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Grid Connected Photovoltaic System with Fuzzy Logic Control Based MPPT

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Abstract*—This paper focused on modelling and simulation of grid connected photovoltaic system. This work presents a fuzzy logic control based maximum power point tracking approach to enhance the efficiency and robustness of the solar photovoltaic (PV) power generation and establishes a dynamic model of grid-connected PV system by Matlab/Simulink environment which reflect the characteristics of the system accurately. Grid-connected PV system includes a PV array, dc-dc converter, fuzzy logic control based MPPT, inverter, LC filter, P-Q based inverter control, a distribution network. Improved fuzzy logic control based MPPT and P and Q based inverter control scheme provides a closed loop active and reactive power control and accurate synchronisation to grid. Simulation results presented here validate the component models and the chosen control schemes.

***Index Terms*—Maximum power point tracking, Fuzzy logic control, Distributed generation, Photovoltaic system.**

I. INTRODUCTION

The increasing of the world energy demand, due to the modern industrial society and population growth, is motivating a lot of investments in alternative energy solutions, in order to improve energy efficiency and power quality issues. The use of photovoltaic energy is considered to be a primary resource, because there are several countries located in tropical and temperate regions, where the direct solar density may reach up to 1000 W/m2. At present, photovoltaic (PV) generation is assuming increased importance as a renewable energy sources application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts.

The cell conversion ranges vary from 12 percentage of efficiency up to a maximum of 29 percentages for very expensive units [1]. In spite of those facts, there has been a trend in price decreasing for modern power electronics systems and photovoltaic cells, indicating good promises for new installations. However, the disadvantage is that photovoltaic generation is intermittent, depending upon weather conditions. Thus, the MPPT makes the PV system providing its maximum power and to help get stable and reliable power from PV system for both loads and utility grid, and thus improve both steady and dynamic behaviours of the whole generation system [3]. In this project I have studied a grid-connected photovoltaic generation system which is composed of PV array, power electronic converters, filter, controllers, local loads and utility grid as shown in figure.

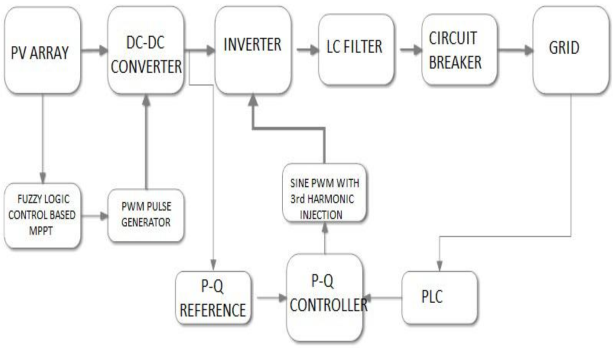

Fig 1: Block diagram of grid connected PV system

The block diagram representation of grid connected PV system is given in figure.1. In this PV array is connected to dc-dc converter. The switching pulses for dc-dc converter is generated by fuzzy logic control based MPPT and gate generator arrangement. By using feedback voltage and power taken from the PV array, fuzzy logic control based MPPT produces a reference for the converter and using this reference, pwm generator produces switching signal for the dc-dc converter. These reference signals are given to sinusoidal pwm generator which produces six switching pulses for the inverter. The overall system uses a high efficiency fuzzy logic control based MPPT [6] and buck converter, produces PV array voltage corresponding to the maximum power. The three phase inverter with P-Q control [10] and LC filter produces sinusoidal ac voltage and current having less than 3 percent THD.

II. MODELLING OF PV ARRAY

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity. It has an equivalent circuit [2] as shown figure 2. The current source Iph represents the cell photo current; Rj is used to represent the non-linear impedance of the p-n junction; Rsh and Rs are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis.

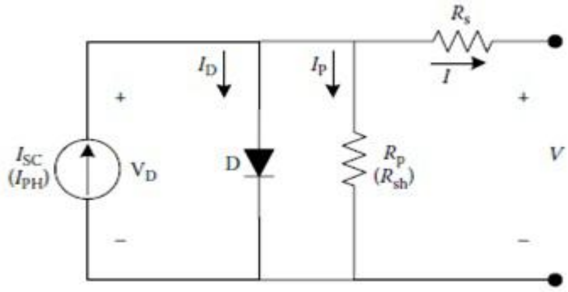

Fig 2: One diode model of solar cell

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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 [3] used to simplify our PV array is represented by the equation (1).

$$I = n_p I_{ph} - n_p I_{rs}\left[exp\left(\frac{q}{KTA}\cdot\frac{V}{n_s}\right)\right] \quad (1)$$

where I is the PV array output current; V is the PV array output voltage; ns is the number of cells in series and np 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); Irs is the cell reverse saturation current. The factor A in equation determines the cell deviation from the ideal p-n junction characteristics ranges 1-5 The cell reverse saturation current Irs varies with temperature according to the following equation (2)

$$I_{rs} = I_{rr}\left(\frac{T}{Tr}\right)^3 exp\left[\frac{qEg}{KA}\left(\frac{1}{Tr}-\frac{1}{T}\right)\right] \quad (2)$$

Where Tr is the cell reference temperature, Irr is the cell reverse saturation temperature at Tr and EG is the band gap of the semiconductor used in the cell. The photo current Iph depends on the solar radiation and cell temperature as in equation (3).

$$I_{ph} = [I_{sc} + K_i(T - T_r)]\frac{S}{100} \quad (3)$$

Where Iscr is the cell short circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient, and S is the solar radiation in mW/cm2. The PV power can be calculated using equation (4)

$$P = IV + n_p I_{ph} V\left[\left(\frac{q}{KTA}\frac{V}{n_s}\right) - 1\right] \quad (4)$$

III. MAXIMUM POWER POINT TRACKING

The power output from the solar panel is a function of irradiation level and temperature. But for a given operating condition, we have a curve which gives the voltage level maintained by the panel for a particular value of current. This plot is known as the characteristics of the cell. From the characteristics plot, we will be able to derive the power output with respect to the output current. The operating point of any source sink mechanism is the intersection point of load line with the source characteristic plot. What we attempt here to do is change the load angle theta to intersect the characteristics at maximum power point. The PV characteristics and maximum power point is shown in figure (3).

Photovoltaic modules have a very low conversion efficiency of around 15 percentage for the manufactured ones. Besides, due to the temperature, radiation and load variations, this efficiency can be highly reduced. In fact, the efficiency of any semiconductor device drops steeply with the temperature. In order to ensure that the photovoltaic modules always act supplying the maximum power as possible and dictated by ambient operating conditions, a specific circuit known as Maximum Power Point Tracker (MPPT) is employed. In most common applications, the MPPT is a DC-DC converter controlled through a strategy that allows imposing the photovoltaic module operation point on the Maximum Power Point (MPP) or close to it.

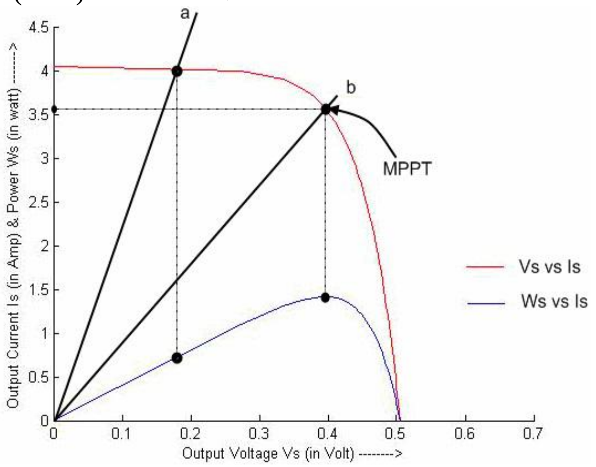

Fig 3: Maximum power point in PV characteristics

On the literature, many studies describing techniques to improve MPP algorithms were published permitting more velocity and precision of tracking [4]. There are different types of MPPT techniques are used. Some of them are Incremental Conductance Based MPPT Technique, Perturb and Observe Based MPPT, MPPT Controller Based on linearised IV Characteristics, Fractional Open-Circuit Voltage-Based MPPT, Fractional Short-Circuit Current-Based MPPT, Fuzzy Logic Control Based MPPT [7], Neural Network Based MPPT, Ripple Correlation Control Based MPPT, Ripple Correlation Control Based MPPT, Current Sweep Based MPPT, and DC Link Capacitor Droop Control Based MPPT. Out of which, due to several advantages like fast operation, digital implementation Logic Control Based MPPT is preferred.

IV. FUZZY LOGIC CONTROL BASED MPPT

Due to developments in micro controller and DSP technologies, fuzzy logic control has received increased interest in MPPT applications. Fuzzy logic controllers have the advantages of working on systems with nonlinearities [5], not needing an accurate dynamic model and working with imprecise inputs. Fuzzy logic control is based on three stages [7].

The fuzzification stage converts input variables into linguistic variables based on a membership function as shown in Figure. In this case, there are seven fuzzy levels, which are NB (Negative Big),NM(Negative Medium), NS (Negative Small),ZE(zero),PS(Positive Small), PM(Positive Medium), and PB (Positive Big).As number of fuzzy levels increases, the accuracy . a and b are based on the range of values of the numerical variable in Figure 5. In the membership function, some specific fuzzy levels can be designed as unsymmetrical

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to make them more dominant, in other words to give them more importance. The error E and its variation (E) are inputs to the fuzzy logic-based MPPT controller. E and E can be calculated based on the user's preferences.

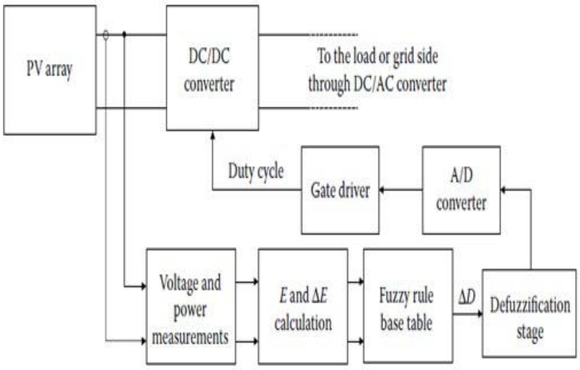

Fig 4: Block diagram of fuzzy logic control based MPPT

$$E(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} \quad (5)$$

$$\Delta E(n) = E(n) - E(n-1) \quad (6)$$

The memberships functions and rule base table associated with the fuzzy controller is given in figure (5) and (6).

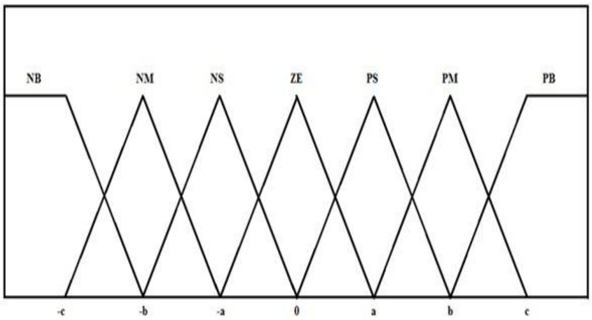

Fig 5: Membership function

E / ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	ND	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Fig 6: Rule base table

The error expressed in is the sum of the instantaneous and incremental conductance and goes to zero while becoming closer to the MPP. Generally, the output of the fuzzy logic controller is the change in duty ratio D of the power converter. This change in the duty ratio can be calculated and converted to the linguistic variables. Different combinations of the error, E, and its variations, E, can be used as the linguistic variables assigned to D. For a boost converter, Table can be used for this purpose. For example, if the operating point is far to the right of the MPP, and E is NB and E is ZE, then a large decrease is required in the duty ratio to decrease the voltage, that is D should be NB to reach the MPP. The fuzzy logic controller output is converted from a linguistic variable to a numerical variable using a membership function as shown in figure (5) in the defuzzifcation stage.

By defuzzifcation, the controller produces an analog output signal, which can be converted to a digital signal and controls the power converter of the MPPT system. Voltage and power are measured to calculate E and E. Then, these values are evaluated by a fuzzy rule base table similar to Table 1. The output of the fuzzy rule base table is the required change in duty cycle. In the defuzzification stage, the numerical value of the duty cycle is determined via the conversion from linguistic values. Finally, through an analog to digital (A/D) converter and a gate driver, the necessary switching signal is applied to the power converter of the MPPT. Under varying atmospheric conditions, the fuzzy logic controllers show good performance in MPPT applications. On the other hand, the effectiveness of the fuzzy logic controller depends on the accuracy of the calculation of error and its variations and the rule base table developed by the user. For better efficiency, the membership functions and rule base table can be continuously updated or tuned to achieve the optimum performance similar to an adaptive fuzzy logic controller. In this way, fast convergence to the MPP and minimal fluctuation around MPP can be achieved. In addition, the tracking performance depends on the type of membership function.

V. SIMULATION RESULTS

A. Simulation of PV array

PV cell is modelled using matlab m file for plotting the characteristics curve. SPR-305 PV cell parameters are used for modelling. Using equations, modelled PV cell equivalent and plotting the PV characteristics in MATLAB environment. The obtained characteristics curves for PV cell are given in figure 6. The characteristics curves shows the P-V and I-V curves for different irradiations and cell temperatures.

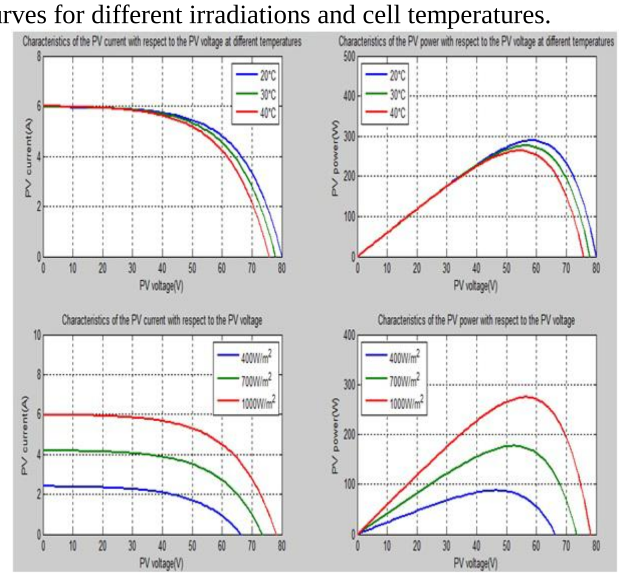

Fig 6: PV cell characteristics

The one diode model of solar cell is modelled using equations 1-4 in MATLAB/Simulink. The simulink model of PV cell is given in figure 7.

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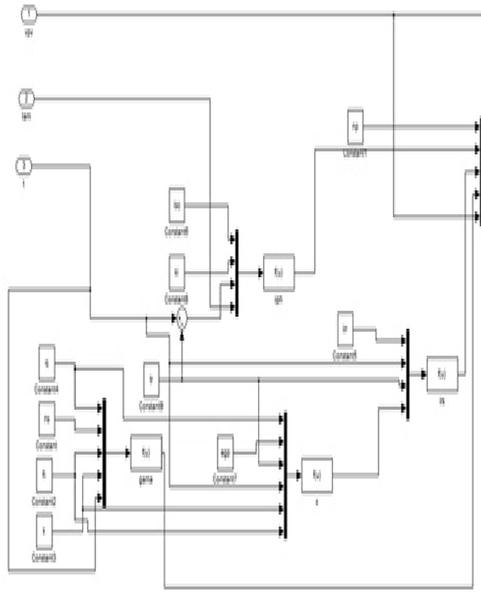

Fig 7: PV array simulink model

B. Simulation of MPPT

Fuzzy logic control based MPPT having three parts. First part takes instantaneous feedbacks of voltage and current from the PV system and processing and sampling it according to the requirement of the controller. Second part is the fuzzy logic controller. This controller produces the modulation level for the maximum power point based on the control algorithm. Third part is the pwm generator which produces switching pulse for the dc/dc converter.

Fuzzy logic controller have three operations. Fuzzification, fuzzy rule base and defuzzification. The physical inputs e and de are given to the fuzzy controller. These variables are converted into seven linguistic variables such as PB, PM, PS, ZE, NS, NM, MB. Also the second input and output are converted into linguistic variables. Inputs and outputs are connected together through 49 fuzzy rules. Centroid defuzzification method is used to change the output fuzzy levels to the physical variable. That is fuzzy logic controller produces modulation level for the pwm generator.

In conventional fuzzy logic control based MPPT method, the membership function gives the same weight age to all the variables. But there is a large change in power before and after the maximum power point and there is slight change in power near to maximum power point. Also more number of samples will be taken from the maximum power point region. So in the membership function of inputs more weight age will be given to linguistic variables corresponding to the midpoint of the operating region that is the maximum power point region. For this purpose in the modified fuzzy logic controller, more weight age is given to linguistic variables PS (positive small), ZE (zero), and NS (negative small). This modified fuzzy logic control based MPPT gave fewer fluctuated output than the conventional one. Figures 8 and 9 shows the membership functions of input E and ΔE respectively

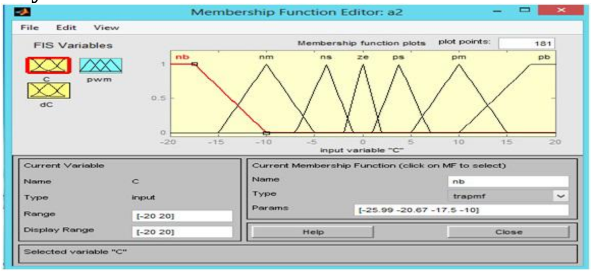

Fig 8: Membership function for input1 (E)

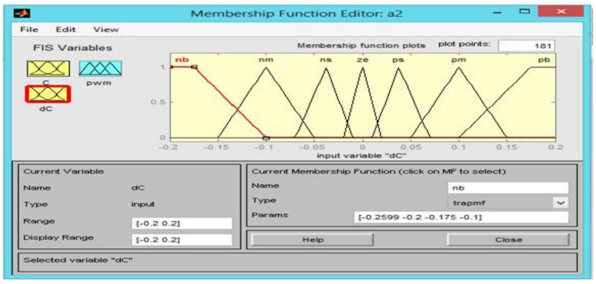

Fig 9: Membership function for input2 (ΔE)

The simulation results of PV system with improved fuzzy logic control based MPPT is given in figure 10. The current, voltage and power output of the PV system is given.

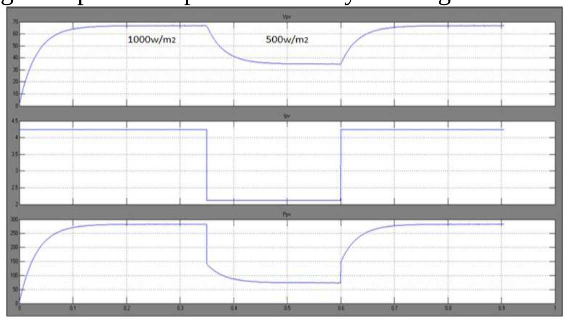

Fig 10: Output of PV system with fuzzy MPPT

This power is the maximum power as per the data sheet of the PV module. On comparing with the waveforms of PV system with conventional controller there is fewer fluctuations in the waveforms and the PV system reaches the maximum power point instantaneously. Under partial shading conditions some of the PV arrays do not get so much sun light than other. Also the irradiation level is varying. The below simulation result gave the tracking of maximum power point under 1000W/m2 and 500W/m2 irradiation levels.

C. Simulation of Grid connected PV system

In grid connected system, the system voltage should synchronise with the grid voltage. For this purpose the the inverter should work in the grid frequency and voltage. The control scheme of grid connected inverter consisting of three parts. Direct and quadrature axis current reference generator, PLL and d-q frame generation of grid voltage and current, Conversion voltage generation, PWM reference generation, Sine pwm with third harmonic injection for switching the inverter. Id-Iq reference generation is shown in figure 11. The dc link voltage feedback and reference dc voltage are given to Id-Iq reference generator. After making per unit the error signal is given to PI controller to produce d axis reference. The q axis component is set to be zero.

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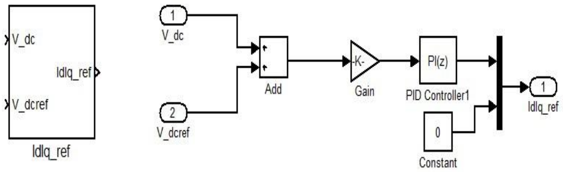

Fig 11: Id-Iq reference generator

The grid voltage and current are given to a discrete three phase PLL to produce wt reference and using Park's transformation current and voltage abc are converted to d-q-o components as shown in figure 12.

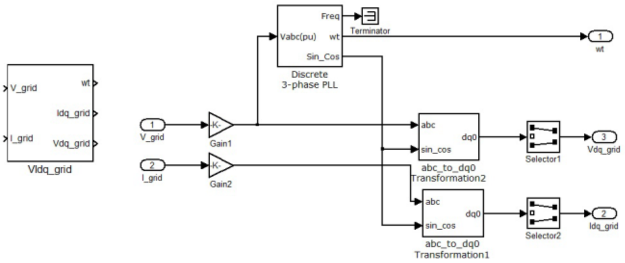

Fig 12: PLL and grid reference generator

From the generated dq current reference and measured grid voltage and current dq reference, the conversion voltage is calculated. The simulink model of conversion voltage generation is given below based on the equations 7 and 8.

$$V_{d\_conv} = V_{d_{mes}} + I_d * R - I_q * L \quad (7)$$

$$V_{q\_conv} = V_{q_{mes}} + I_d * L - I_q * R \quad (8)$$

Figure 11 shows the simulink model of conversion voltage generation.

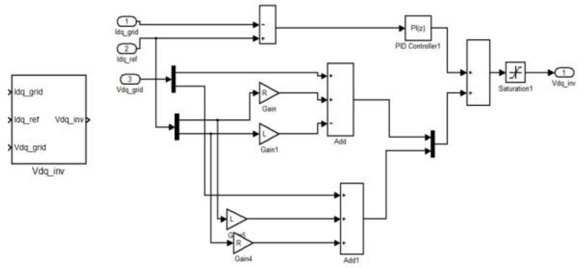

Fig 12: Conversion voltage generation

The reference sinusoidal signals are given to third harmonic injection block to produce third harmonic injected sinusoidal signals. This signal is subjected to pwm generation and the six switching pulses are given to the inverter. Figure 13 and 14 shows the simulink model of pwm reference generator and sine pwm with third harmonic injection respectively.

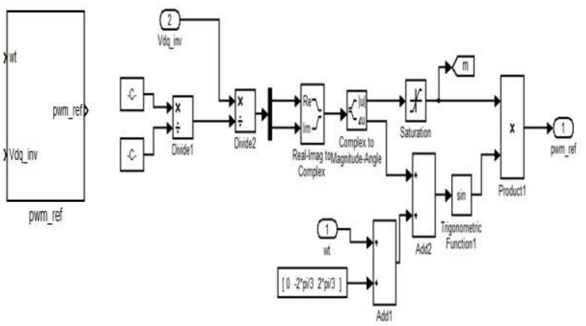

Fig 13: pwm reference generator

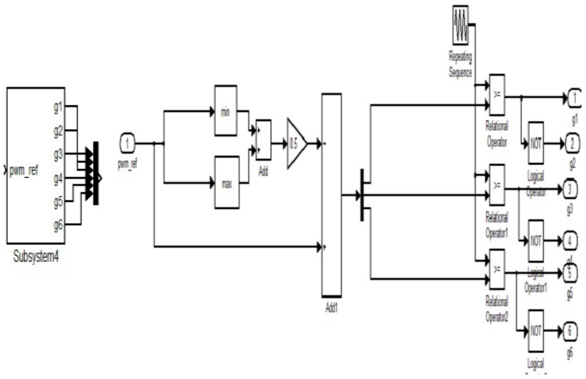

Fig 14: Sine pwm with third harmonic injection

The overall simulink model of P-Q control scheme for grid connected PV system given in figure 15. This control scheme includes Id-Iq reference generator, PLL and grid reference generator, pwm reference generator and Sine pwm with third harmonic injection

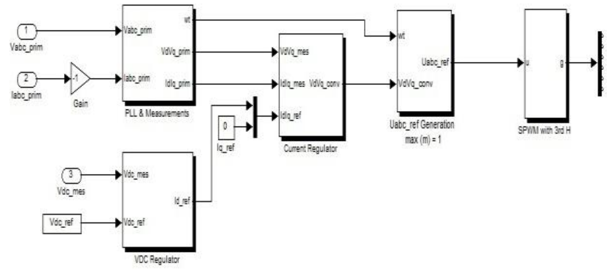

Fig 15: Simulink model of grid connected inverter control

The overall simulink model of grid connected PV system with fuzzy logic control based MPPT is given in figure 16. This model includes PV array, dc-dc converter, fuzzy logic control based MPPT, inverter, P-Q control scheme for inverter, LC filter, circuit breaker, local loads, grid and measuring system.

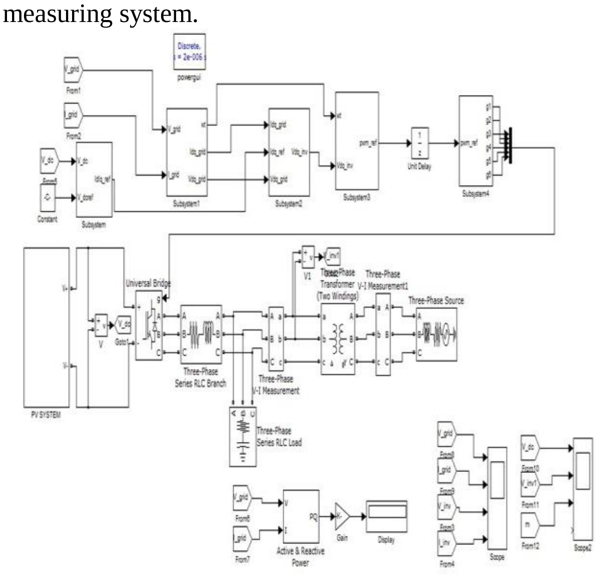

Fig 16: Simulink model of grid connected PV system

The grid connected PV system is simulated and the simulation result is given below. Figure 17 shows the duty ratio, control signals and gate pulses for the inverter obtained from the P-Q control schemes.

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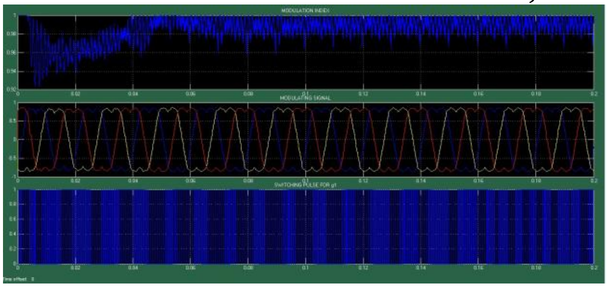
Fig 17: Outputs of grid connected inverter control

Figure 18 shows the active and reactive power obtained from the PV system. The active and reactive powers can be controlled independently by this P-Q control scheme.

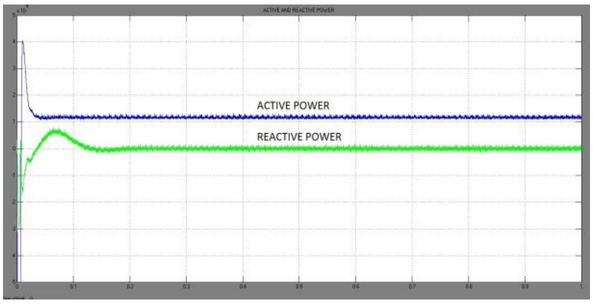

Fig 18: Active and reactive power output from PV system

The simulation result of grid connected PV system is given in figure 19. Dc link voltage, voltage and current of grid connected PV system are given. THD analysis of the output voltage of grid connected PV system is given in figure 20. From the THD analysis it is clear that the total harmonic distortion is very less (2.08%)

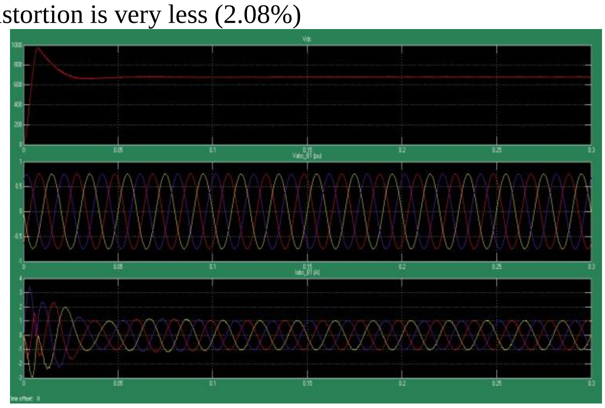
Fig 19: Simulation outputs of grid connected PV system

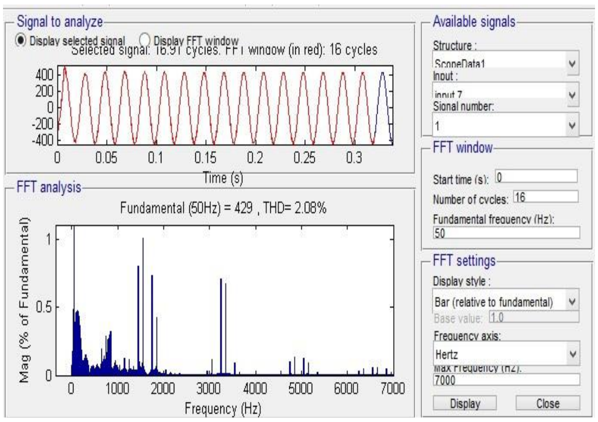

Fig 20: THD analysis

VI. CONCLUSION

Detailed model of grid-connected photovoltaic generation system components, in MATLAB /Simulink software was done. Fuzzy controlled MPPT strategy is used for PV output voltage to achieve closed loop control which can smoothly and quickly track the maximum power point of PV array. Stand alone and grid connected PV systems are modelled and simulated. P-Q based control scheme provides fast closed loop control. The PV system generated a sinusoidal voltage having THD less than 3%. P-Q control scheme provide exact synchronisation of photovoltaic system with the utility grid. Also the P-Q control scheme provides independent active and reactive power control. Simulation results presented here validate the component models and the chosen control schemes.

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