Simulation of fuzzy logic based MPPT solar Photovoltaic system and integration with Distribution Grid

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Abstract: Conventional methods of Maximum Power Point tracking (MPPT) have drawback of having less accuracy and slow response to the output. In this project, a method of Maximum Power Point tracking, MPPT using Fuzzy logic controller forDistribution Grid connected Photovoltaic system has been presented. The system composed of photovoltaic module, buck-boost converter, Fuzzy logic controller and inverter with sinusoidal pulse width modulation (SPWM). The maximum power point tracking control is based on Fuzzy logic to control ON/OFF time of MOSFET switch of buck-boost converter.

Keywords - Photovoltaic system, MPPT, Fuzzy Logic control.

I. Introduction

The conventional sources of energy are rapidly depleting. Moreover the cost of energy is rising and therefore photovoltaic system is promising alternatively. They are abundant, pollution free, distributed throughout the earth and recyclable. The hindrance factor is its high installation cost and low conversion efficiency. Therefore the aim of the project is to increase the efficiency and power output of the system. It is also required that constant voltage must be supplied to the load irrespective of the variation in solar irradiance and temperature. PV arrays consist of parallel and series combination of PV cells that are used to generate electrical power depending upon the atmospheric conditions (e.g. solar irradiance and temperature). So it is necessary to couple the PV array with DC-DC converter, and Fuzzy logic controller is used to control the ON/OFF time of the converter to provide a constant voltage at the output terminal.

The objective of this paper is to carry out the simulation of PV system [1] using Fuzzy logiccontroller for maximum power point tracking [2], integration of this system with Distribution Grid [9].

II. PHOTOVOLTAIC SYSTEM

An ideal PV cell is modelled by a current source in parallel with diode. However no solar cell is ideal so shunt and series resistances are added to the model. The value of the series resistance is very small and the value of shunt resistance is very high.

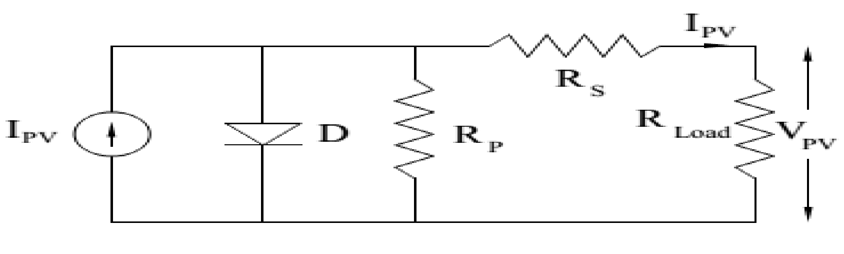


Fig 2.1 Constant Current Model of PV cell

Applying Kirchhoff's laws to the node where I_{ph}, diode current, R_p and R_s meet, we get

$$I_{ph} = I_D + I_{R_p} + I \tag{2.1}$$

We get following equation for the photovoltaic current

$$I = I_{ph} - I_D - I_{R_p} \tag{2.2}$$

$$I = I_{ph} - I_s\left(exp^{\frac{q(V+R_S I)}{AKT}} - 1\right) - \left(\frac{V+R_S I}{R_{sh}}\right) \tag{2.3}$$

Where, I_{ph} is the Insolation current, I is the cell current and I_s is the reverse saturation current, V is the cell voltage, R_s is the series resistance and R_{sh} is the shunt resistance, V_t is the thermal voltage ($^{KT}/_{q}$), K is the Boltzmann constant, T is the temperature in Kelvin, q is the charge of electron.

PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators. The PV mathematical model used to simplify our PV array is represented by the equation

$$I = n_p I_{ph-} n_p I_{rs}[\text{Exp}\,(\frac{q}{KTA} * \frac{V}{n_s})\text{-}1] \quad (2.4)$$

Where I is the PV array output current; V is the PV array output voltage; n_s is the number of cells in series and n_p is the number of cells in parallel; q is the charge of an electron; k is the Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); I_{rs} is the cell reverse saturation current. The factor A in equation (2.5) determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1 -5 but for ourcase A=1.6 [3]. The cell reverse saturation current I_{rs} varies with Temperature according to the following equation:

$$I_{rs}=I_{rr}[\frac{T}{T_r}]^3 \exp\,(\frac{qE_g}{KA}[\frac{1}{T_r} - \frac{1}{T}] \quad (2.5)$$

where T_r is the cell Reference Temperature, I_{rr} is the cell reverse saturation temperature at T_r and E_G is the band gap of the semiconductor used in the cell. The temperature dependence of the energy gap of the semi conductor is given by

$$E_{g=}E_g(0)\text{-}\frac{\alpha T^2}{T+\beta} \quad (2.6)$$

The photo current I_{ph} depends on the solar radiation and cell temperature as follows:

$$I_{ph}= [I_{scr}+ K_i(\text{T-}T_r)]\frac{S}{1000} \quad (2.7)$$

Where I_{scr} is the cell short-circuit current at Reference temperature and radiation, K_i is the short circuit current temperature coefficient, and S is the solar radiation in mW/cm^2. The PV power can be calculated using equation as follow

$$\text{P=IV}= n_p I_{ph} V[(\frac{q}{KTA} * \frac{V}{n_s}) - 1] \quad (2.8)$$

III. PV SYSTEM CHARACRISTICS

The current to voltage characteristic of a solar array is non-linear, which makes it difficult to determine the MPP. The Figure below gives the characteristic I-V and P-V curve for fixed level of solar irradiation and temperature

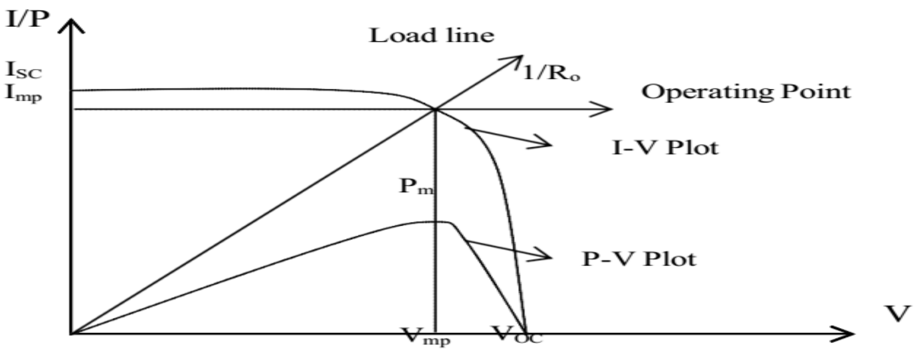


Fig 3.1 characteristic curve of PV system

The characteristic I-V curve tells that there are two regions in the curve: one is the current source region and another is the voltage source region. In the voltage source region (in the right side of the curve), the internal impedance is low and in the current source region (in the left side of the curve), the impedance is high. Irradiance temperature plays an important role inpredicting the I-V characteristic, and effects of both factors have to be considered while designing the PV system. Whereas the irradiance affects the output, temperature mainly affects the terminal voltage.

IV. BUCK-BOOST CONVERTER

A buck-boost converter provides an output voltage that may be less than or greater than the input voltage hence the name "buck-boost" the output voltage polarity is opposite to that of the input voltage. This converter is also known as an inverting regulator. The circuit arrangement of a buck-boost convertor is shown in figure

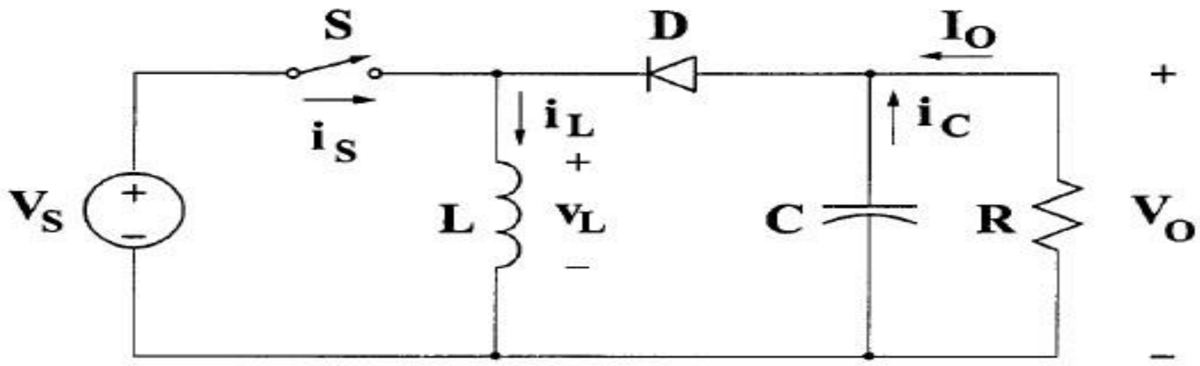


Fig 4.1circuit diagram of buck-boost converter

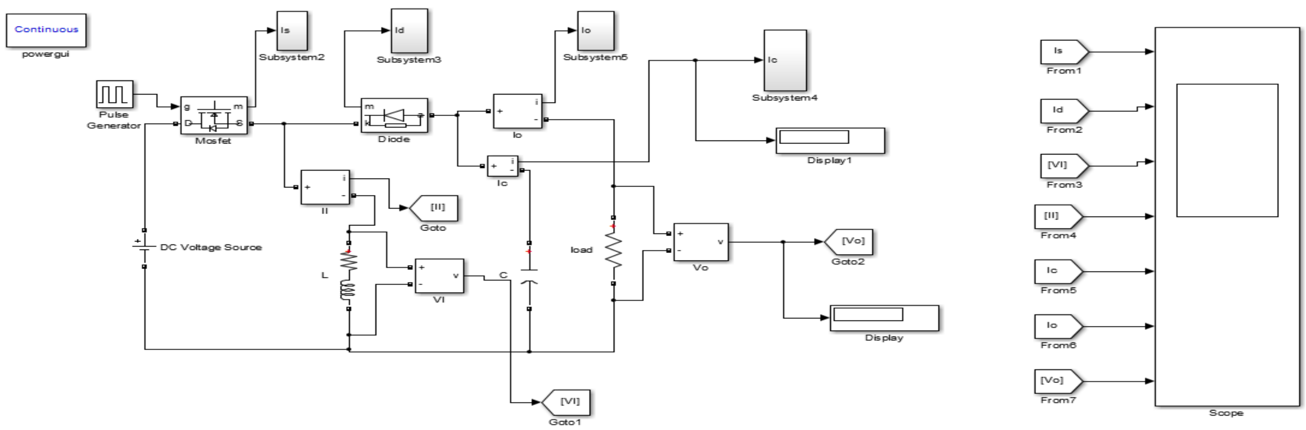


Fig 4.2 Simulation of Buck Boost converter

$$V_o = -V_s[\frac{D}{1-D}] \qquad (4.1)$$

Equation 4.1 shows the output voltage has opposite polarity form the source voltage. Output magnitude of the buck boost converter can be less than the source greater than thesource, depending on the duty ratio of the switch. If D > 0.5, the output is larger than the input, and if D < 0.5, output is smaller than the input.

V. INVERTER

The DC-AC Converter also known as the inverter, converts dc power to ac power at desired output voltage and frequency.
The dc power input to the inverter is obtain from dc-dc converter in this project. Inverter can be broadly classified into two types, voltage source and current source inverter and current source inverters. A voltage source inverter is one in which dc source has small or negligible impedance. The voltage at the input terminal is constant. A current source inverter is fed with adjustable current from the dc source of high impedance that is from a constant dc source [2].

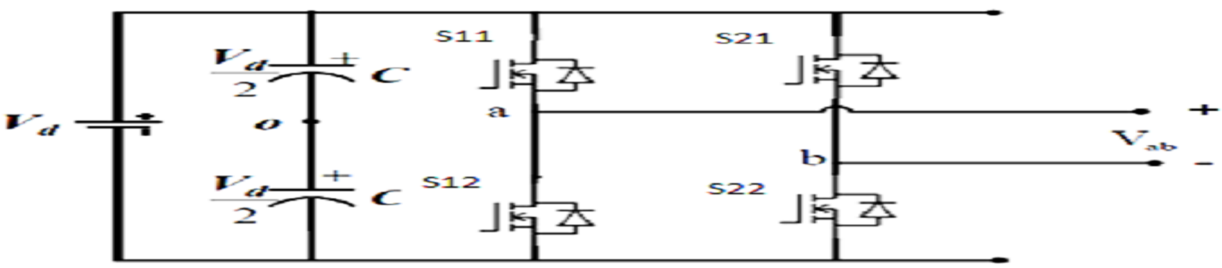


Fig 5.1 circuit diagram of inverter

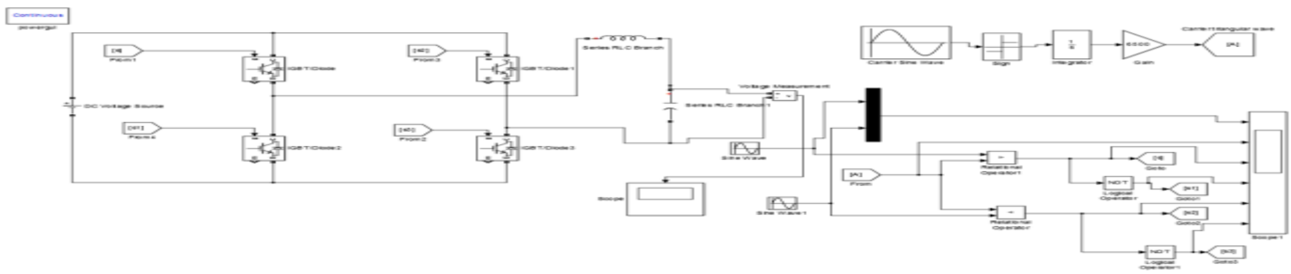


Fig 5.2 Simulation of inverter using SPWM

VI. SINUSOIDAL PULSE WIDTH MODULATION

The sinusoidal pulse width modulation (SPWM) produces a sinusoidal waveform by filtering an output pulse waveform with varying width. A high switching frequency leads to a better filtered sinusoidal output waveform. The desired output voltage is achieved by varying the frequency and amplitude of a reference or modulating voltage.

The variation in the amplitude and frequency and amplitude of the reference voltage change the pulse width patterns but keep the sinusoidal modulation. A low frequency sinusoidal modulating signal is compared with a high frequency triangular signal, which is called the carrier signal. The switching is state changed when the sine waveform intersects the triangular waveform. The crossing position determines variable switching times between the states.

VII. LC FILTER DESIGN

A low pass LC filter is required at the output terminal of full bridge voltage source inverter to reduce harmonics generated by pulsating modulation waveforms. While designing the L-C filter, the cut-off frequency is chosen such that the low order harmonics is eliminated. To operate as an ideal voltage source, that means no additional voltage distortion even though under the load variation or a nonlinear load. The output impedance of the load must be kept zero. Therefore the capacitance value must be maximized and the inductor value should be minimized at the selected cut-off frequency of the low pass filter.

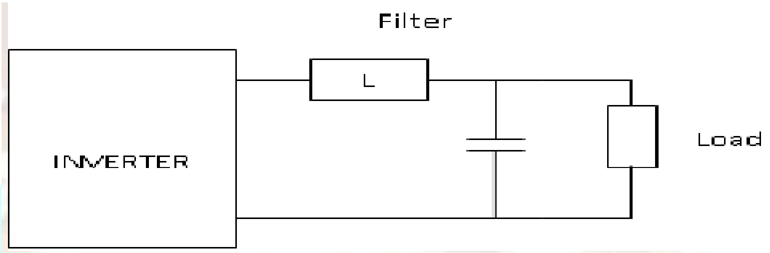


Fig 7.1 circuit arrangement of LC filter

In filter designing the first step is finding the best filter. The second step is calculating the designed value of impedance from the lowest voltage (V_{min}) divided by highest current ($I_{\max}$). the third step is equating the inductor (L) and capacitor (C) values from the second step using following equation [4].

The design impedance form can be calculated by $R_d = \frac{V_{min}}{I_{max}}$ (7.1)

The inductor (L) and the capacitor values of the filter can be calculated by

$$L = \frac{R_d}{2\pi f} \quad (7.2)$$

$$C = \frac{1}{2\pi f R_d} \quad (7.3)$$

VIII. FUZZY LOGIC CONTROLLER

The process of FLC can be classified into three stages, Fuzzification, rule evaluation and Defuzzification. These components and the general architecture of a FLS are shown in FigOutput from FLC is ΔD which correspond to the fuzzification step involves taking a crisp input, such as the change in the voltage reading, and combining it with stored membership function to produce fuzzy inputs. To transform the crisp inputs into fuzzy inputs, membership function must be first assigned for each input. Once the membership functions are assigned, fuzzification take a real time inputs and compares it with the stored membership function information to produce fuzzy input values. The second step of fuzzy logic processing is the rule evaluation in which the fuzzy processor uses linguistic rules to determine what control action should occur in response to agive set of input values. The result of rule evaluation is a fuzzy output for each type of consequent action.

The last step in Fuzzy logic processing in which the expected value of an output variable is derived by isolating a crisp value in the universe of discourse of the output fuzzy sets. In this process, all of the fuzzy output values effectively modify their respective output membership function. One of the most commonly used Defuzzification techniques is called centre of Gravity (COG) or Centroid method.

Fuzzy logic controller [6] has been used for tracking the maximum power of PV systems since it has the advantages such as it is robust, relatively simple to design and does not require the knowledge of an exact model. In this project, a new method based FLC is proposed to achieve tracking the maximum power of the PV module under changing the weather conditions. The oscillation around MPP is decreased and the response is faster in compared with the conventional methods. The proposed inputs of the FLC are the change in the voltage of the PV module (ΔV) and the change in the power of the PV module (ΔP). The proposed the modulation signal which is applied to the PWM modulator in order to produce the switching pulses.

The input variables are defined as in (3.16) and (3.17). During fuzzification, the numerical input variables are converted into linguistic variables based on the membership functions. Figures 3.7, 3.8 and 3.9 show the membership of ΔV, ΔP and ΔD respectively. Five fuzzy levels are used for all the inputs and outputs variables: NB(negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big).

$$\Delta V = V(K) - V(K-1) \quad (8.1)$$

$$\Delta P = P(K) - P(K-1) \quad (8.2)$$

Where V(k) is the voltage at the time instant K, and P(K) is the power at time instant K.

The theoretical design of the rules based on the fact that if the change in the voltage causes the power to increase, the moving of the next change is kept in the same direction otherwise the next change is reversed. After the theoretical design, all the MFs and the rules were adjusted by the trial and error to obtain the desired performance.

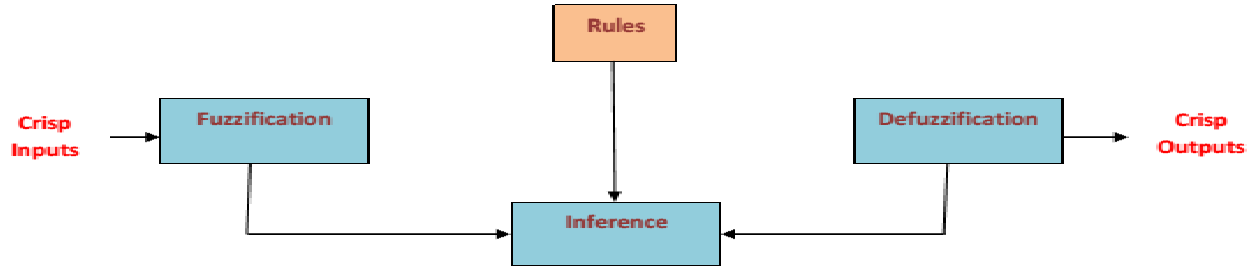


Fig 8.1 block diagram of fuzzy logic controller

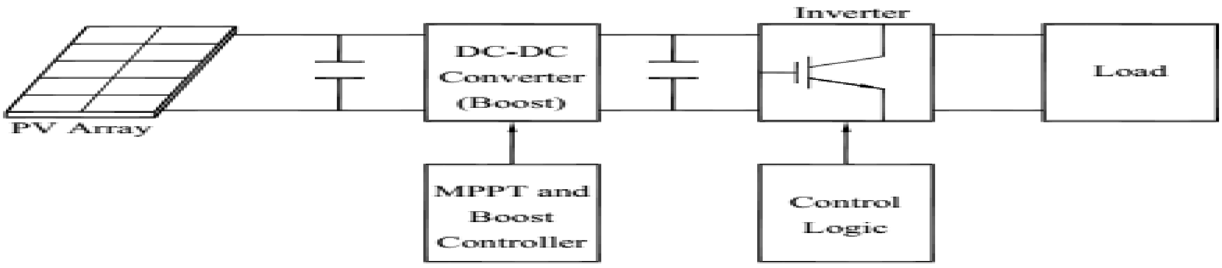


Fig 8.2 proposed block diagram

Table 8.1 Rules for fuzzy logic controller

ΔV/ΔP	NB	NS	Z	PS	PB
NB	PB	PS	NB	NS	NS
NS	PS	PS	NB	NS	NS
Z	NS	NS	NS	PB	PB
PS	NS	PB	PS	NB	PB
PB	NB	NB	PB	PS	PB

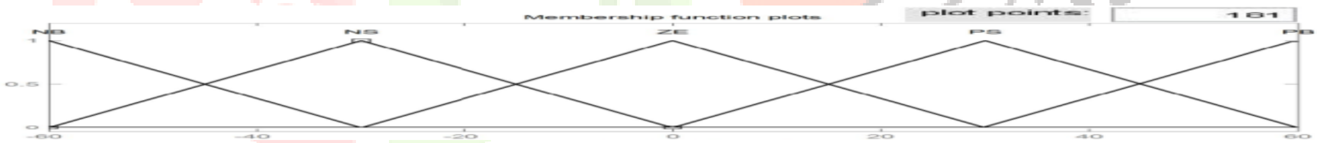


Fig 8.2 Membership function for ΔV

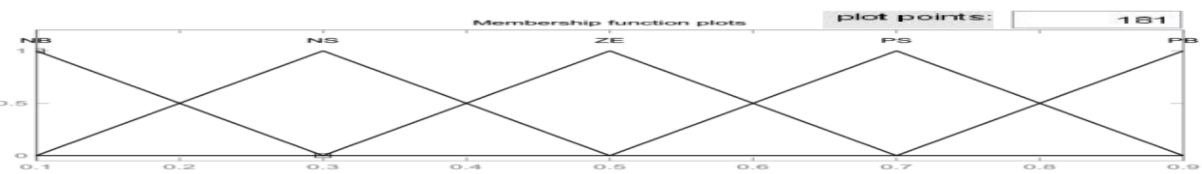


Fig 8.3 Membership function for ΔP

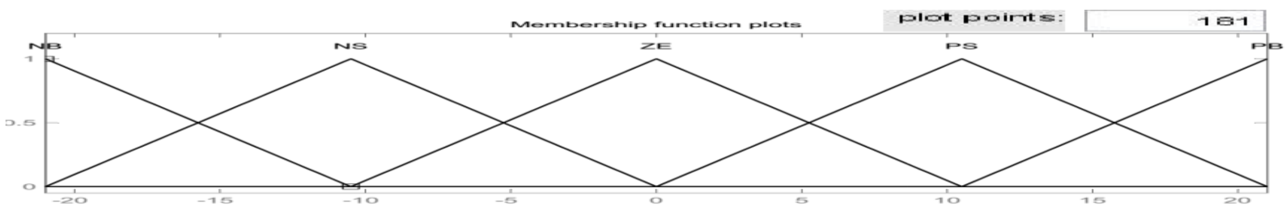
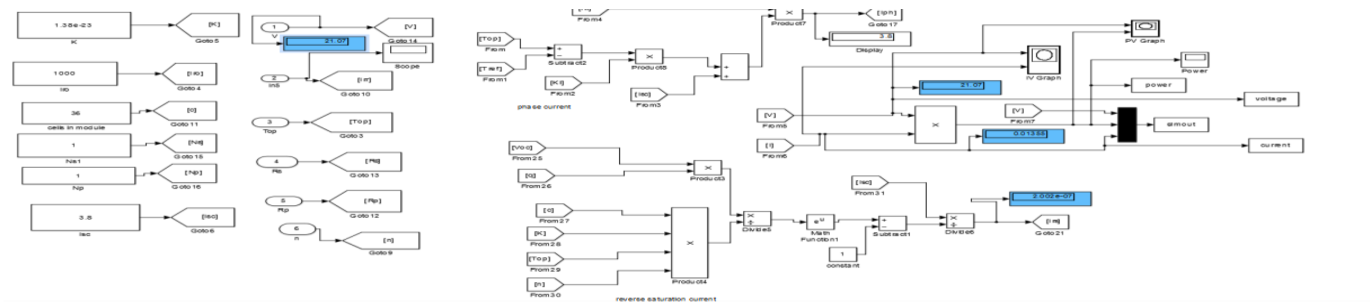
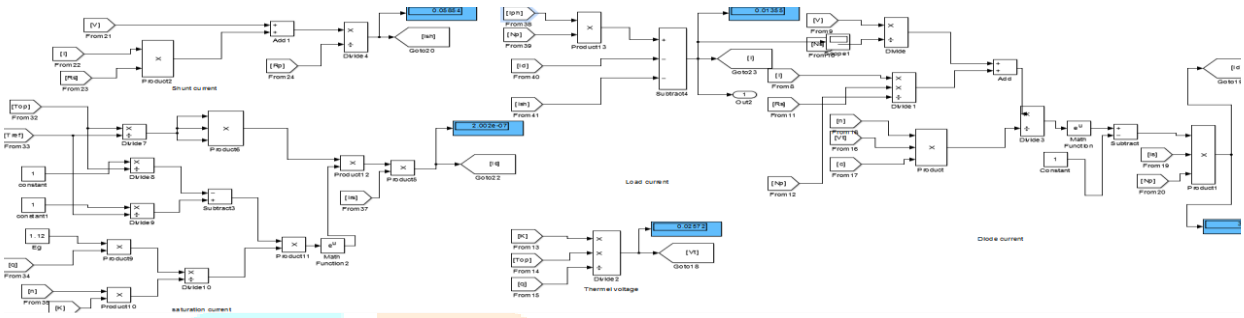


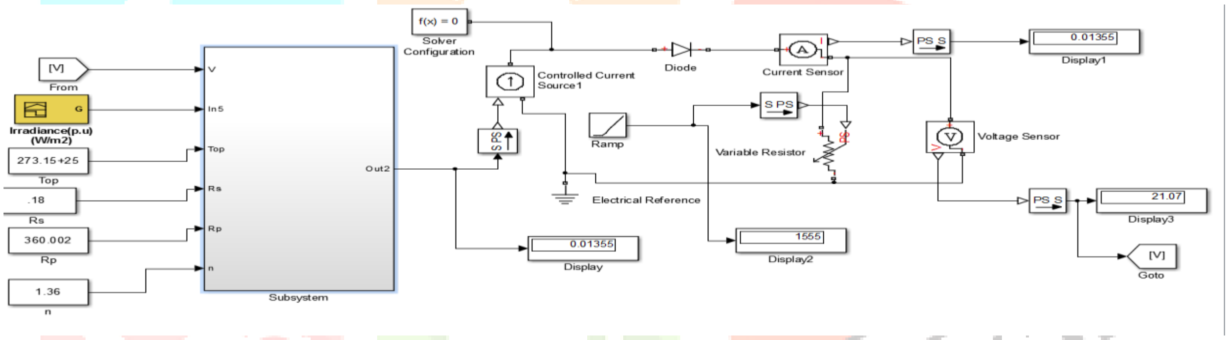
Fig 8.4 Membership function for D

IX. SIMULATION OF PV SYSTEM

Simulation of PV system is carried out in MATLAB/SIMULINK with the help of characteristic equations







X. SIMULATION RESULTS

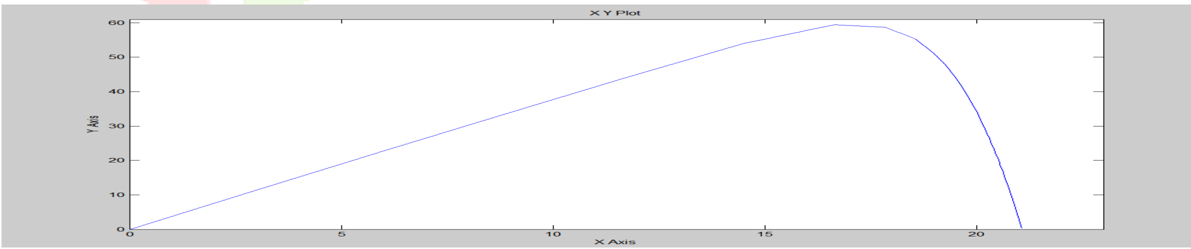


Fig 10.1 PV curve

Fig10.2 IV curve

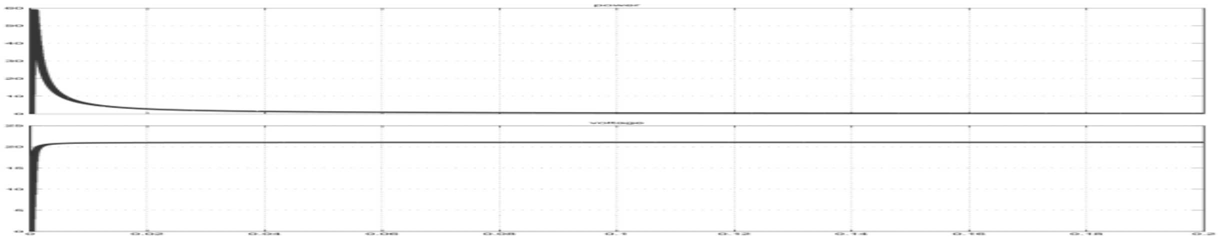


Fig 10.3 power and voltage

Fig 10.4 shunt current

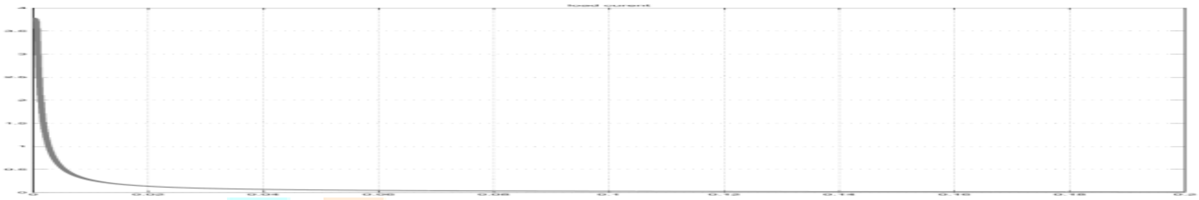


Fig 10.5 load current

Fig 10.6 Diode current

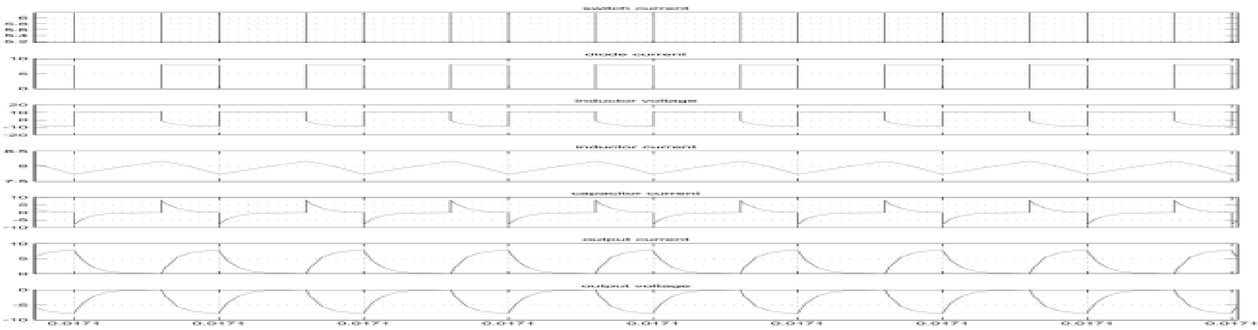


Fig 10.7 Buck-Boost converter output

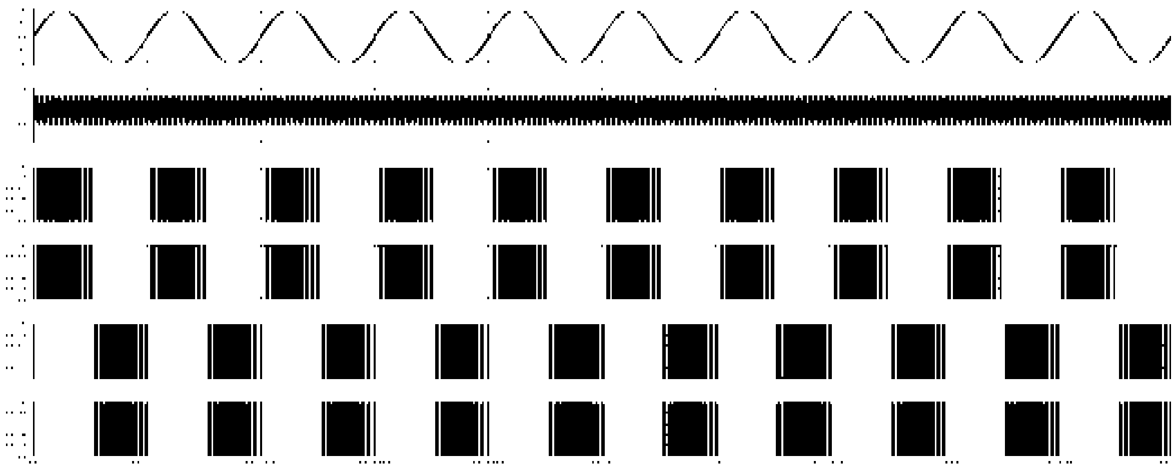


Fig 10.8 Inverter SPWM

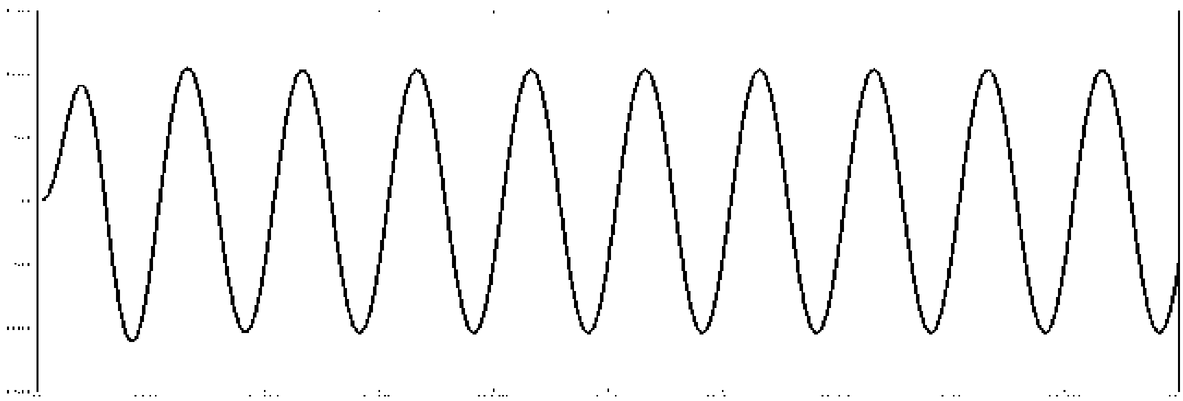


Fig 10.9 Output voltage

XI. CONCLUSION

Photovoltaic model using MATLAB/SIMULINK and design of appropriate DC-DC Buck-Boost converter with a maximum power point tracking facility are presented in this report. The model is tested under disturbence in both solar radiation and temperature. The preposed method effectively tracks the maximum power point under different ambient conditions. The oscillation arround MPP is decreased and response is faster than the conventional methods. The preposed method has higher efficiency than the conventional methods.

The response of Fuzzy Logic based MPPT is faster then the response of conventional method MPPT [6],[9]. We get higher efficiency by using the Fuzzy Logic controller for the maximum power point tracking [8].

By using the Fuzzy Logic controller we can reduce the oscillations arround the maximum power point [7].

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