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Fuzzy Controller Design using Soft Switching Boost Converter for MPPT in Hybrid System

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Abstract— ***In this paper, a fuzzy logic control (FLC) is Proposed to control the maximum power point tracking (MPPT) for a photovoltaic (PV) system and to control the maximum power point for a wind turbine (WT) system. Hybrid integrated topology, fed by photovoltaic (PV) and wind turbine (WT) sources and suitable for distributed generation applications, is proposed. It works as an uninterruptible power source that is able to feed a certain minimum amount of power into the grid under all conditions. PV is used as the primary source of power operating near maximum power point (MPP), with the WT section (block), acting as a current source, feeding only the deficit power. The unique "integrated" approach obviates the need for dedicated communication between the two sources for coordination and eliminates the use of a separate, conventional dc/dc boost converter stage required for PV power processing. The conventional boost converter decreases the efficiency because of hard switching, which generates losses when the switches are turned on/off. During this interval, all switches in the adopted circuit perform zero-current switching by the resonant inductor at turn-on, and zero-voltage switching by the resonant capacitor at turn-off. This switching pattern can reduce the switching losses, voltage and current stress of the switching device. The Hybrid systems have been simulated in MATLAB Simulink software and their Control Schemes have been analyzed and validated.***

Index Terms— ***Photovoltaic (PV) systems, Wind Turbine (WT), Fuzzy Logic Controller, Boost Converter, single phase inverter, Triggering Pulses, Perturb and Observe (P&O).***

I. INTRODUCTION

Because of the demand for electric energy and environmental issues such as pollution and the effects of global warming, renewable energy sources is considered as an option for generating clean energy technologies. Hybrid PV/Wind generation systems is becoming increasingly important as a renewable source since it offers many advantages such as incurring no fuel costs, not being polluting, requiring little maintenance, and emitting no noise, among others. PV modules still have relatively low conversion efficiency; therefore, controlling maximum power point tracking (MPPT)

For the solar array is essential in a PV system. Wind energy has the biggest share in the renewable energy sector.

Generally, MPPT is adopted to track the maximum power point in the PV system. The efficiency of MPPT depends on both the MPPT control algorithm and the MPPT circuit. The MPPT control algorithm is usually applied in the DC-DC converter, which is normally used as the MPPT circuit. Typical diagram of the connection of MPP in a Hybrid system is shown in Fig: 1. One of the most popular algorithms of MPPT is P&O (Perturb and Observe) technique; however, the convergence problem and oscillation are occurred at certain points during the tracking. To enhance the performance of the P&O algorithm, this paper presents the application of Fuzzy Logic Control (FLC) to the MPPT control in PV systems and MPP control in wind turbine.

The PV array has a particular operating point that can supply the maximum power to the load which is generally called maximum power point (MPP). The maximum power point has a non-linear locus where it varies according to the solar irradiance and the cell temperature [2]. To boost the efficiency of PV system, the MPP has to be tracked followed by regulating the PV panel to operate at MPP operating voltage point, thus optimizing the production of electricity. This process can draw as much power as possible that the PV panel can produce. There are several methods that have been widely implemented to track the MPP. The most widely used methods are Perturb and Observe (P&O), incremental conductance and three-point weight comparison. In this paper, P&O MPPT is investigated. P&O technique apply perturbation to the buck-boost DC-DC controller by increasing or decreasing the pulse width modulator (PWM) duty cycle, subsequently observes the effect on the PV output power [3]. If the power at present state is larger than previous state, the controller's duty cycle shall be increased or vice-versa until the MPP operating voltage point is identified. Problem that arises in P&O MPPT method is that the operating voltage in PV panel always fluctuating due to the needs of continuous tracking for the next perturbation cycle.

In this paper, fuzzy logic is proposed to be implemented in MPPT. Fuzzy is robust and relatively simple to design since fuzzy do not require information about the exact model [4]. The PV power at the present state will be compared with the PV power at the previous state and the change of power will be one of the inputs of fuzzy. Another input is the change of power with respect to change of voltage. Based on these two inputs, fuzzy can determine the size of perturbed voltage. Therefore, fuzzy based MPPT can track the maximum power point faster from the Hybrid Systems. Recently, fuzzy logic has been applied for tracking the MPP of Hybrid systems in [5] because it has the advantages of being robust, design simplicity, and minimal requirement for accurate mathematical model. It is found that fuzzy logic based P&O and hill climbing MPPT methods perform better due to optimized perturbation.

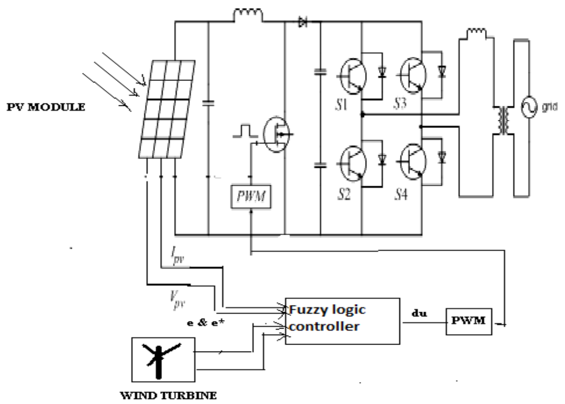

Fig: 1 Typical diagram of MPP in a Hybrid Systems

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The paper is organized as follows. The PV Systems design is discussed in Section II. Designs of wind turbine are discussed in Section III. Designs of Fuzzy Logic Controller are discussed in Section IV. Section V discusses the overall Buck-Boost converter and inverter Design. Section VI gives the Simulation Results. Section VII Concludes the Paper.

II. PV SYSTEM DESIGN

A. MPPT Control Method

Many methods for tracking maximum power point had been proposed [1]. Two algorithms often used to achieve the MPPT are: The perturbation & observation (P&O) method, incremental conductance (IncCond) method. On the other hand fuzzy logic has received attention of number of researchers in the area of power electronics. The fuzzy logic control is somewhat easy to implement because it does not need the mathematical model of a system.

The Perturbation and Observation Method (P&O) has a simple feedback structure and fewer measured parameters. It operates by periodically perturbing (incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of previous perturbation cycle. If the perturbation leads to an increase (decrease) in array power, the subsequent perturbation is made in the same (opposite) direction. In this manner, the peak power tracker continuously seeks the peak power condition.

Fig: 2 shows the representation of the typical flow chart for P&O algorithm and Fig: 3 shows the representation of the typical power-voltage characteristic of photo voltaic array.

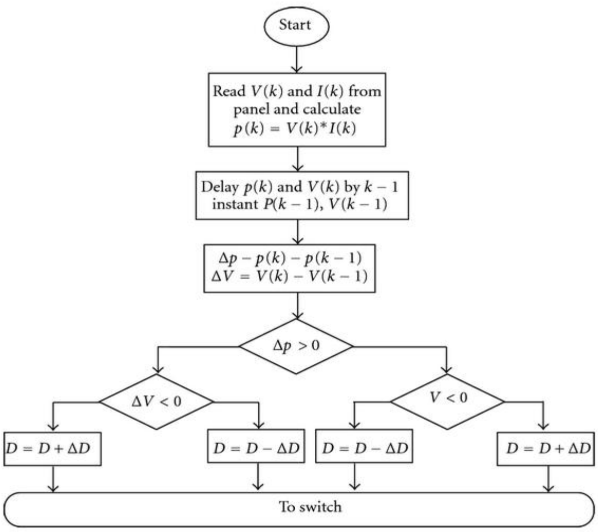

Fig: 2 Typical Flow chart for P&O MPPT

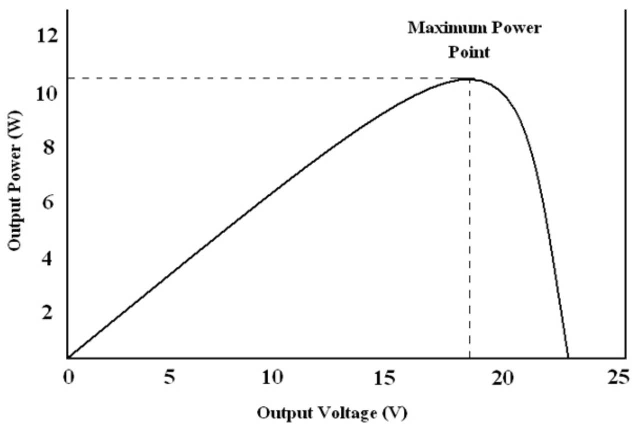

Fig: 3 Typical power-voltage characteristic of photovoltaic array

B. Mathematical solar array modeling

The general model of solar cell can be derived from physical characteristic called one diode model. The PV panel Buck-boost DC-DC converter Load Fuzzy based MPPT control unit V I PWM equivalent circuit of solar cell is shown as Fig: 4.The Shockley diode equation which describes the I-V characteristic of diode D is shown in equation 1

$$I_{DM} = I_0 \left[\exp\left(V_{DM}/\eta V_T\right) - 1\right] \quad (1)$$

Where I_D is the diode current, I_O is the reverse bias saturation current, V_D is the voltage across the diode, η is ideality factor of the diode and V_T is the thermal voltage. Thermal voltage V_T however can be defined as in equation (2).

$$V_T = KT / q \quad (2)$$

Where K is Boltzmann constant (1.3806503×10^{-23} J/K), is T temperature in degrees Kelvin and q is electron charge (1.60217646×10^{-19} C). To model the I-V characteristic of PV array, equation (3) has been derived based on the Equivalent circuit in Fig. 4,

$$I = I_{PV} - I_0 \exp\left[\left(V_{PV} + I R_S/\eta V_T\right) - 1\right] - V_{PV} + I R_S/R_P \quad (3)$$

Where I is the current at terminals of PV array, I_{PV} is the PV array current, V_{PV} is the PV array terminal voltage, R_s is the equivalent series resistance of the array and R_P is the equivalent parallel resistance. Unlike the electrical generators which are generally classified as either current source or voltage source, the PV device presents hybrid behaviour. PV panel acts as a current source when PV panel operates at voltage smaller than MPP voltage point but it acts as voltage source when it operates at voltage larger than MPP voltage point [6]. The series resistance R_s has strong influence when PV panel acts as voltage source whereas the parallel resistance R_P has great influence when the PV panel acts as current source. R_s is the sum of structural resistance of PV panel however R_P exists due to leakage current of p-n junction depending on the fabrication method of the PV cells. Generally, R_P is very high and R_s is very low. High resistance R_P blocks the PV panel from short-circuited and low resistance of R_s allows the current flow to the load without resistance. Hence, these parameters can be neglected [8].

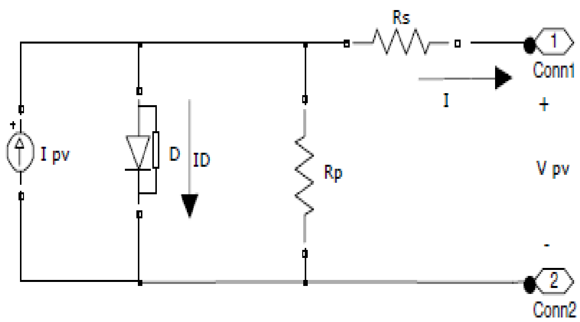

Fig.4 Equivalent circuit of PV Module

C. Effect of irradiation and temperature

PV is not a constant DC energy source but has variation of output power, which depends strongly on the current drawn by the load. Besides, PV characteristic also changes with temperature and irradiation variation [9]. Thus, the output voltage (V) of PV varies with the current (I). Fig: 5 show the characteristic of a 200 W Sanyo PV module [9]. The module can be used as a single system or it can be connected to other

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similar modules to increase the voltage and current. In multi module systems, PV modules are wired in series and parallel to form a PV array. From Fig: 5, it can be seen that the PV module voltage varies from 0 V until the open circuit voltage (Voc) of the module. Similarly, the current varies from 0 A until the short circuit current (Isc) of the module. The Voc and Isc of a PV module also depend on temperature and solar irradiation.

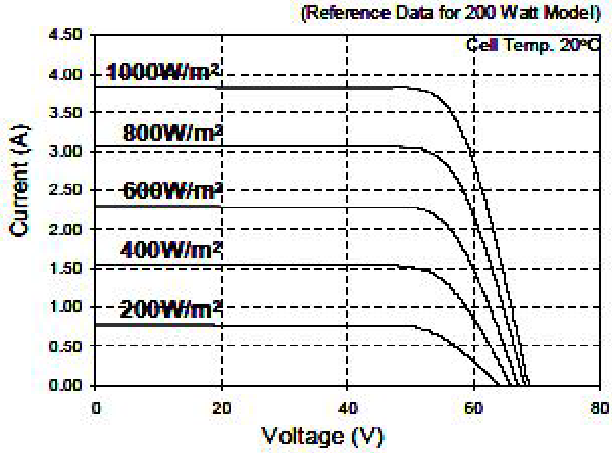

Fig: 5 Effect of Irradiation

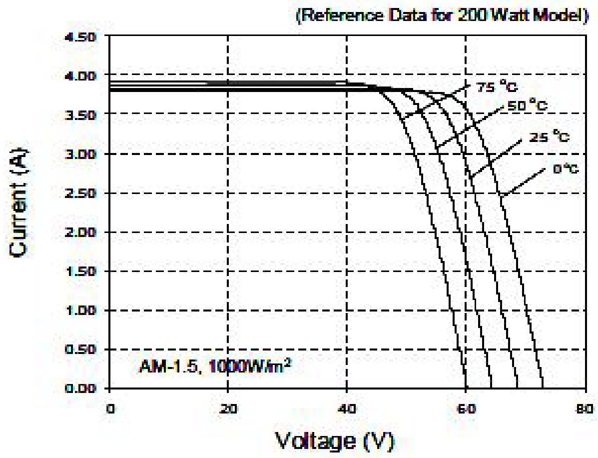

Fig: 6 Effect of Temperature

For any PV system, the output power is increased by tracking the maximum power point (MPP) of the system. To achieve this, a MPPT controller is required to track the optimum power of the PV system and it is usually connected to a boost converter located between the PV panel and load as shown in Fig: 7. Many different control techniques such as the P&O and fuzzy logic are used in the MPPT controller.

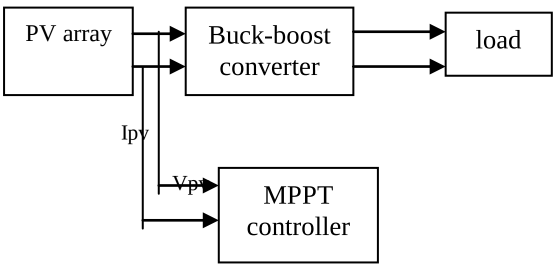

Fig: 7 MPPT Controller in a PV system

III. WIND ENERGY SYSTEM DESIGN

Wind energy has the biggest share in the renewable energy sector [6]. Over the past 20 years, grid connected wind capacity has more than doubled and the cost of power generated from wind energy based systems has reduced to one-sixth of the corresponding value in the early 1980s [7]. The important features associated with a wind energy conversion system are:

- Available wind energy
- Type of wind turbine employed
- Type of electric generator and power electronic circuitry employed for interfacing with the grid

Wind energy – Wind speeds, air pressure, atmospheric temperature, earth surface temperature etc., are highly inter-linked parameters. Due to the inherent complexity, it is unrealistic to expect an exact physics based prediction methodology for wind intensity/sustainability. However, distribution based models have been proposed, and employed to predict the sustainability of wind energy conversion systems [6]. Detailed explanation of the wind energy resources is beyond the scope of this paper. Based on studies it has been reported that the variation of the mean output power from a 20 year period to the next has a standard deviation of less than 0.1 [7]. It can be concluded with reasonable confidence that wind energy is a dependable source of clean energy. Basics of physics of wind energy can be summarized as below. The power that can be extracted from the wind is

$$P_W = \tfrac{1}{2}\pi R^2 \rho V^2 C_P(\lambda) \qquad (4)$$

Where R is the blade length, ρ is the density of air, v is the wind velocity, λ is called the tip speed ratio, C_P and is called the power coefficient [8].

C_P Versus λ characteristics are important indicators of the aerodynamic efficiency of a wind turbine. Based on the aerodynamic blade theory, there is an optimal $\lambda_{(opt)}$ corresponding to $C_{p(opt)}$. The present day variable speed wind turbines follow the $\lambda_{(opt)}$ point to extract the maximum power. This is enabled by variable speed operation and the power electronic module interfacing the turbine and the grid. Based on the aerodynamic principle utilized, wind turbines are classified into drag based and lift based turbines. Based on the mechanical structure, they are classified into horizontal axis and vertical axis wind turbines. With respect to the rotation of the rotor, wind turbines are classified into fixed speed and variable speed turbines.

Fig: 8 shows the representation of the typical diagram for Variable speed wind energy conversion system and Fig.9 shows the representation of the typical diagram for Limited range, variable wind energy conversion system.

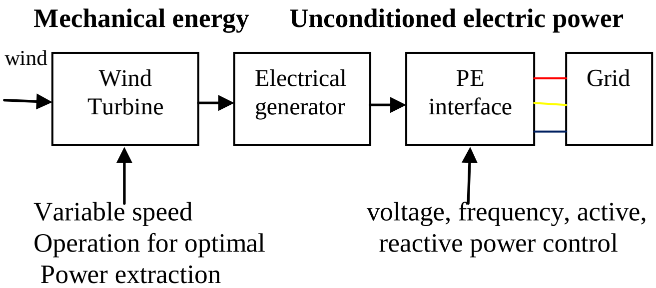

Fig: 8 Variable speed wind energy conversion system.

Presently the focus is on horizontal axis, lift based variable speed wind turbines [6]. Power electronic circuits play a crucial enabling role in variable speed based wind energy conversion systems. Fixed speed wind turbines are simple to operate, reliable and robust. However the speed of the rotor is fixed by the grid frequency. As result, they cannot follow the optimal aerodynamic efficiency point. In case of varying wind speeds, fixed speed wind turbines cannot trace the optimal power extraction point C_{Pmax}. In variable speed wind turbines, power

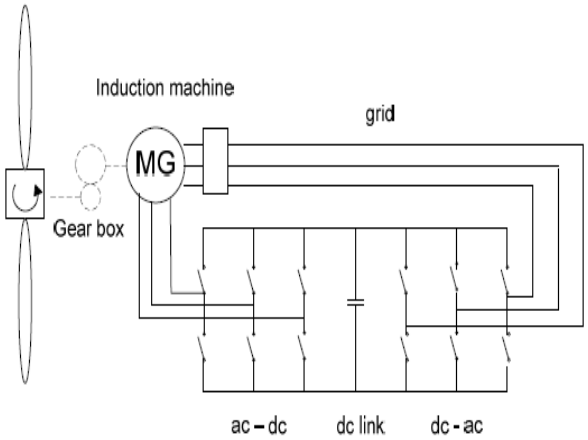

Fig: 9 Limited range, variable wind energy conversion system.

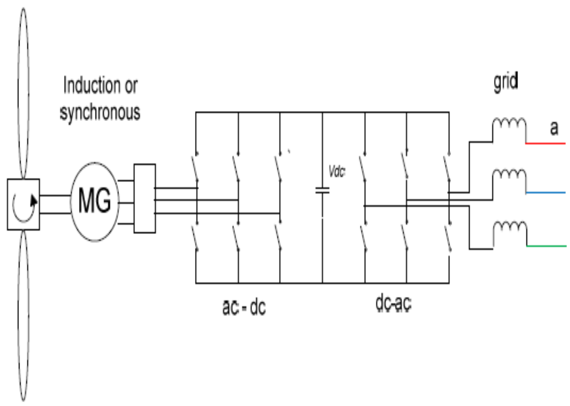

Fig: 10 Fully variable wind energy conversion system.

Electronic circuitry partially or completely decouples the rotor mechanical frequency from the grid electrical frequency, enabling the variable speed operation. The type of electric generator employed and the grid conditions dictate the requirements of the power electronic (PE) interface. Fig: 8 depict a variable speed wind energy conversion system. The electrical generator popularly employed for partially variable speed wind energy conversion systems are doubly-fed induction- generators [5]. Fig.9 depicts a doubly-fed induction-generator where the rotor circuit is controlled by the power converter system via the slip rings and the stator circuit is connected to the grid. This method is advantageous as the power converter has to handle a fraction ~ 25% - 50 % of the total power of the system [5]. The power converter system employs a rotor side ac-dc converter, a dc link capacitor, and a dc-ac inverter connected to the grid as shown in Fig: 10. The power converter enables vector control of the field which facilitates active/reactive power control.

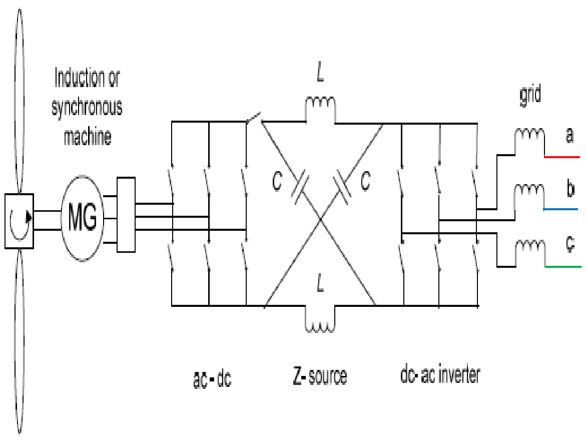

Fig: 11 Z- source based variable speed wind energy conversion system.

The rotor side converter controls the speed and torque of the rotor and the stator side convertor maintains a constant voltage across the dc link capacitor, irrespective of the magnitude of the rotor power. This method is more efficient than the fixed speed system; however it does not reflect the possible optimal efficiency. By employing a full scale ac-ac converter system the wind turbine can be completely decoupled from the grid, enabling a wider range of optimal operation. Such a scheme is depicted in Fig: 10. The variable frequency aciform the turbine is fed to the three phase ac-dc-ac converter. The generator side ac-dc converter is controlled to obtain a predetermined value at the terminal of the dc link capacitor. The dc voltage is then inverted using a six-switch dc-ac inverter. Inversion is inherently buck operation hence the turbine side ac-converter has to ensure sufficient voltage level is obtained in order to integrate with the grid. If additional boosting of the voltage is required, an additional dc-dc boost converter can to be employed. This increases the overall cost and complexity. To overcome the shortcomings a Z-source inverter based conversion system can be employed [9]. Z-source inverter is a relatively new topology and has the following advantages over the conventional voltage source/current source inverters:

- Buck-boost ability
- Inherent short circuit protection due to Z- source configuration
- Improved EMI as dead bands are not required.

Z-source inverter based wind power conversion systems are relatively new, however researches are investigating its applicability. A Z-source converter based wind energy system has been studied and presented in [9]. Fig: 10 shows the representation of the typical diagram for Fully variable wind energy conversion system and Fig: 11 shows a Z-source based wind energy conversion system. A single stage three phase ac-ac Z-source converter is presented in Fig: 11 [10]

IV. FUZZY LOGIC CONTROLLER DESIGN

P&O method for MPPT tracking will not respond quickly to rapid changes in temperature or irradiance. Therefore the fuzzy control algorithm is capable of improving the tracking performance [3].The block diagram of fuzzy logic controller (FLC) is shown in Fig: 12. It consists of three main blocks: fuzzification, inference engine and defuzzification. The two FLC input variables are the error e and change of error e*.

The behavior of a FLC depends on the shape of membership functions of the rule base.

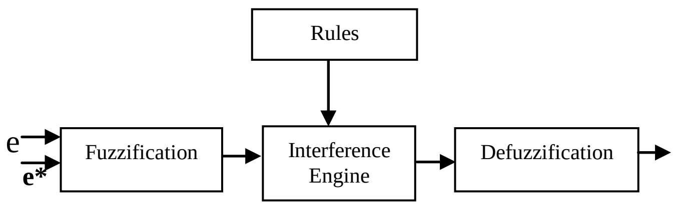

Fig.12 Block Diagram of Fuzzy Logic Controller

A. Fuzzification

The membership function values are assigned to the linguistic variables using seven fuzzy subset called negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM),positive big (PB). Table-1 shows the rule table of fuzzy logic controller. Variable e and e* are selected as the input variables, where e is the error between the reference voltage and actual voltage of the system, e* is the change in error in the sampling interval. Triangular membership functions are selected for all these process.

B. Inference engine

A fuzzy inference method, Mamdani's method, is used with Max-Min operation fuzzy combination. Fuzzy inference is based on fuzzy rule base system. Rules are framed in inference engine block. The commonly used method is MAX-MIN. The output membership function of each rule is given by MIN (Minimum) operator and MAX (Maximum) operator.

C. Defuzzification

The output of fuzzy controller is a fuzzy subset. As the actual system requires a non fuzzy value of Control, defuzzication is required. Defuzzifier is used to convert the linguistic fuzzy sets back into actual value. The membership function of error, change in error and input of the PWM generator are shown in Fig: 13 and Fig: 14 shows the representation of Membership functions for Duty ratio (D). Fig: 15 show the representation of the typical Rule Surface of fuzzy logic controller.

Table-1 Rule Table of FLC

e* / e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

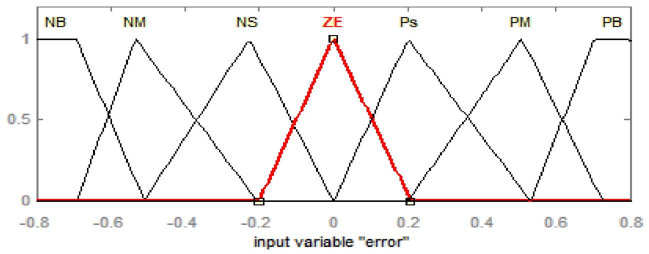

Fig: 13 Membership functions for Error (e)

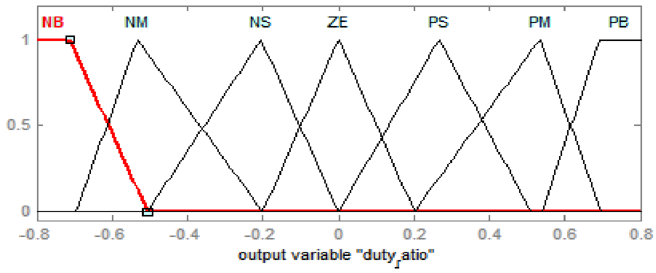

Fig: 14 Membership functions for Duty ratio (D)

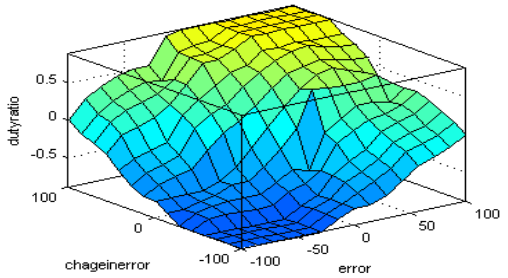

Fig: 15 Rule Surface of FLC

V. BUCK-BOOST CONVERTER AND INVERTER ITS COMPONENTS

A. Buck-Boost Converter

Buck-boost DC-DC converter is an important element in PV system since buck-boost converter is able to regulate the output voltage that may be less or greater than the input voltage. Buck-boost converter allows more flexibility in modulating the energy transfer from the input source to the load by varying the duty cycle D. Fig: 16 shows the circuit diagram of buck-boost DC-DC converter.

The operation of the buck-boost converter can be divided into two modes, namely "on" state and "off" state. During the "on" state the IGBT is turned on and the diode D_m is reverse biased. The current from

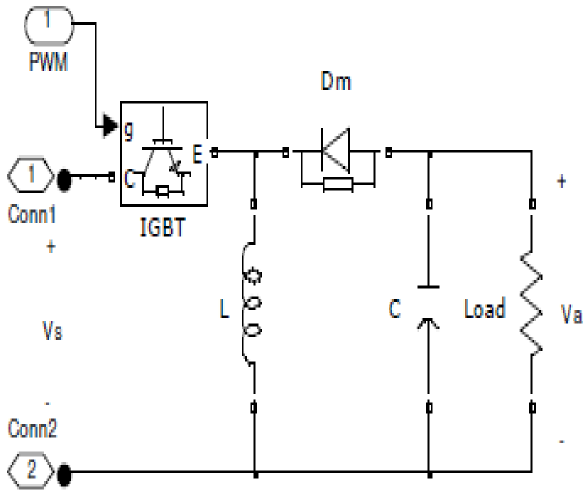

Fig: 16 Circuit diagram of buck boost converter.

The input source flows through the inductor L. When IGBT is turned off during "off" state, the energy stored in the inductor L will be transferred to the load until the next "on" state. By varying the duty cycle D, the output voltage is changed accordingly. The duty cycle D, however can be delivered by MPPT control unit.

In buck-boost converter, the output polarity is opposite to the input polarity. Fig. 17 shows the operation of buck-boost converter. The relationship among the load voltage, V_a, input source voltage, V_s and duty cycle, D can be described as equation (5).

$$D=V_a/V_a-V_s \quad (5)$$

B. Inverter

The inverter control is based on a decoupled control of the active and reactive power.

The DC voltage is set by a PI controller that compares the actual DC bus voltage and the reference generated by the MPPT, and provides a Id* active current reference in a synchronous reference frame attached at grid voltage vector. By applying the inverse Park transformation to d-q current vector components, the desired Iabc * phase current references are obtained. The output line voltage of the inverter is shown in Fig: 17.

As there is no DC/DC converter between the PV generator and the inverter, the PV array configuration has to be chosen so that the output voltage of the PV generator suits the inverter's requirements.

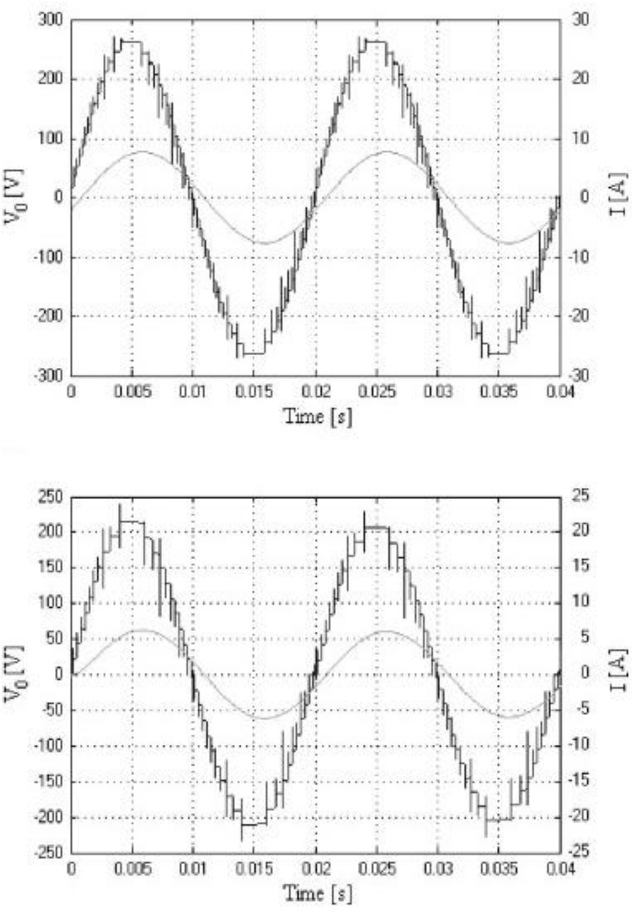

Fig: 17 Output voltage characteristics of inverter

In this case a 400V grid has been chosen, so the inverter will need at least 600V in the DC bus in order to be able to operate properly.

The lowest DC voltage will occur with high ambient temperature and high irradiance (because the irradiance increases the cell temperature and this effect predominates over the increase of optimal voltage caused by an increment of the irradiance at a constant cell temperature), so the minimum number of series connected modules should be determined by this worst case. As the PV array model estimates cell temperature as a function of irradiance and ambient temperature, for the worst case an ambient temperature of 50ºC and an irradiance of G=1000W/m were chosen. The PV array was found to require 35 series connected modules per string.

The optimal voltage for this configuration should stay around 700-800V most of the time, with some peaks that could reach a minimum of 600V and a maximum of 900V in very extreme situations. The only drawback of such a voltage is a slight increase of the inverter price as higher rated voltage of DC link capacitors and switches are required.

VI. SIMULATION RESULTS

This paper simulated the adopted soft-switching buck-boost converter, PV module modeling and wind turbine modeling using the MATLAB SIMULINK software.

A. PV Modeling for Simulation.

The equations from 1 to 3 for generating the current by array are represented by MATLAB/SIMULATION as shown in fig.18. Simulated output circuit of PV Array System is connected to the Boost Converter and to track the maximum power point using the Fuzzy Logic Controller Circuit.

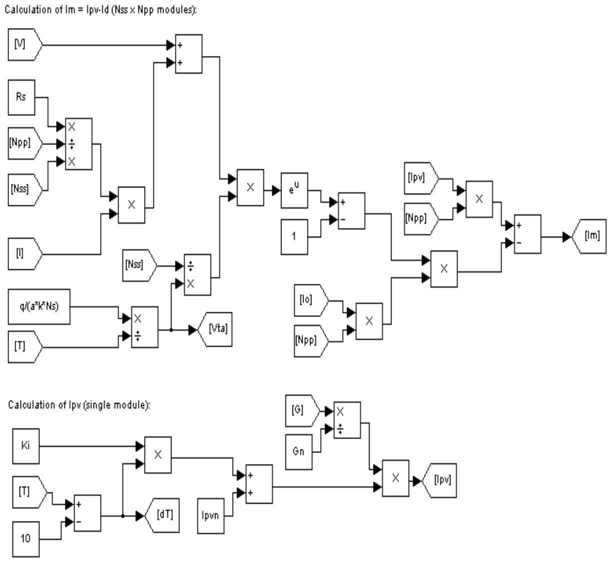

Fig: 18 Simulation Diagram for PV System Using MATLAB/Simulink

B. WIND Turbine Modeling for Simulation

The 4th equation for generating the current by PV array is represented by MATLAB/SIMULATION as shown in fig: 19. Simulated output circuits of Wind turbine system are connected to the Buck-Boost Converter and to track the maximum power point using the Fuzzy Logic Controller Circuit.

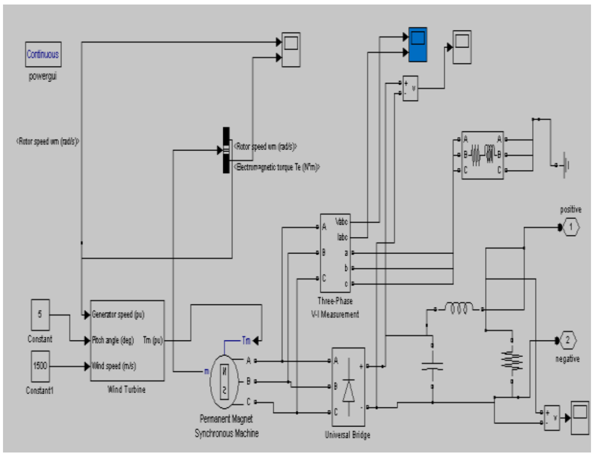

Fig: 19 Simulation Diagram for WIND Turbine System Using MATLAB/simulink.

Fig: 20 shows simulated power generated output waveforms of Wind Turbine Systems. Fig.21. shows simulated voltage output waveforms of Wind Turbine Systems using MATLAB/Simulink.

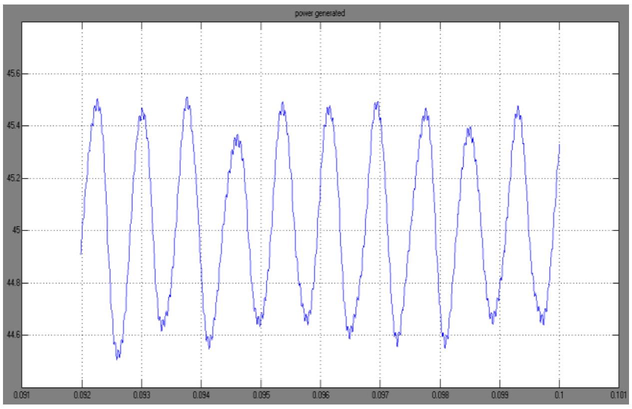

Fig: 20 Simulated Power generated Output Waveform for Wind System

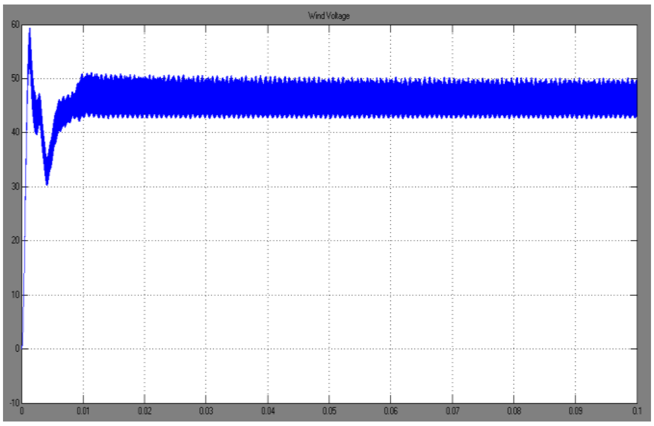

Fig: 21 Simulated Voltage Waveform for Wind System

C. Inverter Modeling for simulation

Fig.22 shows simulated single phase inverter Systems. The Designed Wind Turbine System and PV systems are connected to the Boost Converter and to track the maximum Wind speed and maximum power point using the Fuzzy Logic Controller Circuit and then connected to the Inverter circuit. Fig.23. shows simulated output waveforms of inverter circuit.

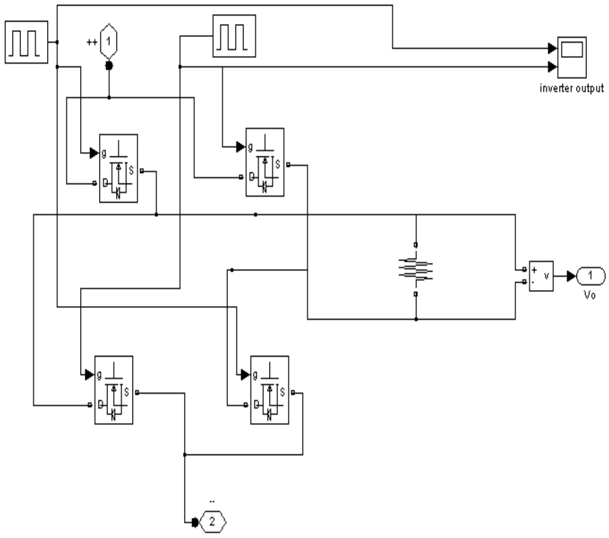

Fig: 22 Simulation Diagram for Inverter System Using MATLAB/Simulink

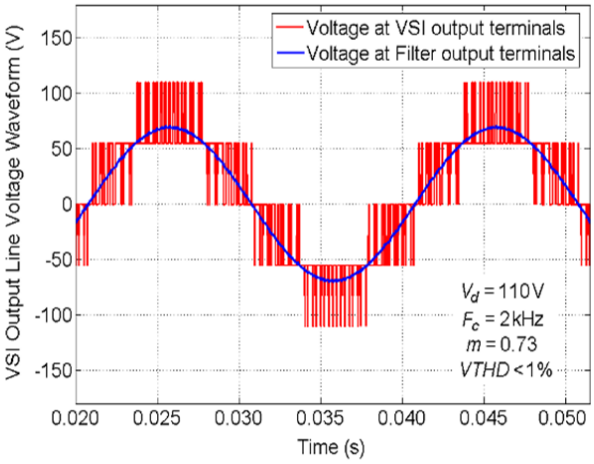

Fig: 23 Simulated Voltage and current waveforms for Inverter

D. Simulation of Boost Converter

The test signal when applied voltage waveform as shown in fig: 24. The various parameters used for the simulation boost converter are as shown in Table-2

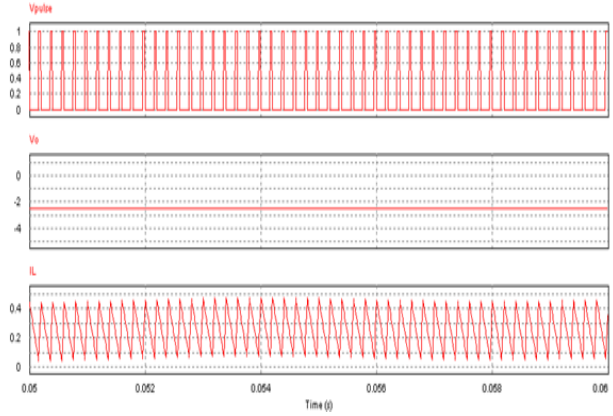

Fig: 24 Output voltage waveforms of Buck-Boost converter.

Table-2 Simulation Parameters

Switching frequency	30KHZ
Filter inductance	0.4 mHO
Filter capacitance	350 µf
Output resistance	20 ohm
Output inductance	40 mHO

E. Simulation of Overall Hybrid system

Fig.25 shows simulation diagram for Hybrid System using a MATLAB/Simulink. The Design values of the. PV and WIND systems are realized in the MATLAB Function with the help of governing equations.

Fig.26.shows simulated input voltage and current waveforms of PV and Wind System Using MATLAB/simulink.

Fig.27.shows simulated output voltage and current waveforms of PV and Wind System Using MATLAB/simulink.

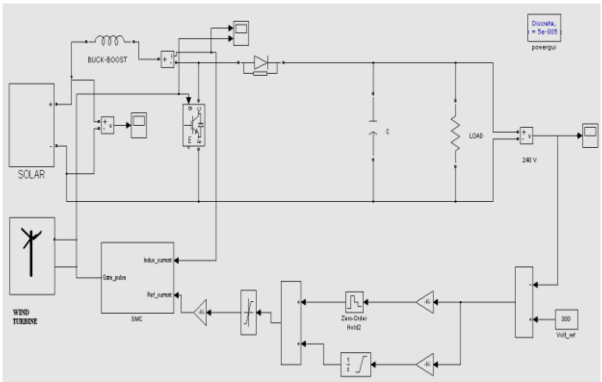

Fig: 25 Simulation Diagram for Hybrid System Using MATLAB/simulink

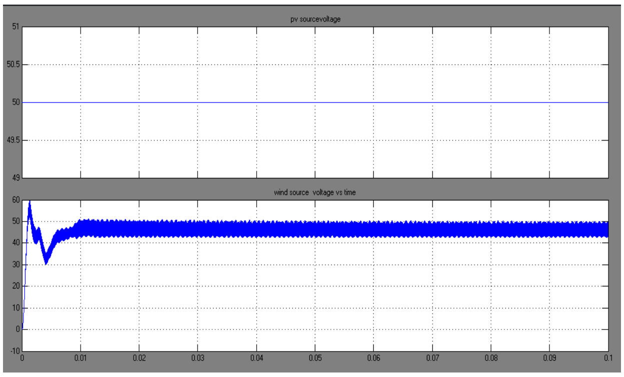

Fig: 26 Simulated input voltage and current waveforms of PV and Wind System Using MATLAB/simulink

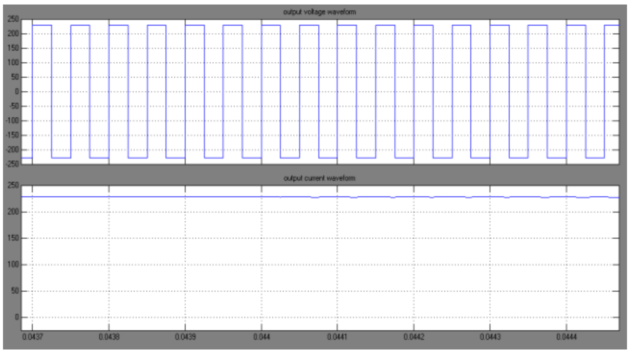

Fig: 27 Simulated output voltage and current waveforms

VII. CONCLUSION

In this paper improved modelling of PV array and Wind turbine has been presented. To extract the maximum power from the Hybrid Systems, Fuzzy Logic Controller is used. The optimized values of power and the corresponding voltage values for different isolation and temperature have been used for fuzzy logic controller. For different conditions the proposed algorithm has been verified and it is found that the error percentage lies between 0.07% to 3.46%.In this Paper a Fuzzy based Hybrid System on PV and WECS was proposed. This soft-switching boost converter is easy to control because the two switches are controlled by the same PWM signal. This paper has analysed the operational principles of the hybrid systems and maximum power point tracking fuzzy logic systems. A Fuzzy based Hybrid system improve the efficiency of the energy conversion systems because of reducing the switching losses The importance of renewable energy, renewable energy based energy conversion systems, and distributed power generation has been reiterated. The major principle of MPPT is to extract the maximum available power from PV panels by making them operating at the most efficiency voltage. Our proposed MPPT's charge controller is easier and cheaper to build. It improves efficiency of the energy conversion systems. Controlling the Buck-boost DC/DC converter in order to get the system operating at the Hybrid Systems maximum power. Simulations show that the system follows the irradiance and the temperature changes and the wind speed changes rapidly and the regulation is robust against disturbances. The basic electrical characteristics of wind turbine and photovoltaic based systems have been presented. The simulation results show that this system is able to adapt the fuzzy parameters for fast response and good transient performances. The Proposed system was simulated using MATLAB/Simulink software.

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