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Multi Input SEPIC Converter based Grid Connected Hybrid Energy System

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Abstract : Renewable energy sources plays a vital role for sustainable energy resources. These renewable energy resources should provide constant power to the load according to the load requirement. This paper proposes a renewable hybrid solar and fuel cell energy system fed single phase three level inverter. The hybrid energy system is the combination of group of fuel cells and solar panels. The green energy is generated from the photovoltaic panel and the chemical energy is converted into electrical energy by fuel cells. The generated voltages are filtered and boosted by Single Ended Primary Inductor converter. The SEPIC converter provides constant DC voltage to the single phase three level inverter. The fuzzy logic control based maximum power point tracking algorithm is used to extract the maximum power from the hybrid energy system. The PI controller makes the inverter output voltage equal to the grid voltage. The results are verified through MATLAB/SIMULINK.
Keywords : SEPIC converter, Inverter, Solar panel, Fuel cell, THD.

1. INTRODUCTION

The renewable energy resources are naturally available and environmentally pollution less sources. A hybrid energy system is the combination of two or more very good naturally optional renewable energy sources. These hybrid energy resources are becoming easily available in remote areas. In hybrid distribution generation systems individual converters are used for each source.SEPIC converter is used for Maximum power point tracking (MPPT) from PV panel and boost converter from PMSG in [1]. Instead of having separate converters for each source combined DC-DC converter is used in [11].The combined multi input converter stage allows maximum power point tracking from the wind and sun when it is available in [3].In [19,20], CUK-SEPIC converter will filter out high frequency harmonics and perturb and observe algorithm for MPPT. High efficiency buck type DC-DC converter and a microcontroller based control unit running the MPPT, give high reliability, lower complexity, less mechanical stress of the WG in [6, 10, 16]. To reduce harmonics LCL filter is provided at the front end rectifier in [13,21].Without using additional filters, to reduce high frequency harmonics in the wind/solar hybrid system TCSC and SEPIC converter is used in [18].Moreover, fuzzy logic controller can control the duty cycle of the converter switch, so that maximum power is extracted from solar array [17].Fuzzy logic based effective energy management controller controls hybrid power system to have an uninterrupted power ,minimizing usage of diesel, effective utilization of sources to improve life time of battery in [2,9]. For minimizing the usage of diesel generator fuzzy logic controller is adapted which gives an uninterrupted power with pollution free green energy system in [15]. To obtain minimum value of maximum output voltage ripple (MOVR), minimum value of equivalent inductance and capacitance calculated in [6].To share the power effectively to meet the load demand fuel cell is added with solar photovoltaic array [4,7,14]. The voltage THD is reduced to 3.5% for solar mini grid AC power system [12].

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In this paper the photovoltaic system and fuel cells are combined to form the hybrid energy system. The solar energy is present throughout the day but radiation levels will vary due to intensity, clouds and trees. The fuel cells provide constant power throughout the time from the various chemicals. The combined power sources makes the system efficiency too high.

When the sources are unavailable or very less when meeting the load demands it requires another power source. In this paper the SEPIC converter makes the constant power to the inverter. This Single ended primary inductor converter is the DC-DC converter which works as the second order filter that reduces the ripples from the hybrid energy sources and also the boost inductances will store the energy. This second order filter makes the double frequency suppression in the DC source. The boost converter can able to do these function but in this boost converter the boost ratio is less, at the same time the energy stored in the inductance is very less compared to the SEPIC converter.

The load requires AC voltage so the next step is to convert DC voltage into AC voltage. In these three level inverter, the total harmonics distortion level in the voltage and currents are high. The PI controller and LC filter makes the three level voltage into sinusoidal output voltage, this voltage is connected to the grid. This PI controller compensates the reactive power and provides sufficient active power to the grid. For this it is very important to use MPPT algorithm in SEPIC converter.

As compared to previous MPPT algorithm like perturb & observe algorithm, incremental conductance algorithm, hill climbing algorithm the proposed fuzzy logic algorithm extracts maximum power from the hybrid energy system.

2. SEPIC CONVERTER

Single-ended primary-inductor converter (SEPIC) is a type of chopper that has two inductors L_1 & L_2, Capacitors C_1 & C_2 and diode D which will protect the source from back emf. Similar to the buck boost converter it also has both buck and boost operation. The series inductor L_1 will provides continuous input current, when the duty cycle is less than 0.5, it will works in discontinuous mode that means buck mode so that the output voltage is less than input voltage. When the duty cycle is greater than 0.5, it is in continuous mode that means boost mode. So that output voltage is greater than input voltage. The PWM pulse control the output of the SEPIC converter. In this SEPIC converter the output voltage is non inverted so that it overcomes the drawbacks of buck boost and cuk converter. The input power factor becomes unity due to this continuous input current. The SEPIC converter have internal protection that has provided by the diode D, so it does not require any snubber protection.

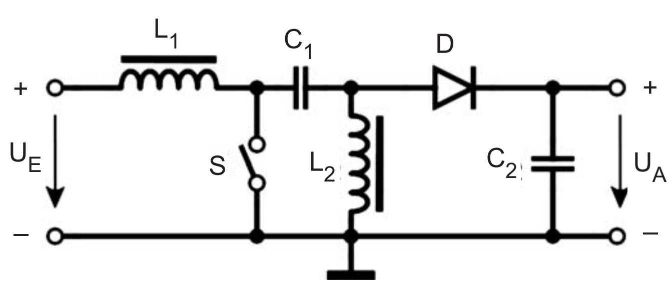

Figure 1: Single Ended Primary Inductor Converter

3. HYBRID SYSTEM OPERATION

The block diagram shows the solar and fuel cell based hybrid energy system with SEPIC converter. The output from the solar panel is directly connected to the SEPIC converter, fuel cell output are also connected in parallel with the source from the solar energy. That means hybrid energy sources may be connected in series or parallel. This multi input voltage is connected to the SEPIC converter, it will work as a second order filter and reduce the ripple contents. The main advantage of the SEPIC converter is for double frequency suppression effect in the DC voltage.

Here the energy sources may provide supply to the SEPIC converter using both sources or individually. The fuel cell energy is connected to the SEPIC converter through diode, this will protect the fuel cell from the return current of the SEPIC converter. The inductor and capacitor in the SEPIC converter will store the energy and this converter provide the continuous input current to the grid, so that reactive power has reduced. This variable boosted DC output voltage is given to the three level inverter. The reference voltage and currents are generated from the fuzzy logic algorithm and by MPPT PWM pulses has produced. This pulses width has been automatically adjusted by fuzzy logic control technique.

Fuzzy logic based maximum power point tracking method extracts the maximum power from the hybrid energy sources, it will provide constant voltage to the inverter. The switching frequency of the carrier signal that has used in the PWM technique is 10 KHz. The three level inverter has four devices S_1, S_2, S_3, and S_4. The switches S_1 & S_2 are turned ON for positive cycle, S3 & S4 are turned ON for negative cycle. The mode of operation is 180 degree conduction mode. To avoid the short circuit problems four micro seconds dead band has provided in the PWM pulses. The grid voltages and currents are taken to calculate the real and reactive power. From this reactive power the comparator compares the actual and the reference grid voltages and current. This error signal has fed to the PI controller, the controller produce the reference sinusoidal signal that is compared with the carrier signal which has 10KHz switching frequency. These PWM pulses are fed to the three level voltage source inverter. This inverter will give AC output voltage to the grid.

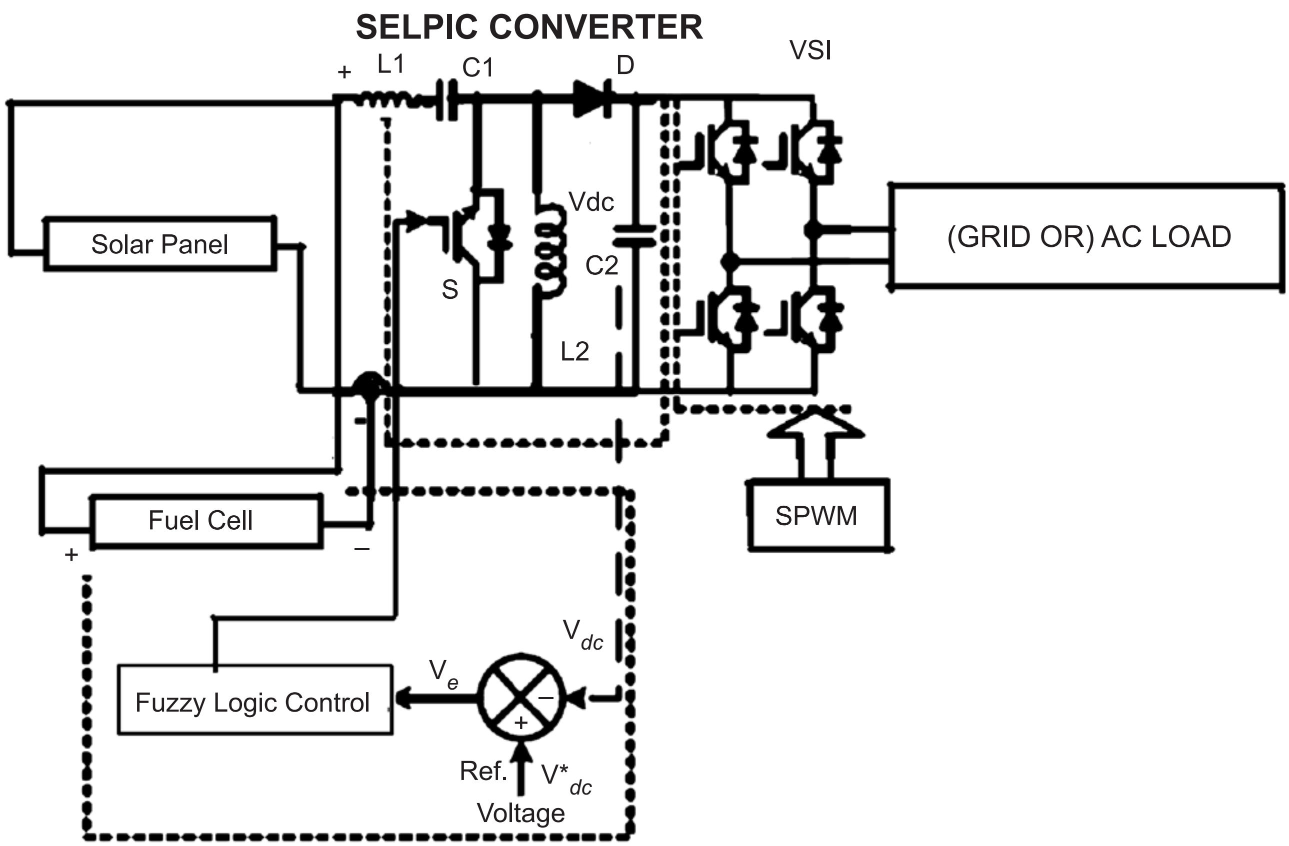

Figure 2: Hybrid energy system circuit diagram

The PI controller makes reactive power compensation, so that the power quality issues like sag, swell and harmonics problem has reduced at point of common connection in the grid.

3.1. When low output voltage

The output voltage of the SEPIC converter can be lower than the input voltage. In this mode the duty cycle is less than 0.5 that means the converter is in discontinuous mode. Slowly the inductor current L_1 comes to zero. The capacitor voltage C_1 is lower than input voltage Vg.

In this mode the current through the inductor L_1 is

$$\Delta IL1 = \frac{V0}{V1}(0.5 - D)T \tag{1}$$

Where k is the winding constant.

D is the PWM duty cycle of the SEPIC converter.

T is the total time of the PWM pulse.

$$\frac{d1L1}{dt} = (Vg + kV0)/\,(1 - k^2)L1 \tag{2}$$

$$\frac{d1L2}{dt} = -\,(V0 + kVg)/(1 - k^2)L2 \tag{3}$$

From the above equation the inductor current is decreasing. Therefore the SEPIC converter output voltage will decrease. It is the buck mode.

3.2. Higher output voltage

In this mode the duty cycle is more than 0.5, it is the boost mode. Here the inductor current I_{L1} and I_{L2} is keeps on increasing.

$$\frac{d1L1}{dt} = Vg/\,(1 - k)L1 \tag{4}$$

$$\frac{d1L2}{dt} = Vg/\,(1 - k)L2 \tag{5}$$

The capacitor voltage C_1 is equal to the input DC voltage Vg. The change in inductor current can be expressed as,

$$\Delta IL1 = \frac{V0}{L1}(D - D')T$$

Due to this inductor current the output voltage becomes high.

4. MPPT ALGORITHM

To extract the maximum power from the solar array and fuel cell, and to track the changes due to environment, maximum power point tracking should be implemented. The hill climbing MPPT method involves moving the operating voltage by one step and then examining the change in generated power. If the power increases, the operating point moves in the same direction; otherwise it moves in the opposite direction. The power generated from a given PV module mainly depends on solar irradiance and temperature for a system without MPPT, the voltage will quickly collapse to zero. A system with MPPT avoids the voltage collapse by keeping the operating point near the Maximum Power Point. The advantages of MPPT algorithm are robustness and it is easy to implement.

Fuzzy inference is the process of formulating mapping from a given input to an output using fuzzy logic. The mapping provides a basis, from which decisions can be made or patterns discerned. The process of fuzzy inference involves membership functions, fuzzy logic operators, and if-then rules. Two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox are,

- Mamdani type
- Sugeno type

Mamdani type inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output member ship functions rather than a distributed fuzzy set. This type of output is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the general Mamdani method, which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, we use the weighted average of a few data points. Sugeno-type systems support this type of model. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant.

4.1. Basic Fuzzy Algorithm

In a fuzzy controller as shown in figure 3, the control action is determined from the evaluation of a simple linguist rules. The development of the rules requires a thorough understanding of the process to be controlled but it does not require a mathematical model of the system. A fuzzy controller consists of four stages: fuzzification, knowledge base, inference mechanisms, and defuzzification. The knowledge base is composed of a data base and rule base, and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbance. The data base, consisting of input and output membership functions, provides information for the appropriate fuzzification operations, the inference mechanism, and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert the fuzzy outputs into control signals.

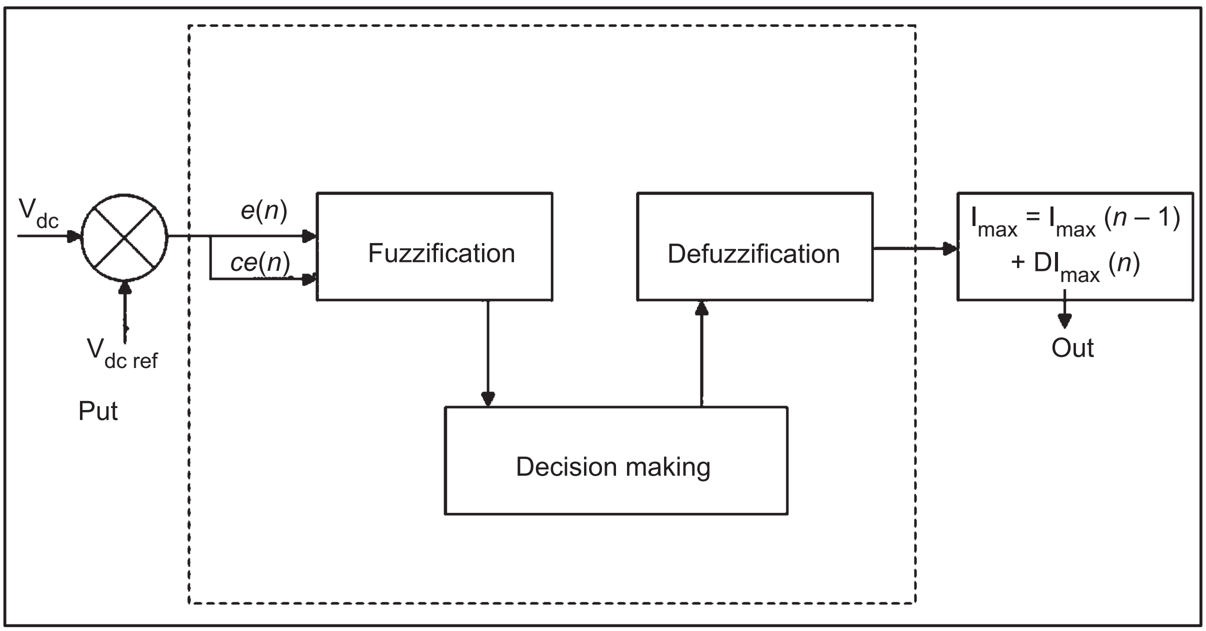

Figure 3: Schematic Diagram of FLC

In order to implement the control algorithm of a SAPF in closed loop, the optimum value of K gain is calculated by a fuzzy inference system, which receives as inputs, the slope of D.C. average bus voltage and D.C. voltage error. Both quantities (error and slope of DC voltage) are normalized by suitable values. Thus, each range is between -1 and 1 normalized unity. Taking into account that the value of K is quite near unity, we consider the range of the output weight membership function between 0.6 and 1.4.We have chosen to characterize this fuzzy controller by seven and five sets respectively for the error and slope inputs. The output is defined by seven sets. The D.C. voltage error and the D.C. voltage slope is normalized. The linguistic rules for the fuzzy logic controller are chosen, in most cases, depending only on the D.C. voltage error. The fuzzy controller is characterized as follows:

The desired switching signals, according to output inverter currents to follow the reference ones, a current control is made by fuzzy logic controller. The inputs variables for the necessary control action of active filter are the error and the rate of change of error between the reference signal and the active filter output current. The current control method used is related to fuzzy controller based PWM current controller. The switching signals are generated by means of comparing a carrier signal with the output of the fuzzy controller. The error and the change of error are used as numerical variables from the real system. To convert these numerical variables into linguist variables, the following seven fuzzy sets are used: NL (Negative Large), NM (Negative Medium), NS (Negative Small), Z (zero), PS (Positive Small), PM (positive medium) and PL (Positive Large).

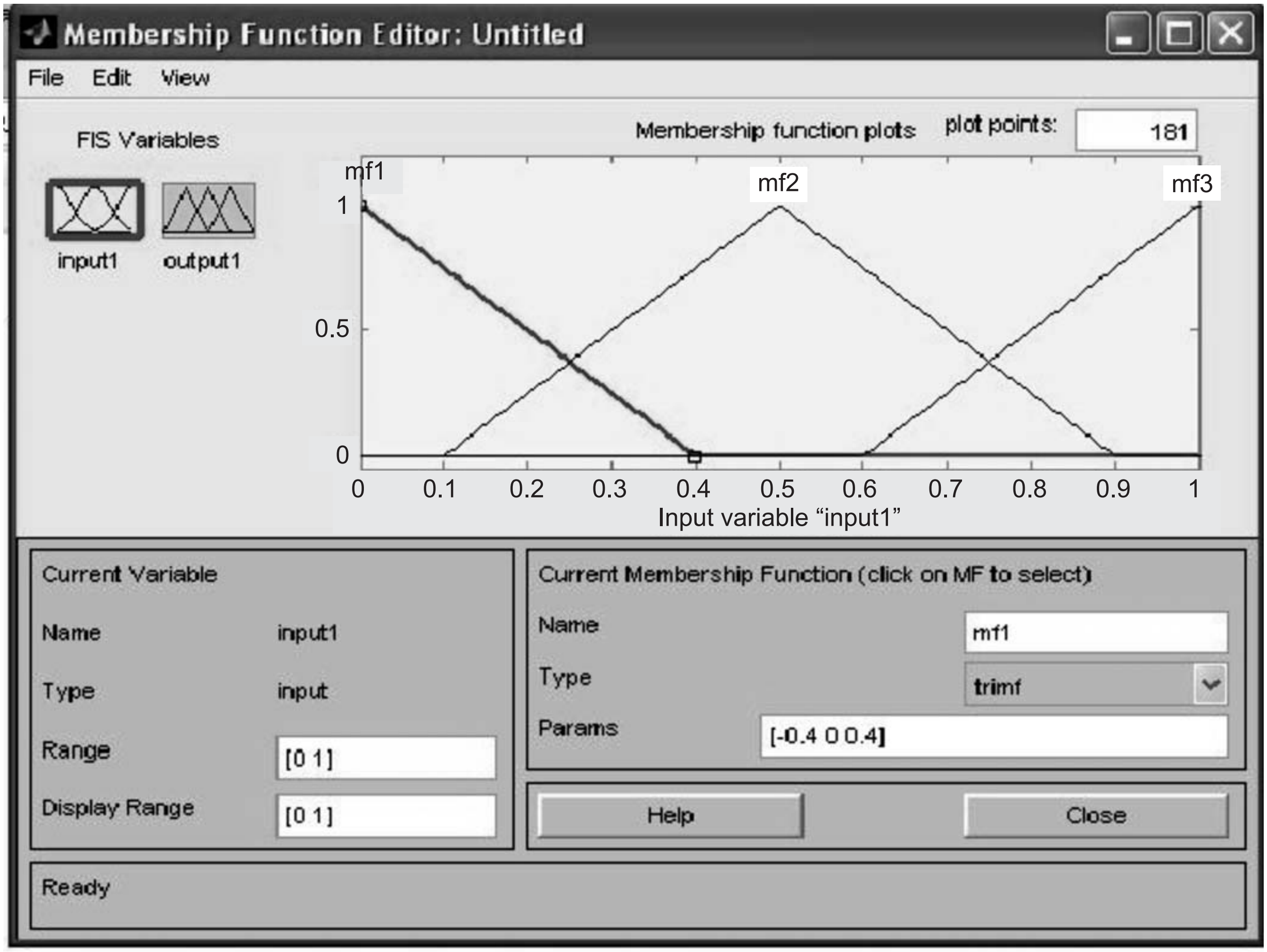

Figure 4: Triangular generation using fuzzy control

- Seven fuzzy sets for each input and output
- Triangular membership functions for simplicity
- Fuzzification using continuous universe of discourse
- Implication using Mamdani type inference system
- Defuzzification using weighted average method

4.2. Design of Control Rules

The fuzzy control rule design involves, rules that relate the input variables to the output model properties as FLC is independent of the system model. The design is mainly based on the intuitive feeling for and experience of the process.

The control rules are formed and the elements are determined based on the theory that, in the transient state, large errors need coarse control, which requires coarse input / output, small errors need fine control, which requires fine input / output variables. Based on this, the elements of the rule table are obtained from an understanding of the filter behavior and modified by the simulation performance.

The three level inverter will convert the DC voltage into AC voltage by sinusoidal PWM technique with four micro second dead band. The carrier signal frequency is 10 KHz. The PI controller makes the inverter output voltage as same as the grid voltage. Due to this the reactive power has compensated in the grid. The SEPIC converter maximum duty cycle is 80%.

5. SIMULATION RESULTS

To verify the feasibility of the proposed strategy, simulations are carried out.

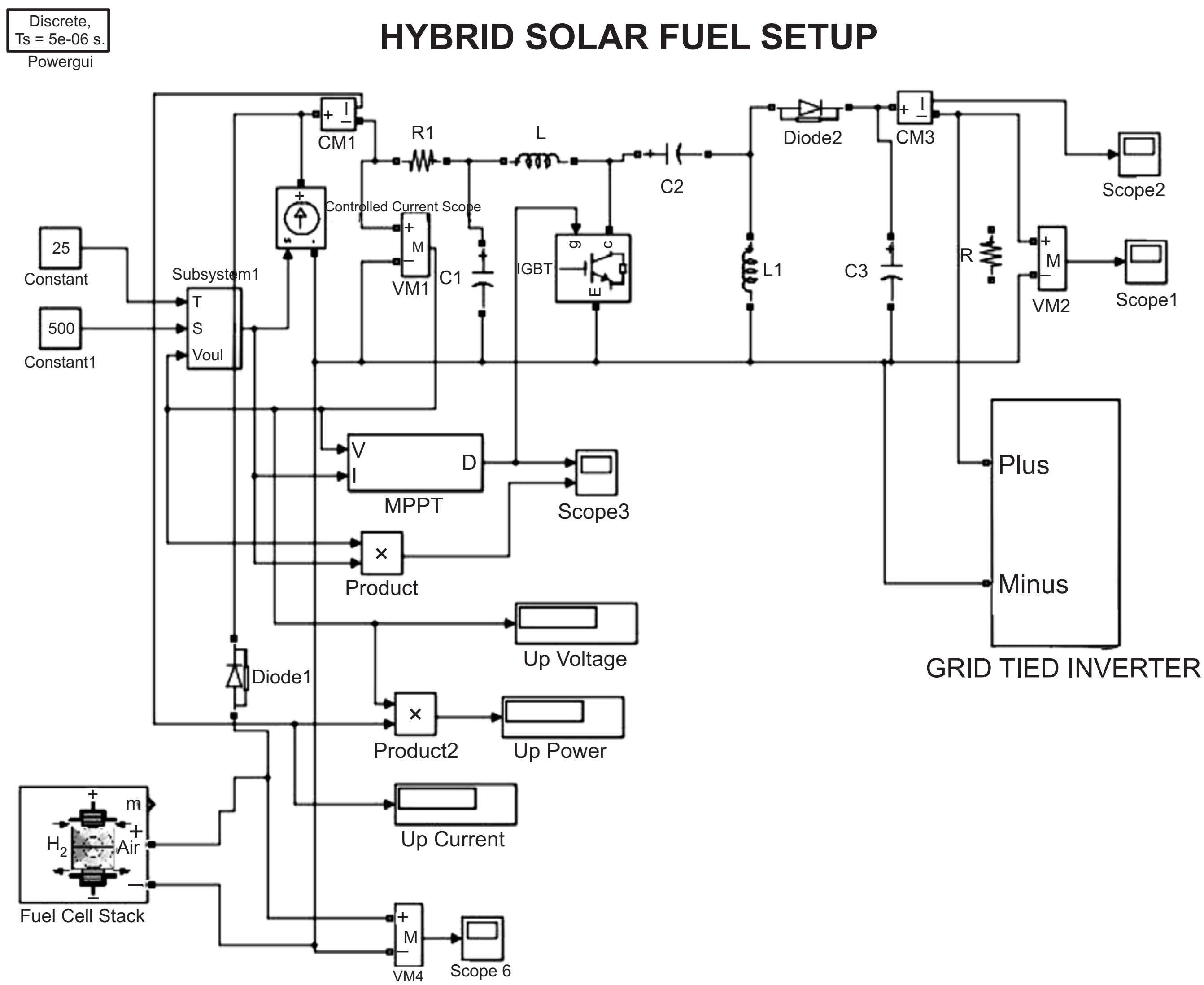

Figure 5: Hybrid energy system Simulink diagram

The figure 5 shows the Matlab Simulink diagram including hybrid sources with SEPIC converter and inverter.

From the solar and fuel cells the input voltage is75V, it is given to the DC to DC converter.

The figure 7 shows the PWM pulse to the SEPIC converter with duty cycle 75%. The fuzzy logic algorithm maintains the width of the pulses.

The figure 8 shows the output voltage of the converter, with 75 volt input.

The figure 10 shows the grid output voltage from the voltage source inverter. The PI controller compensate the reactive power.

The figure 11 shows the THD value, the SEPIC converter will reduce THD by providing constant voltage to the inverter which is 2.95%.

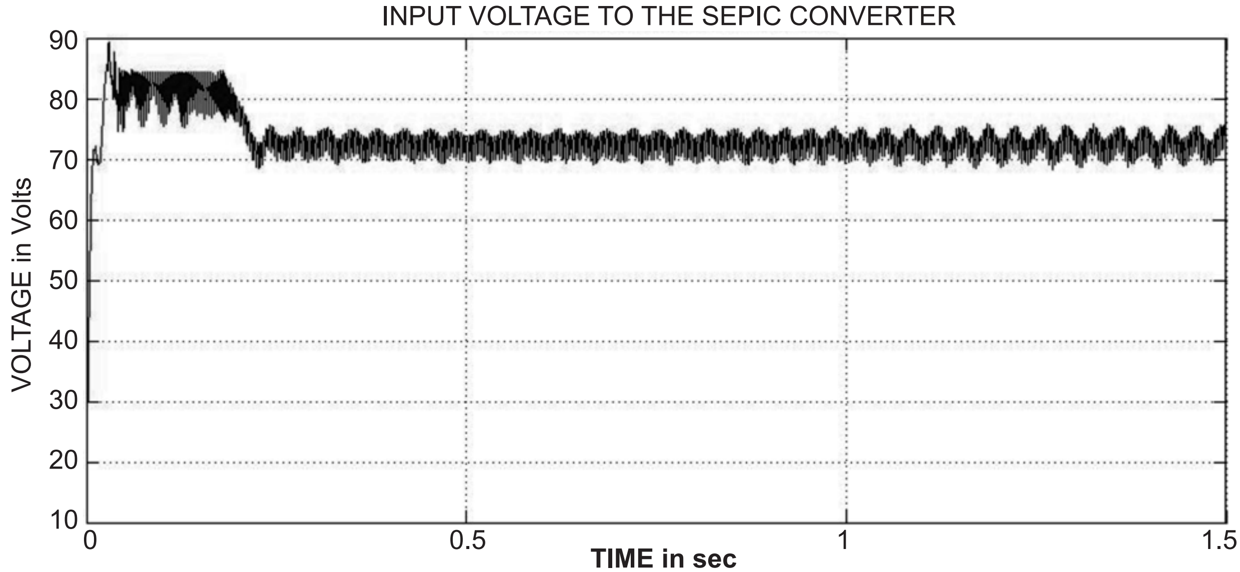

Figure 6: Input voltage to the SEPIC converter

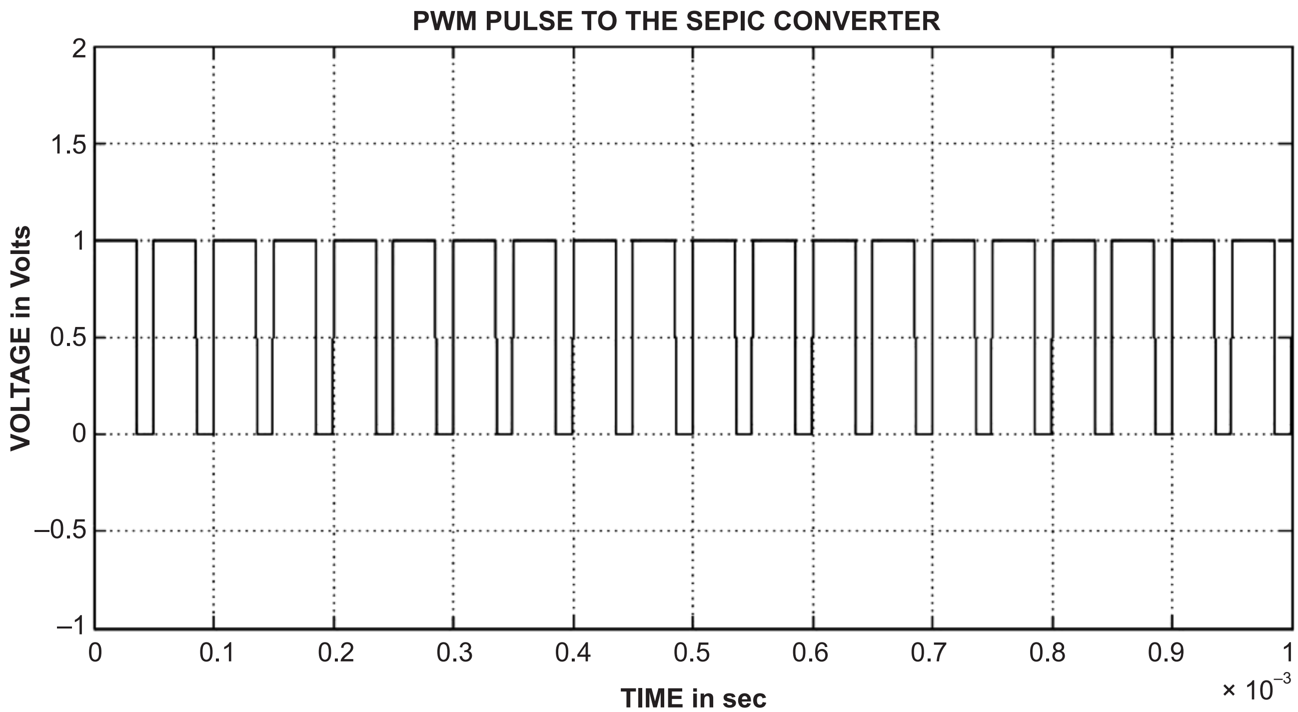

Figure 7: Gate pulse to SEPIC converter

6. CONCLUSIONS

In this paper, a hybrid renewable system based on solar and fuel cell energy system with SEPIC converter fed single phase three level inverter has been implemented. The generated voltages are filtered and boosted by Single Ended Primary Inductor converter. The SEPIC converter provides constant DC voltage to the single phase three level inverter. The fuzzy logic control based maximum power point tracking algorithm has been used to extract the maximum power from the hybrid energy system. The PI controller makes the inverter output voltage equal to the grid voltage. This system has lower operating cost and finds applications in remote area power generation, constant speed and variable speed energy conversion systems and rural electrification. MATLAB/ SIMULINK software is used to model the PV panel, fuel cell, DC-DC converters and the proposed hybrid system. The inverter output voltage THD is 2.95%.

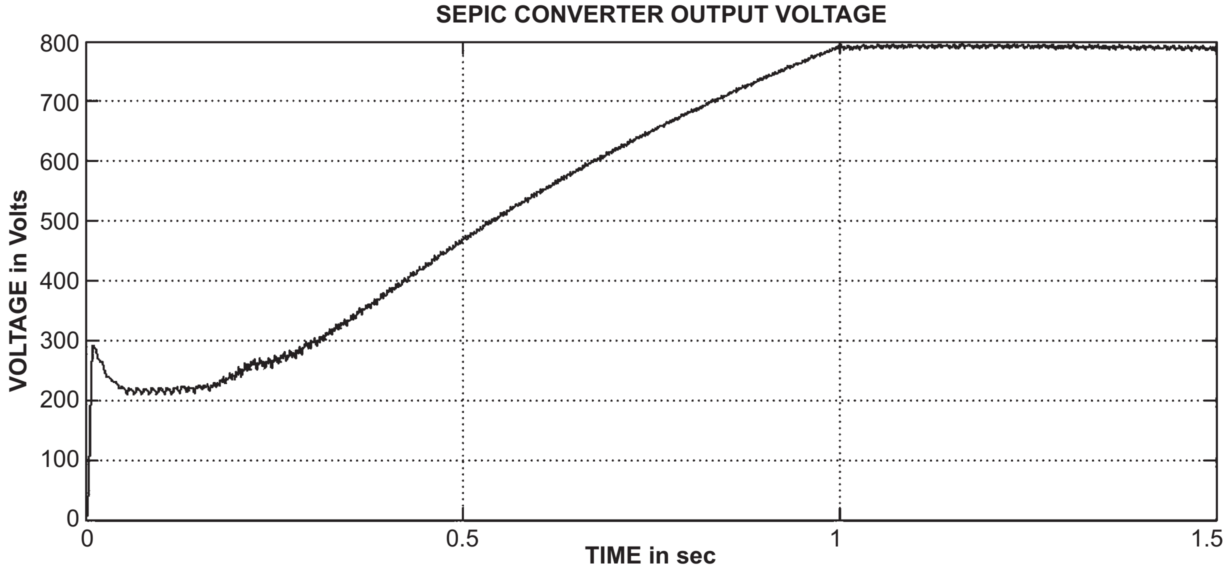

Figure 8: Output voltage of the SEPIC converter

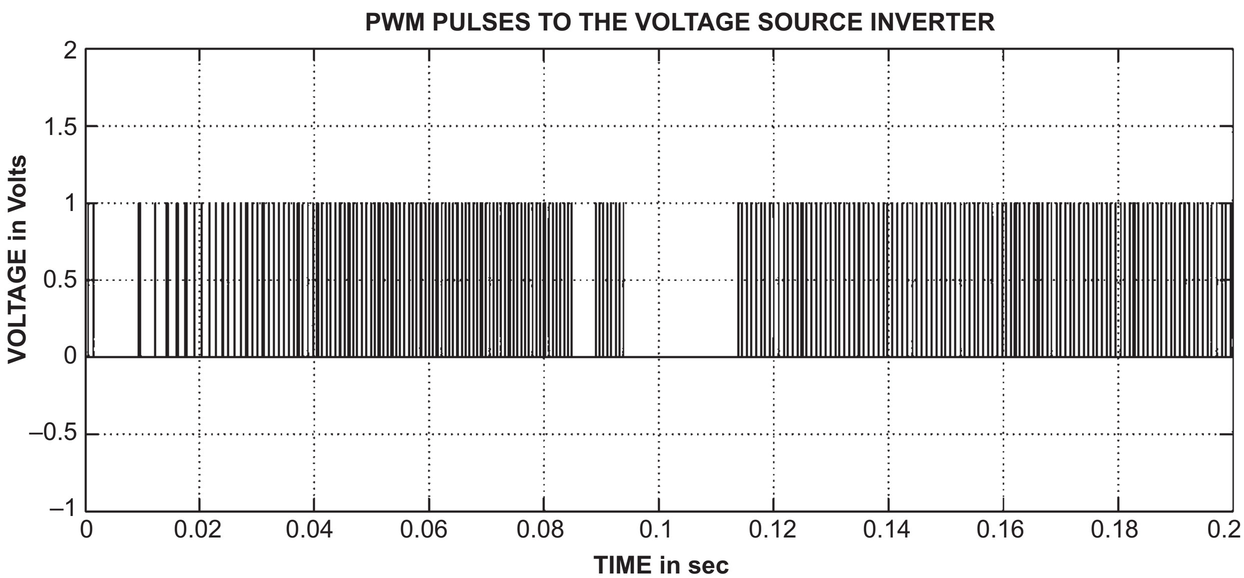

Figure 9: Gate pulse to VSI

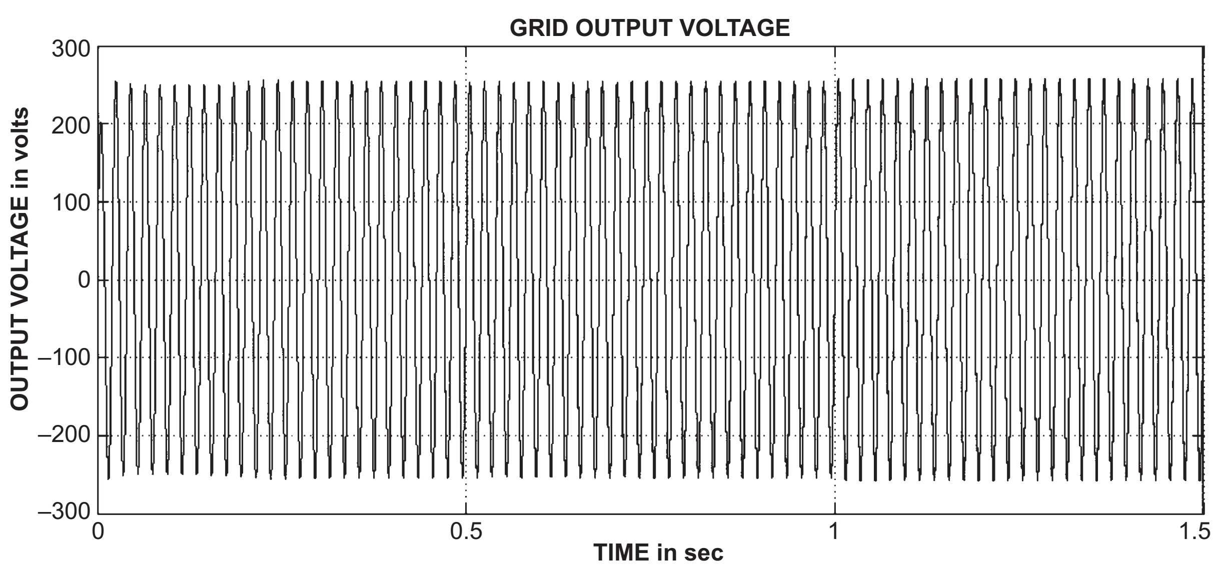

Figure 10: Inverter output voltage

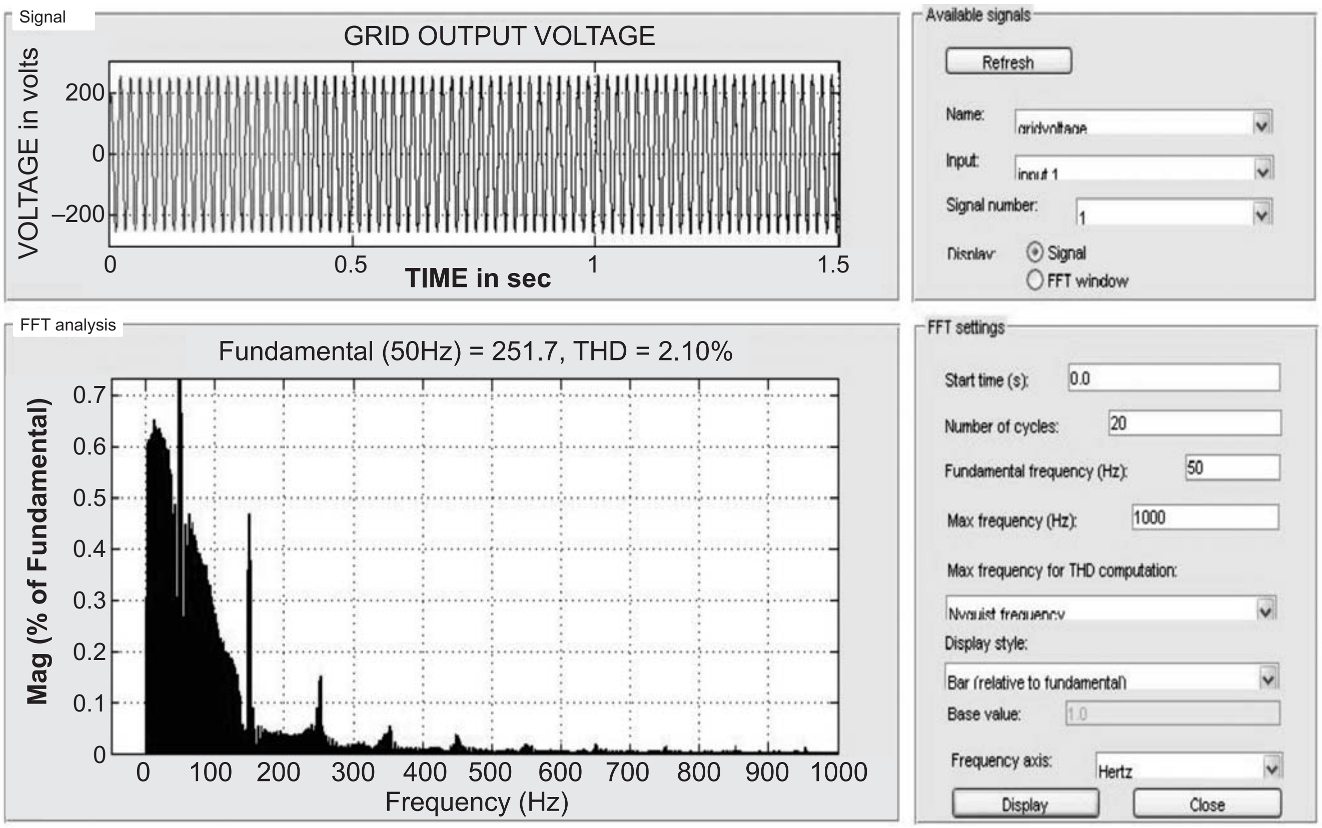

Figure 11: Inverter output voltage THD result

7. REFERENCES

1. Albrez Mondal, 'A dSPACE –based control of a hybrid renewable energy system with wind and photovoltaic power', Fourth International symposium on power electronics for distribution generation system, (2013) pp.1-7.
2. A.Shezan, Noman Khan, T.Anowar, 'Fuzzy logic implementation with MATLAB for solar-Wind-Battery –Diesel Hybrid Energy System ', Imperial Journal of Interdisciplinary Research, (2016), Vol.2, No.5, pp.574-583.
3. B.Dhivya, S.Dhamodran, 'Hybrid renewable energy system using CUK-SEPIC converters', International Journal of Electrical, Electronics and Data communication', (2014). Vol.2.
4. Cherry Lodha,Ved Shukla, 'Power Management of a Stand –Alone Photovoltaic /Fuel cell Hybrid Energy System ',International Journal of Scientific Research Engineering and Technology , (2016) Vol.5,No.4,pp.222-228.
5. C. Hua and C. Shen, "Study of maximum power tracking techniques and control of DC/DC converters for photovoltaic power system," Power Electronics Specialists Conference, vol. 1, 17-22 May 1998, pp. 541 – 548.
6. Ebrahim Babaei, Esmaeel Syed Mahmoodieh, 'Calculation of output voltage Ripple and design considerations of SEPIC converters', IEEE transactions on Industrial Electronics (2014), Vol.61, No.3, pp. 1213-1222.
7. J. J. Baschuck and X. Li, "Modeling of Polymer Electrolyte Membrane Fuel Cells With Variable Degrees of Water Flooding," Journal of Power Sources 86, 2000, pp.181- 196.
8. John A. Duffie, William A. Beckman, Solar Engineering of Thermal Processes, 2nd ed., New York: Wiley, 1991.
9. Liu Baoding, Zhao Ruiqing, Monte Carlo Programming andFussy Programming, Beijing: Tsinghua University Press, 2001.
10. K .Koutroulis, K .Kazantzakis, 'Multi input inverter for grid connected Hybrid PV/Wind power system', IEEE transactions on Power Electronics (2015), Vol.22, No.2, pp. 486-494.
11. M.Dharani,K.Rajalakshmi, Dr.S.U.Prabha ,K.Indu Rani , 'Integration of CUK and SEPIC converters for Renewable Energy systems',South Asian Journal of Engineering and Technology , (2016) Vol. 2,No16 ,pp.1-6.
12. Muhammad Riazul Hamud, M.D.Jakaria Rahim, Asma Jahan Huque, 'Study of harmonic contents of applicances in various combinations and their appropriateness for use in solar mini grid ac power systems', American Journal of Engineering Research, (2016),Vol.5,No.1,pp.105-110.

13. M.Liserre.F.Blaabjerq, Hansen, 'Design and control of an LCL filter based three phase active rectifier ', IEEE transactions on Industry Applications, Vol.41.No.5, pp.1281-1291.

14. N.S.Jayalakshmi,D.N.Gaonakar,Pramod Bhat Nempu, 'Power Control of PV/Fuel cell/Super capacitor Hybrid System for Stand-Alone Applications ', International Journal of Renewable energy Research(2016) ,Vol.6,No.2.

15. Pooja Patel, Dr.Jyothi Srivastava, (2016) 'Modelling &Performance Analysis of Hybrid Renewable energy Resources using Fuzzy logic controller', International Journal of science, Engineering and Technology research, Vol.5, No.5, pp1421-1428.

16. R. Esmaili, L. Xu and D. K. Nichols, "A New Control Method of Permanent Magnet Generator for Maximum Power Tracking in Wind Turbine Application," to be presented at Power Engineering Society General Meeting,June 2005.

17. S.Balaganesh, R.Perumal, T.S.Anusha, 'A study of SEPIC converter based Fuzzy logic controller for Hybrid system ', International Journal of Research in Science and Technology (2014), Vol.2, No.1.

18. S.Uma ,P.Balamurgan,'Power quality improvement in Wind/PV Hybrid system by using converters', International Journal of Multidisciplinary Research and Modern Education,(2016) ,Vol.2,No.1,pp..361-366.

19. W. Cui, H. Luo, Y. Gu, W. Li, B. Yang and X. He, "Hybrid-bridge transformer less photovoltaic grid-connected inverter," IET Elect. Power Elect. vol.8, no.3, pp.439-446, 2015.

20. Yaow-Ming Chen, 'Multi-input Inverters for grid connected Hybrid PV/Wind power system ', IEEE transactions on Power Electronics (2016), Vol.22, No.3, pp. 1070-1077

21. Z. Yang, H. Li, F. Lin, B. Zhang and J. Lu, "Common-mode Electromagnetic Interference Calculation Method for a PV Inverter with Chaotic SPWM," (accepted for publication in IEEE Trans. Magne.).