Middle-East Journal of Scientific Research 24 (1): 142-148, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.01.22733

Fuzzy Logic Control Based Permanent Magnet Synchronous Generator with Sepic Converter for Wind Energy Conversion System

[1]K. Kavin Mullai, [2]R. Harikumar and [3]P. Santhoshini

[1]Department Of Electrical and Electronics Engineering, Kongu Engineering College, Perundurai
[2]Department of Electronics and Communication Engineering,
Bannari Amman Institute of Technology, Sathyamangalam
[3]Department of Electrical and Electronics Engineering, Kongu Engineering College,Perundurai

Abstract: Due to the increasing energy demands, the development of renewable energy sources is becoming more attractive and essential. The Proposed system employs permanent magnet synchronous generator which uses a fuzzy controlled MPPT controller for controlling the output power of the generator. This output power from PMSG is rectified and supplied to the SEPIC converter which increase or decreases the output power according to the load. The MPPT controller is used to control the duty cycle of the switch. This system provides a constant DC power output to the load.

Key words: Permanent magnet Synchronous Machine(PMSG) · Maximum Power Point Tracking (MPPT) · Perturb and Observe (P&O) · Single Ended Primary Inductor Converter (SEPIC) Equivalent Series Resistance (ESR) Fuzzy Logic Controller (FLC)

INTRODUCTION

Due to the depletion of non renewable energy sources, high cost, polluting environment, renewable sources has gained more interest in the past decade. Out of this renewable sources wind energy has gained more interest because of its availability and it is also an non polluting and inexhaustible in nature.

As the wind velocity is varying in nature, the constant output is required to be delivered to the load, So the use of power converters has been essential to maintain constant output and the advancement in power electronics plays a wide role in getting the maximum output power from the varying wind velocity.

The proposed system consists of the wind turbine, permanent magnet synchronous generator and the output of generator is converted to DC by rectifier, Since the output is variable it is given to DC-DC converter which can increase or decrease the voltage and constant voltage is delivered to the load. The Maximum power point tracking algorithm is used to control the duty cycle of the switches in the converter and maximum power output is obtained [1].

System Overview: The wind energy conversion system has the turbine blades and the turbine is connected to the generator. The output of generator is connected to the three phase rectifier where the AC is converted to dc and it is connected to DC-DC Converter to get the constant DC output voltage, where the Duty cycle of the switches is controlled by the MPPT algorithm, so that the maximum power is achieved.

The generator may be of two types and commonly used generators are Squirrel cage induction generator and permanent magnet synchronous generator. In the proposed system Permanent magnet synchronous generator is used because of its high efficiency, reliability, power density; gearless construction, light weight and self-excitation features [7, 8]. The PMSG is connected to the DC-DC converter which is controlled by the MPPT algorithm to obtain the maximum output and the constant DC voltage is supplied to the load.

The formula for finding the maximum power generated from the turbine is given by

E = Kinetic Energy (J)

Corresponding Author: K. Kavin Mullai, Department Of Electrical and Electronics Engineering, Kongu Engineering College, Perundurai, India.

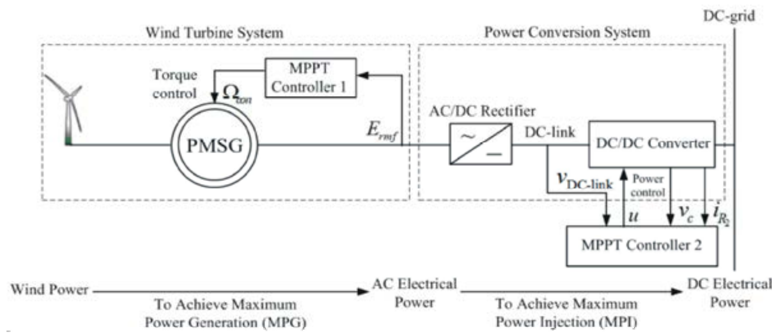

Fig. 1: Block diagram of the proposed systemG2

ρ = Density (kg/m3)
m = Mass (kg) A = Swept Area (m2)
v = Wind Speed (m/s)
Cp = Power Coefficient
P = Power (W) r = Radius (m)dt
dm =Mass flow rate(kg/s)
x = distance (m) dt
dE =Energy Flow Rate (J/s)
t = time (s)

kinetic energy of a mass in motion is

$$E = W = FS \quad (1)$$

The power in the wind is given by the rate of change of energy

$$P = \frac{dE}{dt} = \frac{1}{2} v^2 \frac{dM}{dt} \quad (2)$$

As mass flow rate is given by

$$\frac{dM}{dt} = \rho A \frac{dx}{dt} \quad (3)$$

and the rate of change of distance is given by

$$\frac{dx}{dt} = V \quad (4)$$

We get

$$\frac{dM}{dt} = \rho AV \quad (5)$$

Hence, the power can be defined as

$$P_m = \frac{1}{2} \rho A V^3 C_p \quad (6)$$

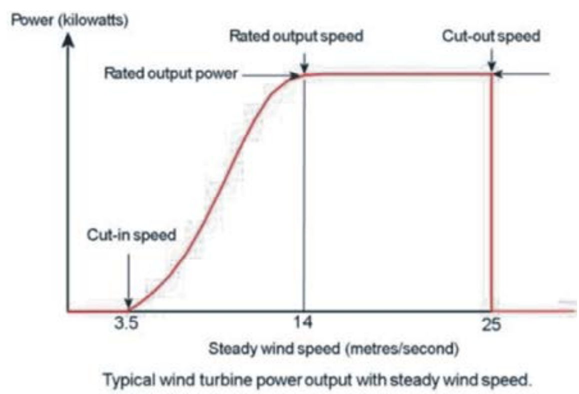

Fig. 2: Power output of Wind Turbine

The output of the wind turbine under steady wind speed [1] is given as

Cut in Speed: At lower wind speed the torque produced is insufficient to rotate the blades of the turbine; The speed at which the turbine first starts to rotate and generate power is called the cut-in speed.

Rated Output Power: As the wind speed increases above the cut-in speed, the electrical ouput power rises rapidly as shown. The maximum limit to the generator output is called the rated power output and the speed of wind at which it is reached is called the rated output wind speed.

Cut-out Speed: As the speed increases above the rated output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the cut-out speed.

Modelling of PMSG: The source EMF (e_w) is proportional to the generator speed (ω_m) [7],

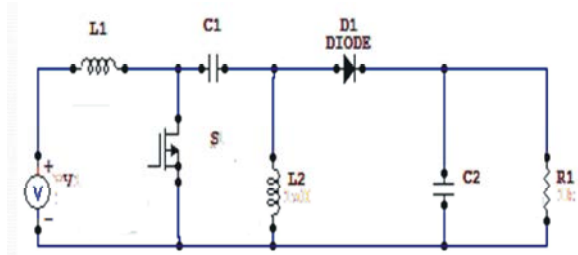

Fig. 3: Sepic converter

$$e_W = K_W \omega_m \tag{7}$$

Neglecting damping and friction, the mechanical dynamics can be reduced to:

$$J \frac{d\omega_m}{d_l} = T_m - T_m \tag{8}$$

$$T_e = \frac{P_e}{\omega_m} = \frac{e_w i_{dc}}{\omega_m} = K_w i_{dc} \tag{9}$$

K_w = Generator emf constant

T_m = *Turbine mechanical torque*

T_e = Generator electrical Torque

Power Electronic Converters: The power electronic converters plays an important role in providing a constant DC output to the load, the output of the converter is controlled by the switching sequence of converter and the switching is done by maximum power point tracking algorithm [2, 6].

SEPIC Converter: A SEPIC converter has a single MOSFET (Q1) and a single diode (D1).The MOSFET and diode in a SEPIC converter have voltage and current requirements similar to their counterparts in an inverting buck-boost converter. As such, the power losses of the MOSFET and diode are similar. On the other hand, a SEPIC converter has an additional inductor (L2) and an additional ac-coupling capacitor. (CP) [3].

In a SEPIC converter, the average inductor current Of L1 equals the input current (IIN), whereas the average inductor current of L2 equals the output current (IOUT). In contrast, the single inductor in an inverting buck-boost converter has an average current of IIN + IOUT. The coupling capacitor sees significant root-mean-square (RMS) current relative to both input current and output current, which generates extra power loss and reduces the converter's overall efficiency.

Table 1: Design of Sepic Converter

PARAMETERS	VALUE
Input voltage, V_{in}	100V
Output voltage for D=40%,D=75%	64V,295V
Switching frequency	500kHz
L_1	5mH
L_2	5mH
C_1	470μF
C_2	22000
R	100Δ

To reduce power loss, ceramic capacitors with low equivalent series resistance (ESR) are desired, which usually leads to higher cost. The additional inductor of a SEPIC converter, coupled with the extra coupling capacitor, increases printed circuit board (PCB) size and total solution cost. A coupled inductor can be used to replace two separate inductors to reduce PCB size. However, the selection of off-the-shelf coupled inductors are limited when compared to separate inductors. Sometimes accustom design will be required, which increases cost and lead time.

Design parameters and equations for SEPIC Converter:

$$L_1 = L_2 = \frac{1}{2} * \frac{v_{in} * D}{\Delta i_L * f_s} \tag{10}$$

$$C_{OUT} \geq \frac{I_{OUT} * D}{\Delta V * 0.5 * f_s} \tag{11}$$

$$C_1 = C_2 = \frac{I_{OUT} * D}{\Delta V * f_s} \tag{12}$$

where,
D=Duty cycle,V_{in} is the input voltage in Volts, ΔV and Δi_L is the ripple voltage and current, f_s is the supply frequency.
Calculated value of design variables are

Output Voltage of SEPIC Converter

Types of Mppt Algorithm: The MPPT algorithms are classified into three types [10]:

Tip-Speed ratio control (TSR),
Power-Signal feedback (PSF),
Hill climb search (HCS) based.

Tip-Speed ratio control (TSR): This method requires the wind speed and rotor speed, keeping these two speeds the rotor speed of the turbine is regulated to its optimal TSR value [10]. The optimal value is calculated from Turbine generator characteristics.

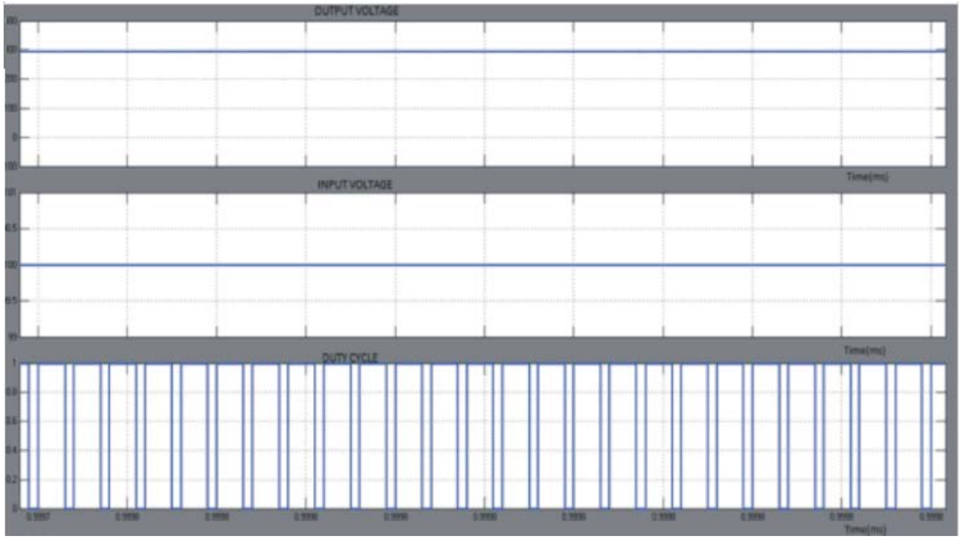

Fig. 4: Sepic converter output waveforms for 75% dutycycle

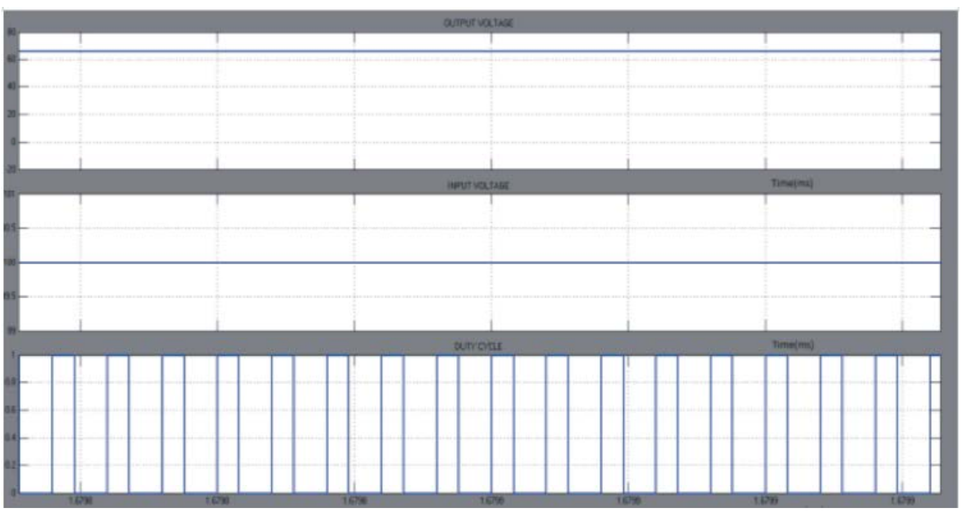

Fig. 5: Sepic converter output waveforms for 40% dutycycle

The main drawback of this control is to measure the wind speed using anemometer and rotor speed.

PSF Control: This method uses data of the wind turbine's maximum power curve obtained for a turbine speed via prior simulations or tests for individual wind turbines and the reference speed are obtained from the curve or it can be stored as look up table. This system needs additional sensors for finding speed. This makes the system complex and cost of the system increases.

Hill Climb Search Algoritham: This method does not require prior knowledge about turbine, generator and wind characteristics. The perturbation and observation (P&O), or hill-climb searching (HCS) method, is the mathematical optimisation technique which search the optimal point and maximum power is extracted. This method is based on perturbing a control variable in small step-size and observing the resulting changes in the target function until the slope becomes zero. Since the P&O method does not require prior knowledge of the wind turbine characteristic curve, it is independent, simple and flexible.

The main disadvantage of this method is it fails to reach the maximum power point under varying speeds and calculating the step size is a difficult task, though larger step-size means a faster response and more oscillations around the peak point and hence, less efficiency, a smaller step-size improves efficiency but reduces the convergence speed.

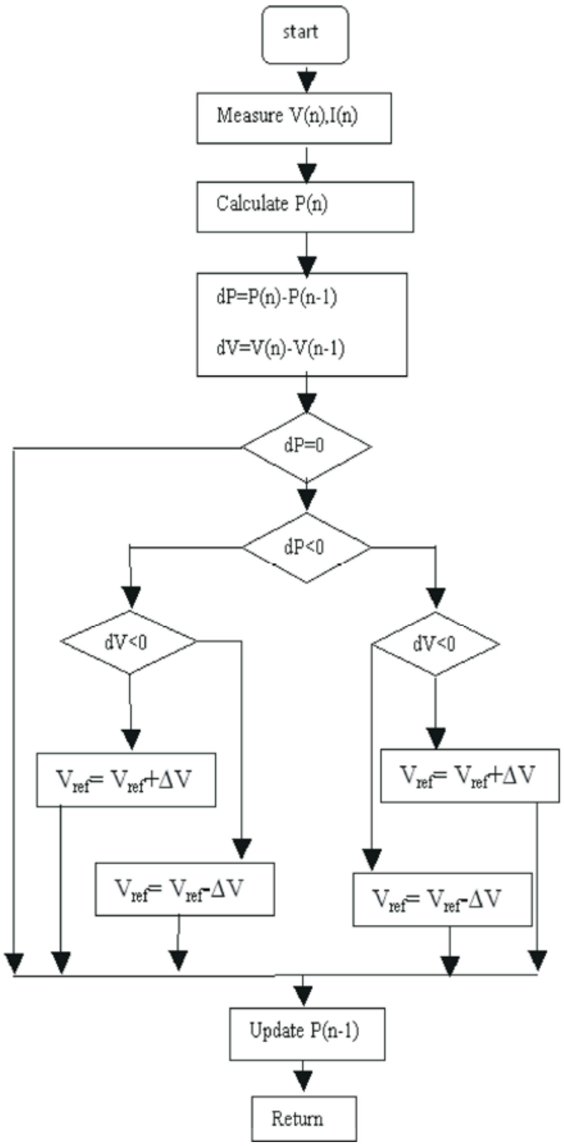

Fig. 6: Flowchart for P&O Algorithm

Advantages of P& O Method:

- P&O method does not require the earlier concept of turbine control Power maximum at exact wind speed.
- P&O method operates on the scenario of operational reason at most outlets.
- P&O method operates backed few increases and decrements of reiteration.

In the proposed system, voltage and current from the SEPIC converter are taken as reference for the P&O algorithm [6, 10]. The flowchart for P&O algorithm is as follows

Fuzzy Logic Control: Many control methods use the FLC for MPPT. Fuzzy logic control consist of 3 stages: fuzzification, guideline base table lookup and defuzzification. To start fuzzification organizing, the data variables region unit received again into etymological variables performance. The generally used inputs to co-partner degree FLC particular unit slip and modify in inaccuracy [3]. Then lookup table got by earlier informative elements of the framework's for different failures, the FLC produce that is often a change in obligation accurate connection or rotor speed. The Third defuzzification stage, the FLC is changed over from a semantic variable to a numerical variable oppression a different capacity. Three FLCs region element used in, with the necessary oppression HCS fundamental method to differ generator speed and simulating the generator speed for a particular wind speed to concentrate the maximum force. In this instance, second FLC is used once the maximum divider attachment is arrived at by the essential FLC to expand the machine-converter strength by reducing the rotor speed.

Here, the fuzzy logic controller is used to control the torque of the PMSG to get the optimal speed by using electromagnetic torque and rotor speed of PMSG as input

Output Current and Voltage of PMSG and Output of Rectifier after FLC:

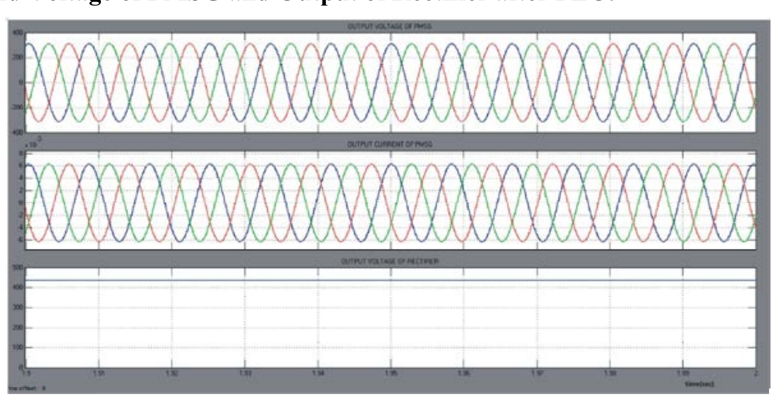
Fig. 7: Output Waveforms

Simulation of Wind Turbine Coupled with SEPIC Converter:

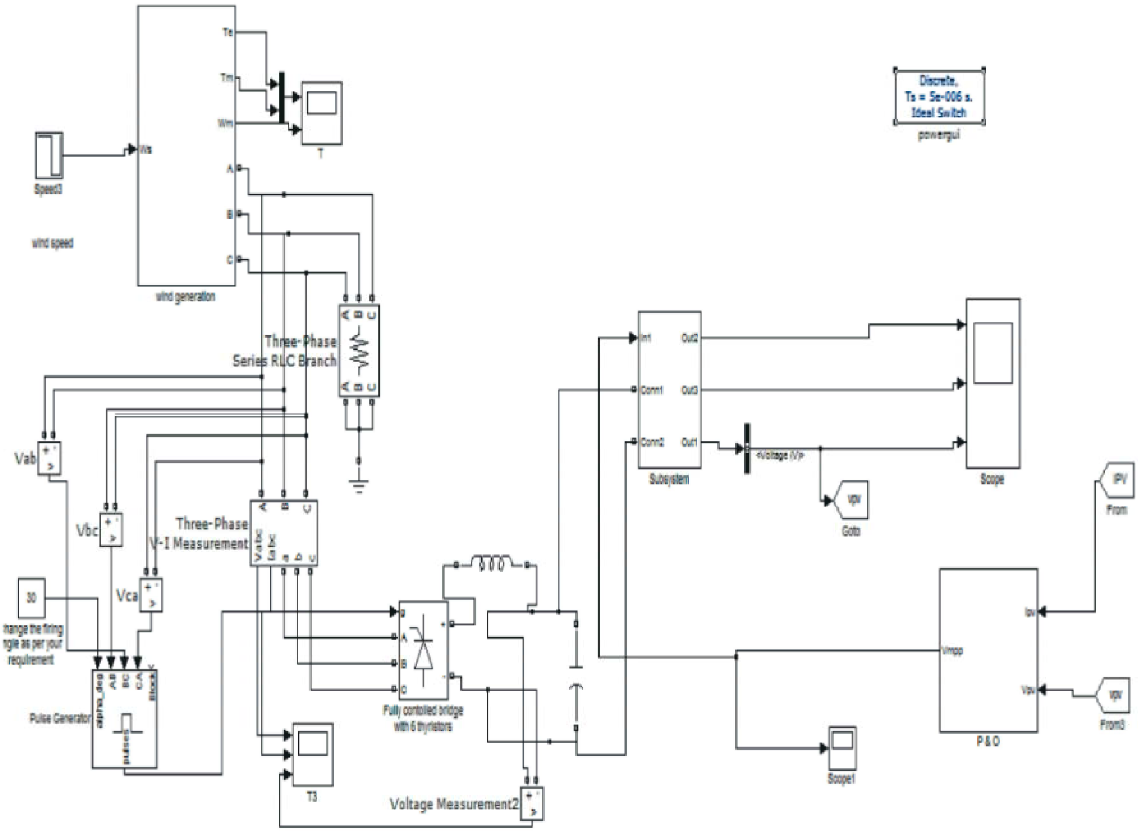

Fig. 8: Simulation circuit for Wind Turbine coupled with Sepic converter

Output Current and Voltage of Wind Tirbine Coupled with SEPIC Converter:

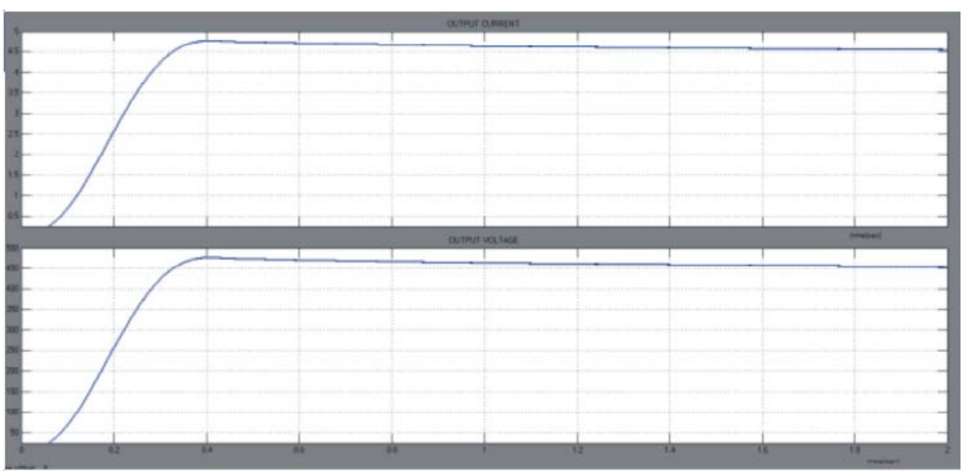

Fig. 9: Output waveforms for Wind Turbine coupled with Sepic converter

CONCLUSION

In this paper, a fuzzy logic controller was presented to control the torque of PMSG to get constant output and it was given to SEPIC converter to meet the load requirement with reduced ripple compared to buck-boost converter. Simulation results have been presented using MATLAB/Simulink.

REFERENCES

1. Yun Yang., Kwan-Tat Mok and Siew-Chong Tan, 2015. Nonlinear Dynamic Power Tracking of Low-Power Wind Energy Conversion System. IEEE Transactions on Power Electronics, pp: 5223-5236.
2. Roger Gules, Walter Meneghette dos Santos, Flavio Aparecido dos Reis, Eduardo Felix Ribeiro Romaneli and Alceu André Badin,2013. A Modified SEPIC converter with high static gain for renewable applications. IEEE Transactions on Power Electronics, pp: 5860-5871.
3. Ahmad El Khateb, Nasrudin Abd Rahim, Jeyraj Selvaraj and Mohammad Nasir Uddin. 2014. Fuzzy-Logic-Controller-Based SEPIC Converter for Maximum Power Point Tracking. IEEE Transactions on Industrial Applications, pp: 2349-2358.
4. Zakariya M. Dalala, Zaka Ullah Zahid, Wensong Yu, Younghoon Cho and Jih-Sheng (Jason) Lai, 2013. Design and Analysis of an MPPT Technique for Small-Scale Wind Energy Conversion Systems. IEEE Transactions on Energy Conversions Electronics, pp: 0885-8969.
5. Vivek Agarwal, Rakesh K. Aggarwal, Pravin Patidar and Chetan Patki, 2010. A Novel Scheme for Rapid Tracking of Maximum Power Point in Wind Energy Generation Systems.IEEE transactions on Energy Conversion, pp: 228-236.
6. Ebrahim Babaei and Mir Esmaeel Seye Mahmoodieh, 2014. Calculation of Output Voltage Ripple and Design Considerations of SEPIC Converter.IEEE transaction on Industrial Electronics, pp: 1213-1222.
7. Bhende, C.N., S. Mishra and Siva Ganesh Malla, 2011. Permanent Magnet Synchronous Generator-Based Standalone Wind Energy Supply System.IEEE Transactions on Sustainable Energy, pp: 361-372.
8. Krishnakumari, V. and Suji Muhammed, 2014. Performance Analysis of a PMSG Based Wind Energy Conversion System. International Journal of Engineering Research & Technology, pp: 2278-0181.
9. Kazmi, S.M.R., H. Goto, G. Hai-Jiao and O. Ichinokura, 2011. A novel algorithm for fast and efficient speed-sensorless maximum power point tracking in wind energy conversion systems. IEEE Transactions on Industrial Electronics, pp: 29-36.
10. Abdullah., M.A., *et al*, 2012. A review of maximum power point tracking algorithms for wind energy systems. Renewable and sustainable Energy Reviews, pp: 3220-3227.