESULTS AND DISCUSSION

3.1 Results from QBlade simulation

Figure 7 shows the coefficient of lift, drag and alpha plots for the NACA SG 6043 air foil model. In the second and third graphs, blade element momentum simulations (BEM) are done comparing the blade designs the green line represents the 5 blade design and the red line represents the 3 blade design. In figure 8 and figure 9, 5 blade design has a higher coefficient of thrust and power when compared to a 3 blade design. Similarly, in figure 10 and figure 11, a better thrust is obtained for low speeds of the rotor for 5 blade design than for a 3 blade.

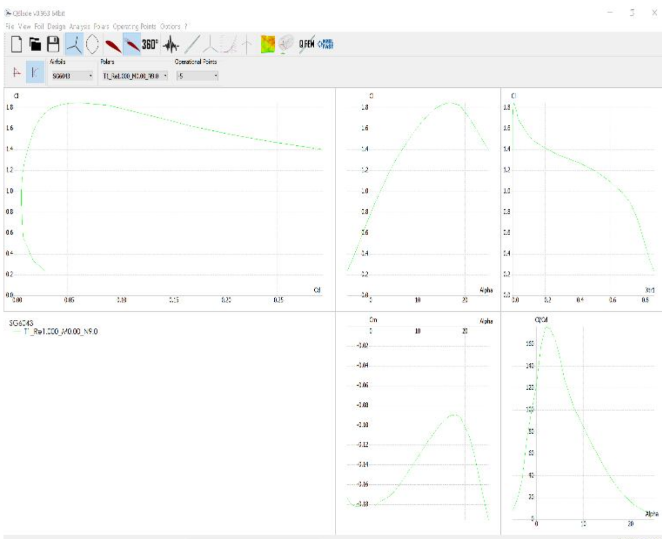

Figure 7: Lift co-efficient [Cl], drag co-efficient [Cd] and angle of attack [alpha] plots

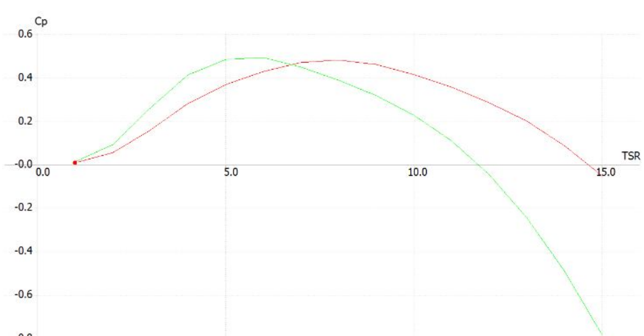

Figure 8: Power co-efficient [Cp] vs tip speed ratio [TSR] plot

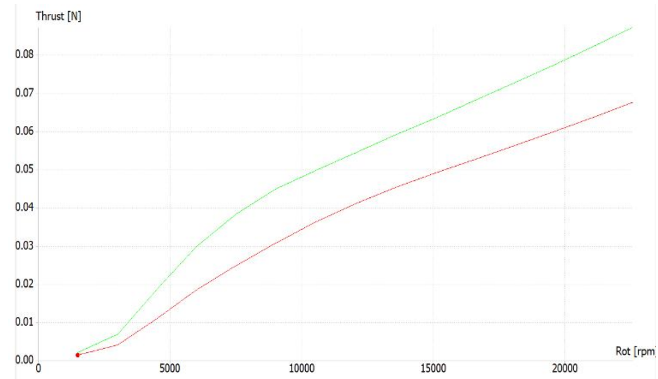

Figure 9: Thrust coefficient [Ct] vs tip speed ratio [TSR] plot

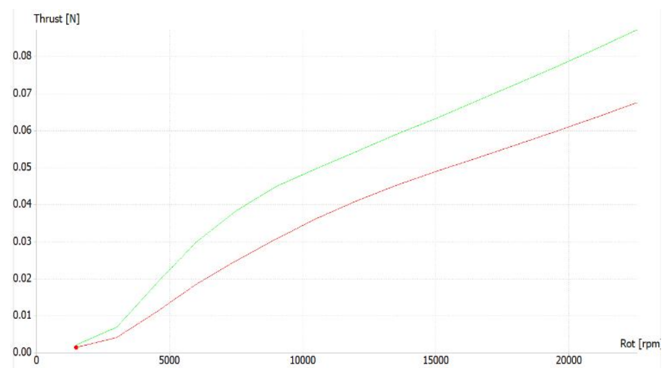

Figure 10: Thrust vs rotor rpm plot

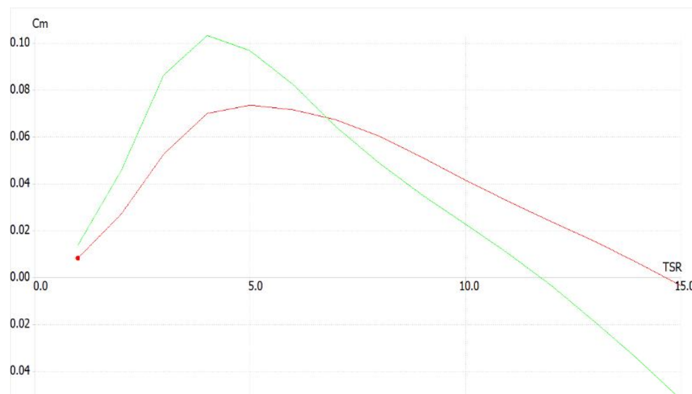

Figure 11: Torque coefficient [Cm] vs tip speed ratio [TSR] plot

3.2 Results from SEPIC simulation

The SEPIC is simulated with the input voltage of 12 V. Figure 12 and 13 show the waveforms for the open-loop control method of SEPIC. Figure 13 represents the output voltage and current waveforms. From these waveforms, we can observe that ripples and harmonics are higher. It is clear that the input voltage is 12V and the output voltage is 24V. The input current value is 4.25A and the output current is 0.9A.

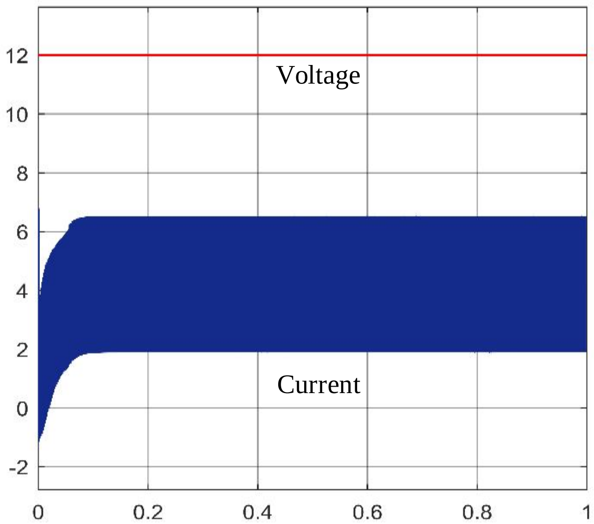

Figure 12: Input voltage and current

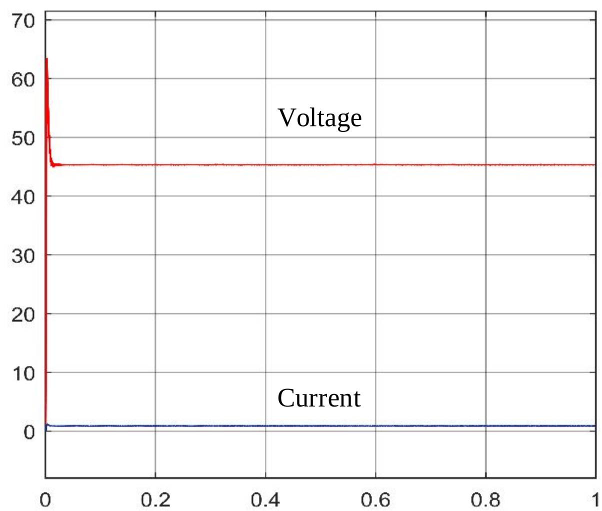

Figure 13: Output voltage and current for open-loop control of SEPIC

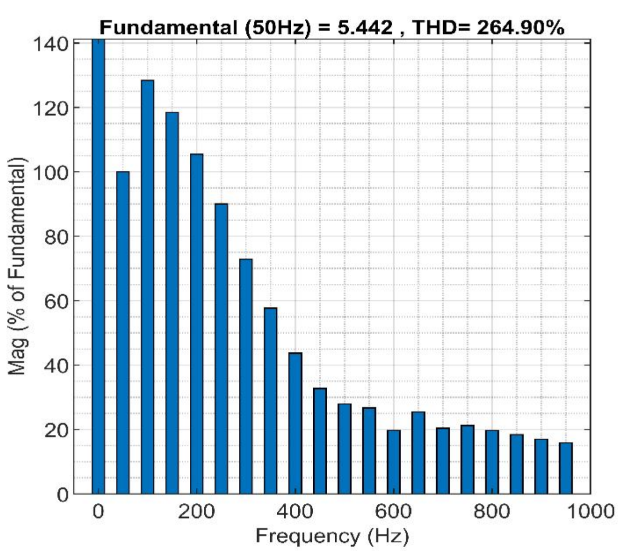

Figure 14: Harmonics for Open-loop control

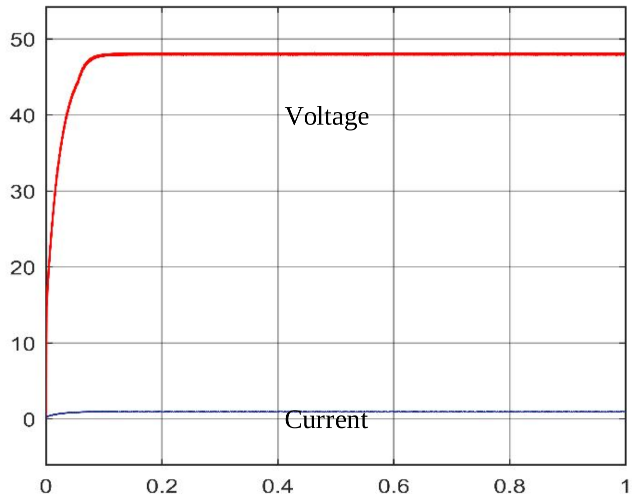

Figure 15: Output voltage and current for closed-loop control of SEPIC

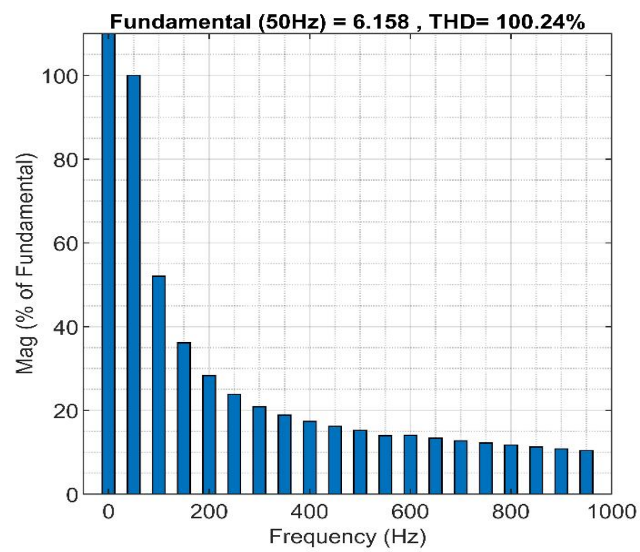

Figure 16: Harmonics for closed-loop control

Figure 12 and figure 15 give a clear view of the input and output waveforms of the SEPIC under closed-loop control method. The PI controller is given a set value of 48V. It is clear that the input voltage is 12V and the output voltage is stepped up to 47.99 V. The input current value is 4.25A and the output current is 1A. We can also see that the output voltage and current signals have fewer ripples and harmonics. Total harmonic distortion for open-loop is 264.90% while for closed-loop it is 100.24%. Therefore, ripples and harmonics content in the closed-loop control of SEPIC is very much less than open-loop control of SEPIC.

4. CONCLUSION

The obtained simulation results of the blade comparison using QBlade software shows that 5 blade design is better than 3 blade design for the small horizontal axis wind turbine that runs at low wind speeds. This has been analyzed using blade element momentum analysis. Furthermore, the MATLAB simulations of open-loop and closed-loop control of SEPIC shows that closed-loop control method produces less harmonics and provides good monitoring for the output electrical parameters than the open-loop control method.

5. FUTURE SCOPE

The proposed system can be used for small scale domestic power production. Furthermore, it can be leveraged for study purposes.

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