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A Review on DC-DC Converters for PMSG based Standalone Variable Speed Wind Turbine System

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***Abstract* – Lack of conventional resources across the globe and its effects of green house emissions track an ideal path towards renewable energy sectors. The deploying conventional energy resources cause uneven climatic changes and there by confront to the innovators in making the transition towards non conventional energy resources. Among the renewable system, wind energy systems which is considered to be the promising resource, track an ideal path and meets the expectation to the demand in the recent decades. Quantity (Real & Reactive Power) and quality (Harmonic pollutants) of power output are the challenging issues faced by the wind energy harvesters. This paper deals with the review of various power electronic DC-DC converters employed for a permanent magnet synchronous generator (PMSG) based variable speed wind turbine system (VSWTS). The output power is analyzed in correlating the voltage gain, voltage stress and circuit complexity. Pulse width modulation inverters (PWM) are used to control the load voltage in terms of magnitude and frequency. Modeling is performed at each section of conversion. The performance comparison of the chart is presented in pertaining to the discussion.**

Index terms – Permanent magnet synchronous generator, Harmonic Pollutants, DC link voltage control, PWM inverter.

I INRODUCTION

The generation and circulation process involved in the non renewable energy creates a drastic pollution which indirectly leads to the changes in the climatic conditions [1] since because of the continuous exposure of this inevitable will creates negative consequences to the mankind in near future [2]. Numerous research proposals and disseminations are published on account by steering committees of renewable sectors focusing the transition towards green energy. Variable speed operation of wind turbines is more popular than fixed speed generation since ability to trap peak power at all intervals of time. Similarly PMSGs are more preferred in comparing with dual fed induction generators because of requirement of excitation and accessories for the rotor circuit [3]. Even though production has been increased accordingly, because of the poor power coefficient and lack of power stabilization, the quantity and quality of power output suffers to feed the energy hungers throughout the world. According to the Betz's limit, the power coefficient of wind energy conversion system is 0.35-0.45. No wind turbine can efficiently convert the complete wind source to electrical energy because of the incorporation of various engineering requirements [4]. The protocol in the transformation includes kinetic energy to rotational cyclic energy which is the mechanical force used to drive the rotor of the wind turbine generator. Since the power conversion has to travel a series of transformations, hopefully the coefficient of power output is low. Hence it is necessary to trap effectively the whole some amount of power coefficient without any loss. So many peak power tracking algorithm is still practiced and the best among them is tip speed ratio [5] - [6]. Speed of the turbine has to be adjusted along with varying wind velocity. Once the optimal operating point through TSR is achieved the juncture can harvest huge power. Similarly the role of converters in WECS is very important. The power generated from wind turbine generator is given to rectifier for AC-DC conversion. Normally uncontrolled switches are used for rectification. In the second stage of conversion the variable DC is tuned to constant Dc output. The active switch in this stage is fired accordingly to reduce the DC link ripples there by ripple voltages are mitigated and thus DC link voltage is balanced across the converters and inverters. PWM inverters are commonly preferred to suppress the uncertainties during non linear load variations. Standalone systems are mainly preferred to compensate the load variations in the absence of source [7]. In this research proposal some of the DC-DC converters preferred for WECS are discussed and the best option among them are suggested for incorporation. The paper is formulated as section 1 describes the importance of renewable energy, PMSG based VSWTS and peak power trackers. Section 2 points out the mains and accessories of the energy conversion system and section 3 includes the modeling of generator systems, converters and section 4 shows the comparison chart of the DC-DC converters preferred for renewable applications.

II DYNAMICS OF WIND TURBINE SYSTEM

A Schematic view of WECS is shown in the Fig. 1. The entire block is constructed with wind turbine system, 3-Phase PMSG, AC-DC converter, DC-DC converter, 3-Phase PWM inverter, inner current control loop (for peak power tracking & reactive power stabilization). Non linear load is connected at the inverter end [8].

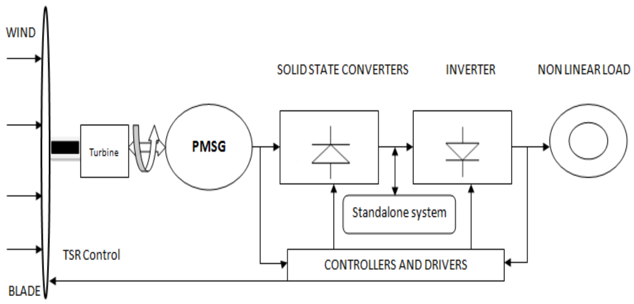

Fig. 1 A Schematic View of WECS

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The output power of the wind turbine blade is proportional to the air density, swept area of blade, velocity of wind, power coefficient (function of TSR and blade pitch angle). The power coefficient has the standard value which ranges between 30% to 50% practically. Theoretically it is maximized as 59% of the input source shown in the Fig. 2.

$$P_t = \frac{1}{2}\rho A V_W^3 C_p(\lambda, \beta) \quad (1)$$

Power coefficient varies with TSR, λ and blade pitch angle, β.

The TSR is given by

$$\text{TSR}, \lambda = \frac{Blade\ Tip\ Speed}{Wind\ Speed} = (rpm\ x\ \pi\ x\ D)/60\,/\,V_W \quad (2)$$

$$\text{Torque coefficient, } C_t = C_p(\lambda)/\lambda \quad (3)$$

$$\text{Turbine torque } T_{t\,(opt)} = P_t / \Omega_{opt} \quad (4)$$

Power coefficient is normally derived from

$$C_p = \frac{1}{2}(\lambda - 0.022\beta^2 - 5.6)\, e^{-0.17\lambda} \quad (5)$$

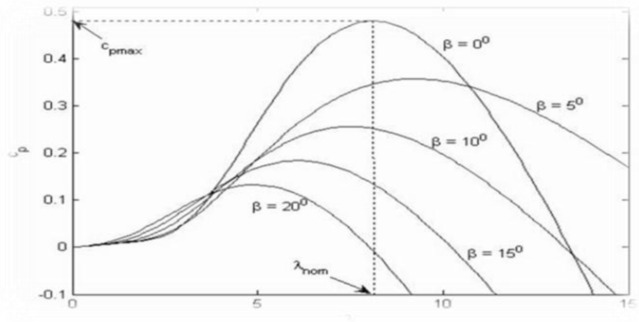

Fig. 2 Power coefficient Vs Tip Speed Ratio.

A. Modeling Of PMSG

PMSG does not require external excitation and it means it has no brushes and slip rings. The steady state PMSG model is shown in the Fig. 3 & 4 [9].

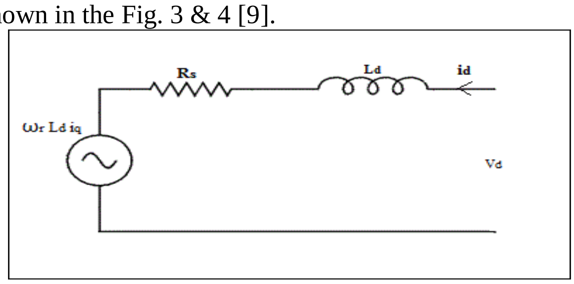

Fig. 3 Direct axis PMSG model

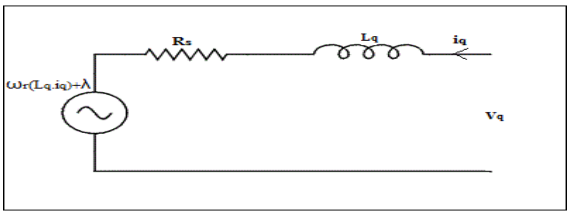

Fig. 4 Quadrature axis PMSG model

The dynamic equation of the stator voltages are given by d and q components of stator voltages are given by

$$V_{Sd} = R_S\, i_d + L_d \frac{di_d}{dt} - \omega_e L_q i_q \quad (6)$$

$$V_{Sq} = R_S\, i_q + L_q \frac{di_q}{dt} - \omega_e L_d i_d + \omega_e \varphi_m \quad (7)$$

Electromagnetic torque of the generator is expressed as

$$T_e = \frac{3}{2} P\,[\,\emptyset_m\, i_q + (L_d - L_q)\, iq\, i_d\,] \quad (8)$$

III DC-DC CONVERTER TOPOLOGY

A. Buck Converter

Generally DC–DC step-down or buck converters are meant for reducing the magnitude of the output voltage than that of input voltage magnitude [10] shown in Fig. 5. Hence these topologies are preferred for connecting high module voltages to low load or battery voltages. Rectifier apparent unit is converter input impedance. By varying the duty cycle ratio, the value can be matched with that of the optimum resistance. As Duty ratios are in the interval, a buck converter cannot reflect impedances that are smaller to that of load impedance value and therefore it does not achieve the values that are near the short circuit current ratio. When the active switch is turned ON, the voltage is applied across the power diode. Therefore diode must be in OFF state as long as active switch remains ON. The ON state of the switch always implies the OFF state of diode. Now the switch is kept ON for a particular time interval and then OFF. At the instant when the switch is turned OFF the peak value of the output current delivers during the first chopper cycle. This peak current occurs at the instant the active switch turns OFF.

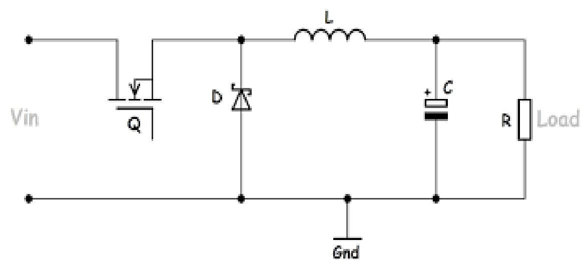

Fig. 5 Circuit configuration of Buck Converter

The presence of the inductance prevents the current to fall suddenly. The decay of inductor current continues as long as converter switch remains OFF. The switching cycle starts conducting when it is turned ON again at the end of the first OFF time and the current again starts to build up. Due to the initial current the second peak will be larger than initial current. In this way, as the switching progresses, both the peak and valley magnitudes progressively increase. After several cycles, the difference between successive cycles becomes relatively very small.

B. Boost Converter

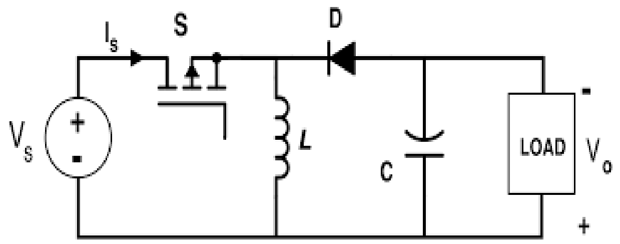

Fig. 6 Circuit configuration of Boost Converter

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In general, DC–DC step-up or boost type converters are used to convert the output voltage magnitude greater than the input voltage magnitude [11]; therefore these topologies are preferred for connecting non linear loads of high voltage rating and battery voltages shown in Fig. 6.. A boost converter will not reflect impedance factor that are greater than load impedances and hence it does not achieve the values near a module's no load voltage. Boost converter cannot follows the optimal operating points that are closer to the open circuit voltage and if the boost converters are applied for peak power tracking, it will be able to track the exact peak operating point within the operation region. But if the magnitude of the input voltage is lower than the minimum value, a boost converter cannot track peak power because the point is in the non-operating region. When the active switch of the boost converter is completely switched, the inductor current will gets increased through the closed path, at that instant the capacitor voltage will supplies the load current. When the active switch is turned off, the inductor discharges along with the source voltage and hence the magnitude gets increases. The boost converters are highly opted for wind turbine applications, since because of the fluctuating wind, the output voltages of the generators are low and hence they are very important for these applications.

C. Buck-Boost Converter

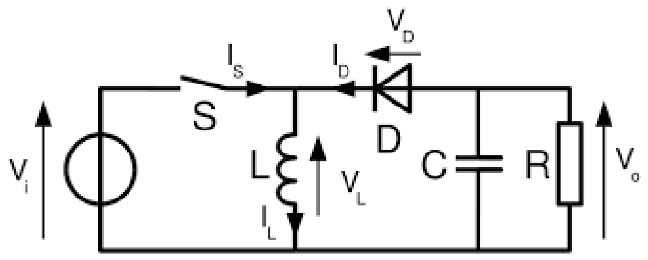

Fig. 7 Circuit configuration of Buck-Boost Converter

Non-inverting DC-DC buck-boost converter is a combination of both buck and boost converter, which has single inductor-capacitor [11]. Diode will be in parallel to the input source voltage, active switch is connected in series with the parallel combination of inductor and diode. Capacitor is connected across the load to balance the output voltage shown in Fig. 7. Operating principal of this type of converter is generally preferred for non linear and variable loads. In buck mode operation, active switch 1 turned ON with the diode. Active switch 2 is turned OFF and diode will be is always ON. When the converter is operated at boost mode then the active switch 1 will be turned off. In order to control the input variable and interrupted DC supply a buck-boost converter may be integrated as the semiconductor interface with renewable systems, where the potential output may have the polarity which is negative in regard to the input DC source and as required the output voltage can be lower or higher than the input voltage. A buck-boost converter can be realized through the cascaded link of the step up and step down choppers. The transformation ratio can be defined as the relation between the ratios of output voltage to input voltage, in static operation of the semiconductor device. The performance of the buck boost topologies of the power electronic DC-DC converters can seems to be affected by the variation in the duty ratios of the active switch. During mode 1 operation, the input current flows through inductor and the active switch. Hence the inductor is completely charged. In parallel the capacitor voltage discharges to the load. When the active switch is made to turn off, then the current will find its path through diode capacitor and load. The energy stored in inductor would certainly transfer to the capacitor and load, automatically inductor current will completely discharged to load until the switch is turned ON.

D. Cuk Converter

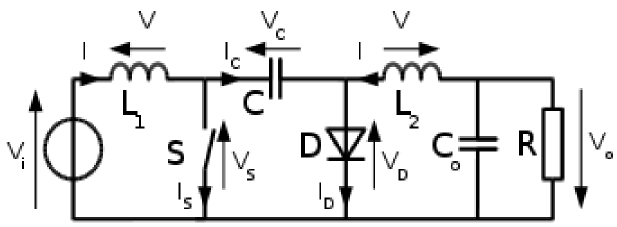

Fig. 8 Circuit configuration of Cuk Converter

The circuit configuration of Cuk converter incorporates two capacitors, two inductors, an active switch and an uncontrolled semiconductor switch [12]. The output voltage of a Cuk converter is negative with respect to the input voltage and hence it is termed as inverting converter. The capacitor is connected in parallel to load and the diode, which transfers the energy between the source and load through the commutation of the active switch and the diode. The inductors are used to convert the voltage sources into current sources shown in Fig. 8. Because of the large inductor value the current becomes unidirectional and the ripples are reduced. If the capacitor is connected in parallel to the voltage source, output current will be reduced because of the parasitic resistance and hence resulting in high energy loss. If the capacitors are charged from the inductor currents, it prevents the resistive current limiting and power loss. The Cuk converters can be operated in both continuous and discontinuous current mode.

E. SEPIC Converter

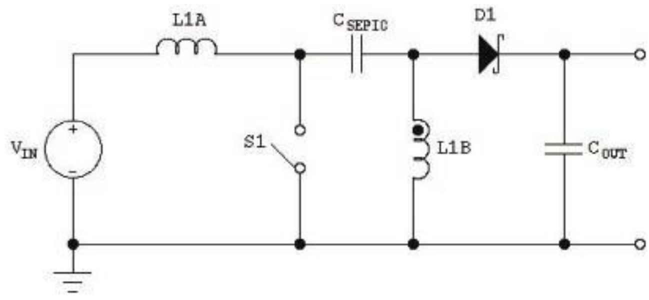

Fig. 9 Circuit configuration of SEPIC Converter

Another type of DC-DC converter is, single ended primary-inductor converter (SEPIC). The functional operation is similar to that of buck boost converter, i.e., capable of operating from an input voltage which is lower or greater [13]. Circuit configurations includes two inductors, two capacitors, a single active switch controller and a clamped switching waveforms that results in less noisy operation shown in Fig. 9. The magnetic windings of the SEPIC converters are wound on a common core which is of coupled type and if it is separately wounded it might be of uncoupled inductor. Power supply from the DC source charges the inductor 1 when the active switch is turned ON, in parallel inductor 2 is charged by the capacitor. The capacitor voltage is proportional to the load voltage, at this condition diode is OFF. The inductor in turns discharges to the load through the diode when the active switch is turned OFF, in parallel capacitor gets charged. The output voltage is proportional to the duty ratios of the converter. Large inductor values certainly reduces the ripples in output, but creates circuit impedances, large operation space and thereby expensive. The impedance reduces the converter efficiency.

F. MOD - SEPIC Converter

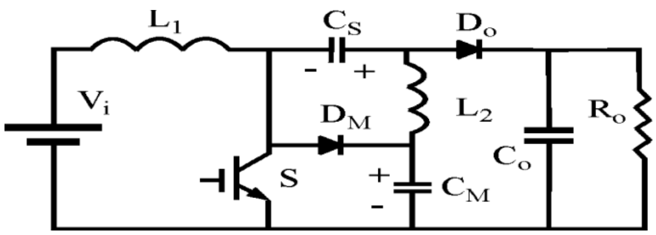

Fig. 10 Circuit configuration of MOD - SEPIC Converter

The modified SEPIC converter is the second level of SEPIC converter, which is accomplished by diode, inductor, active switch and the capacitor as in basic SEPIC converter topology [14]. Voltage multipliers are incorporated to increase the static gain of the boost converters. Here also voltage multiplier technique adjoins the SEPIC converter to yield the configuration shown in Fig. 10. As regards to the configuration, the operation of the modified SEPIC also changes accordingly. The capacitor can be charged from the source and balance the load voltage. When the active switch of the modified SEPIC converter is switched ON, the inductor current will charge the capacitor and hence the static gain is more than the SEPIC converter. There are two modes of operation of converters, at the instant when the active switch is OFF, the inductor energy discharges through the parallel capacitor and the diode, and also to through the series capacitor through the diode. The capacitor voltage is equal to the switch voltages. Similarly the energy stored in the inductor 2 also discharged through the second diode. In the second mode of operation, the active switch is turned ON and hence charging will takes place on the inductors. The input voltage is directly applied to the first inductor 1 and the voltage and potential drop is applied to the second inductor 2. Potential drop across the primary inductor is greater than secondary inductor. The voltage in all diodes is shared and hence the power switch is equal to the capacitor output voltage. The output voltage across the load is equal to the sum of the voltages across the two capacitors respectively. The average inductor 1 current is equal to the input current from the source and the average inductor 2 current is equal to the load current.

Table. 1 Comparison chart of DC-DC Converters

S.No	BUCK	BOOST	BUCK BOOST	CUK	SEPIC	MOD-SEPIC
Polarity	Invert output	Invert output	Invert output	Invert output	Non – Invert output	Non – Invert output
Current	Pulsating	Pulsating	Pulsating	Non Pulsating	Non Pulsating	Non Pulsating
Switching drives	Floated type	Floated type	Floated & grounded type	Floated & grounded type	Grounded type	Grounded type
Duty Ratios	$\frac{V_o}{V_{in}} = \mathrm{D}$	$\frac{V_o}{V_{in}} = \frac{1}{1-D}$	$\frac{V_o}{V_{in}} = -\frac{\mathrm{D}}{1-D}$	$\frac{V_o}{V_{in}} = -\frac{\mathrm{D}}{1-D}$	$\frac{V_o}{V_{in}} = \frac{\mathrm{D}}{1-D}$	$\frac{V_o}{V_{in}} = \frac{1+\mathrm{D}}{1-D}$
Configuration	1 - Switch 1 – Capacitor 1 - Inductor	1 - Switch 1 – Capacitor 1 - Inductor	1 - Switch 1 – Capacitor 1 - Inductor	1 - Switch 2 – Capacitor 2- Inductor	1 - Switch 2 – Capacitor 2- Inductor	1 - Switch 3 – Capacitor 2- Inductor
Efficiency	Low	Low	High (for positive)	Medium	Medium	High
Cost	Medium	Medium	Medium	Medium	Medium	High

IV PERFORMANCE COMPARISON OF DC-DC CONVERTERS

Based on the type of application, converters can be preferred. In some low power applications the output requirements are very low potential and hence small variations or changes are enough from the input voltage. For that cases buck or boost type converters can be used. But the output voltage is of inverted in nature and there may be high input ripples for both buck and boost converters. The output current is also pulsating type for this case. Buck boost converter and Cuk converters impose electrical stress on the converter circuit but it can be minimized in case of SEPIC converter. Here in SEPIC converter, energy can be transferred through the series capacitor and hence it should withstand high voltage, therefore the rating of the capacitor should be made high. Controlling of the active switch is complex in SEPIC converter, but in MOD-SEPIC converter these problems are rectified. In modified SEPIC converter the value of static gain is very close to the boost converters for low

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values of duty cycle, and a static gain will be maximum closed to the voltage multipliers for larger values of duty cycle. Therefore, for lower duty cycle and low value of input voltage, the output voltage is maximum with high gain. Hence the converter works with good efficiency for non linear loads at various duty cycle ratios. SEPIC converter can be used for step down and step up chopper and in case of MOD-SEPIC converters, boost applications are carried out. Here the stress to the inductor and capacitors are reduced with minimized ripple counts. There are some regenerative snubbers introduced to existing MOD-SEPIC converters in order to reduce additional losses created by reverse recovery current, as the comparison is shown in the Table. 1.

IV EXPERIMENTAL DISCUSSIONS

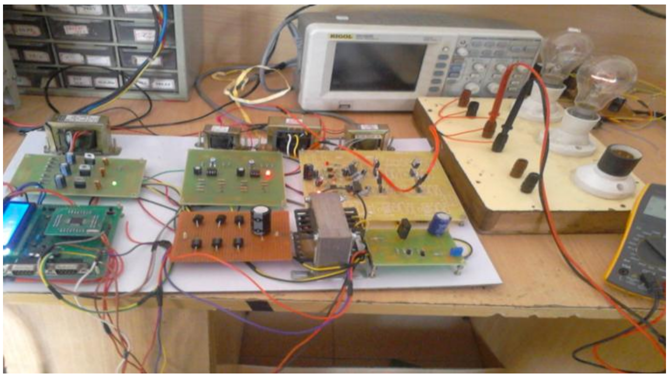

Fig. 10. Prototype platform

The Fig. 11 shown is the prototype module of converter module with variable input. For experimental set up variable PMSG output is considered as the source input for the test rig. The output voltage is controlled by excitation control. Various converters are incorporated with the input system to test the performance of the converters and it is the MOD-SEPIC converter which harvests the output with reduced voltage stress to the converters and its accessories.

V. CONCLUSIONS

The proposed review enabled to study the operation of different DC-DC converters associated in the operation of WECS. Rectifiers are the primary converters used to convert PMSG voltage to DC. In order to stabilize the reactive power components and associated ripples different DC-DC converters are incorporated and their performance in this application was studied. It is figured out that MOD-SEPIC converters has the configured structure to reduce the stress across the switches, capacitors and inductors, also high voltage gain at the minimum duty ratio increases the converter efficiency specifically meant for high power applications. Harmonic pollutants are mitigated with the PWM inverters by introducing harmonic trap filters. Voltage in terms of magnitude and frequency are also adjusted at the load side converters. Hence the power stabilization is achieved.

REFERENCES

[1] Renewables 2014 Global Status Report.www.ren21.net.

[2] A.B. Raju, K.Chatterjee and B.G.Fernandes, "A Simple Power Point Tracker for Grid connected Variable Speed Wind Energy Conversion System with reduced Switch Count Power Converters," IEEE Power Electronics Specialist Conference, Vol. 2, pp. 748-753, 2003.

[3] L. Gidwani, "A Comparative Power Quality Study of DFIG and PMSG Based Wind Energy Conversion System," WSEAS transactions on systems and control, Vol. 10. pp. 38-47, 2015.

[4] A. Uehara, A. Pratap, T. Goya, T. Senjyu, A. Yona, N. Urasaki, and T. Funabashi, "A coordinated control method to smooth wind power fluctuations of a PMSG-based WECS," IEEE Trans. Energy Convers., Vol. 26, No. 2, 2011, 550-558.

[5] Y. Xia, K.H. Ahmed, and B.W. Williams, "A new maximum power point tracking technique for permanent magnet synchronous generator based wind energy conversion system," IEEE Trans. Power Electron., Vol. 26, no. 12, pp. 3609-3620, 2011.

[6] J.S. Thongam, and M. Ouhrouche, "MPPT control methods in wind energy conversion systems," INTECH Open Access Publisher 2011.

[7] I. Abouzahr, and R. Ramakumar, "Loss of power supply probability of stand-alone wind electric conversion systems: a closed form solution approach," IEEE Trans. Energy Convers. Vol. 5, No. 3, pp. 445-452, 1990.

[8] K. Tan, & S. Islam, "Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors," IEEE Trans. Energy Convers. Vol.19, No. 2, pp. 392-399, 2004.

[9] M. Yin, G. Li, M. Zhou, and C. Zhao, "Modeling of the wind turbine with a permanent magnet synchronous generator for integration," In Power Engineering Society General Meeting, IEEE (pp. 1-6), June 2007.

[10] X. Tan, J. Dai, and B. Wu, "A novel converter configuration for wind applications using PWM CSI with diode rectifier and buck converter," IEEE International Electric Machines & Drives Conference (IEMDC) pp. 359-364, May 2011.

[11] J.C Pena, M.A. De Brito, G.D.A e Melo, and C.A. Canesin, "A comparative study of MPPT strategies and a novel single phase integrated buck-boost inverter for small wind energy conversion systems," In XI Brazilian Power Electronics Conference (pp. 458-465). IEEE, September 2011.

[12] A. Sinha, P. Samuel, D. Kumar, and R. Gupta, "Performance analysis of converter based variable speed wind energy conversion system," In Power Systems, ICPS'09. International Conference, pp. 1-6, IEEE, December 2009.

[13] S.Venkatanarayanan, M.R.M. Nanthini, "Design and Implementation of SEPIC and Boost Converters for Wind and Fuel cell Applications," International Journal of Innovative Research in Science, Engineering and Technology, Vol 3, No. 3, pp. 378-383, March 2014.

[14] Kamal Singh, A.N. Tiwari, K. P. Singh, "Performance Analysis of Modified SEPIC Converter with Low Input Voltage," International Journal of Electronics & Communication Technology, Vol. 3, No. 1, pp. 21-25, March 2012.