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CONTROL OF HARMONICS AND PERFORMANCE ANALYSIS OF A GRID CONNECTED PHOTOVOLTAIC SYSTEM

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Abstract: World energy consumption is increasing substantially .Growing scarcity and rising prices of fossil fuels may lead to economic instability. Continuously increasing energy consumption will overloads the distribution grids as well as the power stations, therefore having a negative impact on power availability, security and quality. One of the solutions for overcoming this is use of renewable energy resources. The energy generation from PV based DG is highly intermittent in nature and shows wide variation because of continuous fluctuations in solar radiation intensity, temperature and unpredictable weather conditions (e.g. clouds, snow, wind, etc.). This poses a major challenge for the designers of grid connected PV systems for DG applications. One of the major problems is the increase in the Total Harmonic Distortion (THD) of current injected into the grid. In this thesis basic theory of grid connected photovoltaic system and proposes a new scheme for Total Harmonic Distortion (THD) improvement in grid connected Photovoltaic (PV) systems. A fuzzy logic control can be used to improve the THD in grid connected PV systems. A comparison of PI, hysteresis control and fuzzy logic control gives the feasibility of the method. Thus the proposed scheme ensures that the THD in the injected grid current remains within the limits specified by IEEE-519, IEEE-1547. Simulation results are given to show the overall system performance. Evaluation and analysis of the 100 kW grid-connected PV system in AJCE were done depending on the change of the weather condition. The system performance was also quantified using several quantities which describe both PV array performance and the overall system performance.

Keywords: Photovoltaic, harmonic distortion, variable hysteresis band width control, final yield, performance ratio.

I. INTRODUCTION

Over the past few decades, the demand for renewable energy has increased significantly due to the disadvantages of fossil fuels and greenhouse effect. Among various types of renewable energy sources (RES), solar energy and wind energy have become the most promising and attractive because of advancement in power electronic technique. Photovoltaic (PV) sources are used nowadays in many applications as they own the advantage of being maintenance and pollution free. In the past few years, solar energy sources demand has grown consistently due to the following factors: 1) increasing efficiency of solar cells; 2) manufacturing technology improvement; and 3) economies of scale [1]. A major application of PV is in the area of distributed or dispersed generation (DG). DG facilitates injection of locally generated power into the grid. While DG has several advantages, it also poses several challenges. As the capacity of PV system growing significantly, the impact of PV modules on power grid cannot be ignored. DG penetrates deep into the existing power systems, problems such as voltage variation, instability, interference, flicker, increase of harmonics and frequency drift etc become more pronounced. Practical problems associated with the interaction of the PV system with the grid is the quality of power delivered to grid i.e the power quality problems. Among these problems harmonics is found to be most important issue for grid interconnected PV system [2]. The output power produced by photovoltaic modules is influenced by the intensity of solar cell radiation, temperature of the solar cells and so on . When the quantity of this kind of power output is large enough, voltage pulsation on transmission lines will be obvious and difficult to control. Most of the renewable energy sources are connected to the grid by means of inverter. It is reported that the inverter supplies power of low quality at low level of solar radiation [3]. Under such conditions the PV array power and the corresponding inverter input power are low. The inverter when operating under such low input power exhibits large nonlinearity, hence output power with more harmonics. For reducing harmonics in grid connected PV system several methods have been analysed.

For reducing harmonics in grid connected PV system a new scheme is introduced. Hysteresis current control is a method for controlling a voltage source inverter to force the grid injected current follows a reference current[4]. The line current and reference current are used to control the inverter switches. Lower and upper hysteresis band limitations

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are related to the minimum and maximum error directly. When the reference current is changed, line current has to stay within these limits. The range of the error signal directly controls the amount of ripples in the output current from the inverter which is called the hysteresis band. These kinds of controllers not only are robustness and simple but also have a good transient response. The main drawback of hysteresis current controller is uneven switching frequency which causes acoustic noise and difficulty in designing input filters during load changes. The switching frequency can be reduced by reducing the band width of the hysteresis band but at the same time the current error will increase which produce more distortion in the output current. To eliminate drawback upto certain extent fuzzy is used along with hysteresis current controller.

II. SYSTEM DESCRIPTION

The proposed Sinusoidal hysteresis band control is shown in Figure1.The proposed system consist of PV array, boost converter with MPPT controller and a voltage source inverter with hysteresis controller. The dc-dc converter is used to extract the maximum power from the PV source. As the power output of the PV array varies, the voltage across the dc link capacitor also varies. The incremental voltage change provides a measure of the change in the PV output power. A current reference is generated by comparing V_{DC} with reference voltage feeding the error into a PI controller as shown in the figure.1. The inverter regulates V_{DC} by facilitating the flow of power from the PV source (through the boost converter) into the AC grid by using hysteresis control i.e. by comparing the actual grid current with the reference current and controlling the switching of its devices appropriately. Harmonics in grid connected PV system can be limited by using an appropriate control in the inverter side. Hysteresis controllers are one of the simplest controller available for inverter control [5].

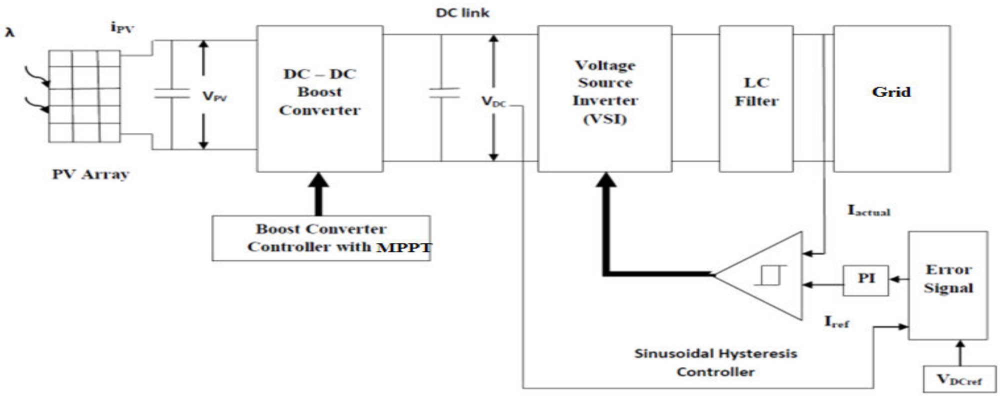

Fig. 1: Block diagram of the proposed system

A. *Modelling of pv array*

A solar PV array is developed in Simulink .The most simple solar cell equivalent circuit is shown in figure:2 from which the nonlinear voltage current curve of the equivalent solar cell, can be obtained through numerical simulation.

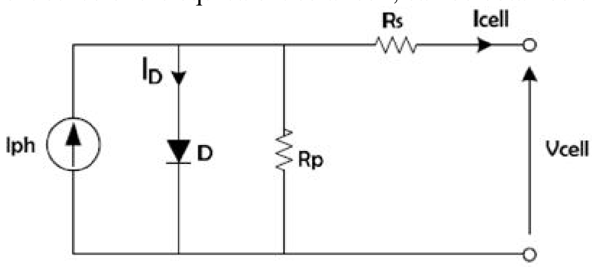

Fig 2:Equivalent circuit of PV cell

The current of the solar cell is given as follows [6]:

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$$I = I_{ph} - I_{rs}\left[\exp\left(\frac{q(V+IR_S)}{AkT} - 1\right)\right] - \left(\frac{V+IR_S}{R_p}\right) \quad (1)$$

Where I_{ph} is the insolation current, Irr is the cell reverse saturation current, I is the Cell current, Io is the Reverse saturation current, V is the Cell voltage, Rs is the Series resistance, Rp is the Parallel resistance, Vt is the Thermal voltage, K is the Boltzman constant, T is the Temperature in Kelvin, q is the Charge of an electron, s is the solar radiation in $\mathrm{mW/cm^2}$.

B. DC – DC converter model

In grid connected PV system regulated dc in maintained at the input of inverter terminals with help of boost converter. The voltage obtained from PV array can be increased with help of a boost converter. The role of the DC/DC boost converter is to increase the PV cell voltage, to control the solar power, and to regulate the voltage. The duty cycle has been varied at a high switching frequency to convert the unregulated voltage into a regulated supply. A circuit diagram of boost converter is shown in figure 3 [7].

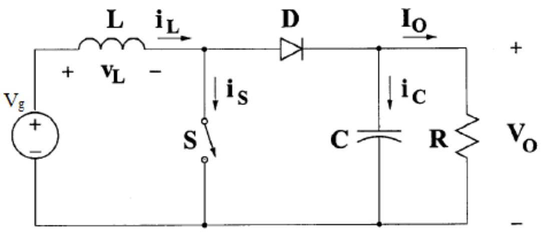

Fig. 3: DC – DC Converter Model

Voltage conversion ratio is given by :

$$\frac{V_0}{V_S} = \frac{1}{1-D} \quad (2)$$

C. DC – DC converter controller

PV cell has non-linear current-voltage characteristics. The power delivered by an array increases to a point, as the current draw rises MPP tracker (MPPT) devices are used between the PV array and load to track MPP and ensure that it works at this point. The Perturb and Observe (P&O) algorithm is the most commonly used in commercial MPPTs. In this method, a small perturbation in array current is introduced at a regular interval and the resultant power is measured. This is usually done by slightly varying the duty cycle of the switching converter (the load) driven by the PV array. Changing the duty cycle changes the load current as well, effecting a small perturbation. Two sensors, one for PV voltage the other for PV current, are commonly used to determine if the perturbation resulted in an increase or decrease of instantaneous power[8].

III. INVERTER CONTROL

Hysteresis inverters are used in many low and medium voltage utility applications when the inverter line current is required to track a sinusoidal reference within a specified error margin. Hysteresis current control is a method for controlling a voltage source inverter to force the grid injected current follows a reference current. A block diagram of a hysteresis controller is shown in figure 4. The line current and reference current are used to control the inverter switches. Lower and upper hysteresis band limitations are related to the minimum and maximum error directly (e_{min},e_{max}). When the reference current is changed, line current has to stay within these limits. The range of the error signal (e_{min} - e_{max}) directly controls the amount of ripples in the output current from the inverter which is called the hysteresis band. The principle of hysteresis current control is that reference current i*, which is synchronous with grid voltage us, compares with inductors actual output current i_L, and then the deviation (i* - i_L) put into hysteresis comparator. When |i*- i_L |H (H is half hysteresis band width), switching status is changed. At every switching cycle T, which is composed of current rise time tir and current fall time tif , inductor current error i_L changes from H to +H and

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then comes back. These kinds of controllers not only are robustness and simple but also have a good transient response [9][10].

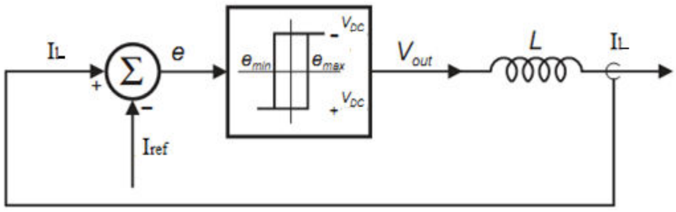

Fig. 4: Block diagram of Hysteresis Current Controller

The mathematical analysis of single-phase grid connected inverter is adopted as example. The inverter consists of the DC source u_d, power electronic devices T1, T2, T3, T4, freewheeling diodes VD1, VD2, VD3, VD4, inductor L and grid voltage u_s, shown as figure 5.

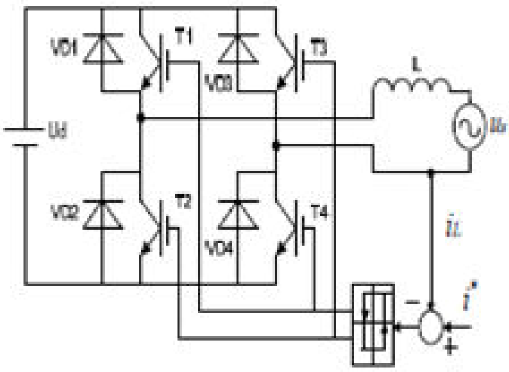

Fig 5: Single-phase grid-connected inverter

In Fixed-band hysteresis control the hysteresis bands are fixed throughout the fundamental period. The algorithm for this scheme is given as:

$$i_{ref} = i_{max} \sin wt \quad (3)$$

Upper band :

$$i_u = i_{ref} + \Delta i \quad (4)$$

Lower band :

$$i_l = i_{ref} - \Delta i \quad (5)$$

Δi = Hysteresis band limit

If $i_a > i_u , V_o = -V_d$

If $i_a < i_u , V_o = V_d$ (6)

In Sinusoidal Band Control the hysteresis bands vary sinusoidally over a fundamental period [11]. The upper and lower bands are given as:

$$i_{ref} = i_a^* = i_{max} \sin wt \quad (7)$$

$$i_u = (i_{max} + \Delta i) \sin wt$$
$$i_l = (i_{max} - \Delta i) \sin wt \quad (8)$$

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Algorithm:

For $i_{ref} > 0$

If $i_a > i_u, V_o = -V_d$ (9)

If $i_a < i_l, V_o = V_d$

For $i_{ref} < 0$

If $i_a < i_u, V_o = V_d$

(10)

If $i_a > i_l, V_o = -V_d$

IV. FUZZY WITH HYSTERESIS CURRENT CONTROLLER

The switching frequency can be reduced by reducing the band width of the hysteresis band but at the same time the current error will increase which produce more distortion in the output current. To eliminate drawback upto certain extent fuzzy is used along with hysteresis current controller as shown in figure 6[12].

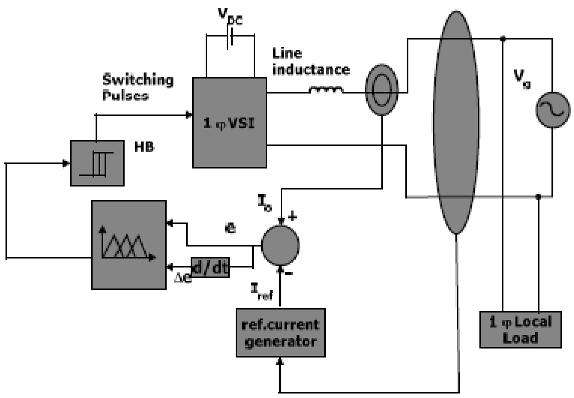

Fig 6 : Block diagram for fuzzy with hysteresis current control

The membership function is chosen as triangular as shown in figure 7 . The input is taken as error (e) and the change in error (Δe) .Total 49 rules are taken into account as given in figure 8.

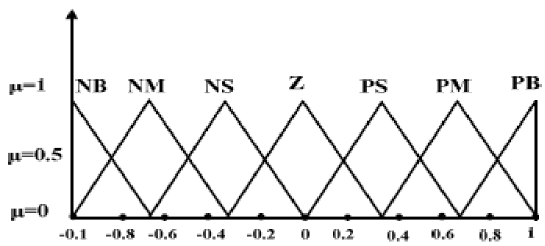

Fig 7: Membership function

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e \ Δe	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Fig 8: Rule base for fuzzy controller

V. SIMULATION RESULTS

The performance of the proposed structure is assessed by a computer simulation that uses MATLAB Software. Fixed band, sinusoidal band and fuzzy logic hysteresis control scheme is analyzed in this work. A flexible and simple simulation model PV cell, boost converter with MPPT controller, single phase inverter with fixed and sinusoidal band hysteresis control is developed. The PV array has been designed by considering the irradiance, temperature, number of PV cells connected in series and parallel. The simulation results P-Vcharacteristics of the PV model at temperature-28ºCand irradiance -100mW/cm2 are plotted and is shown in Fig. 9. For two-stage PV generation system, boost chopper circuit is always used as the DC-DC converter. Since the output voltage of PV cell is low, the use of boost circuit will enable low-voltage PV array to be used, as a result, the total cost will be reduced. The Fig.10 and Fig.11 shows the simulation result of the PV array fed boost converter and output voltage of proposed system. FFT analysis is carried out to find the THD of the proposed system.THD results of the proposed system is shown in figure12.

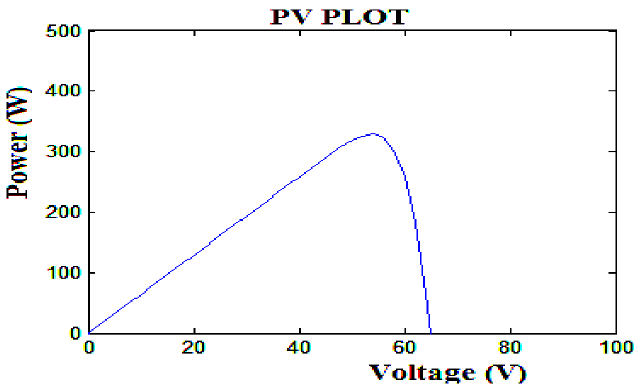

Fig. 9: P-V characteristics of the PV model

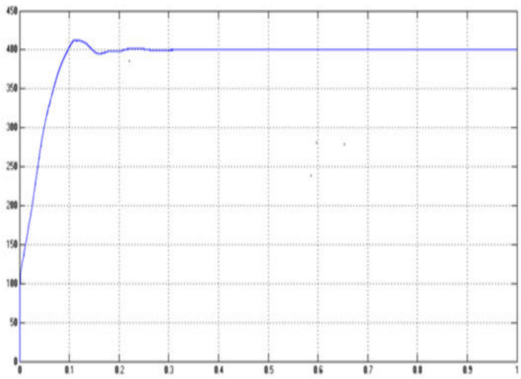

Fig. 10: Output voltage of fuel cell fed boost converter

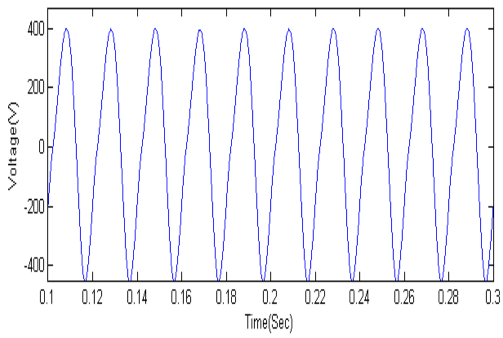

Fig. 11: Output voltage of the proposed system

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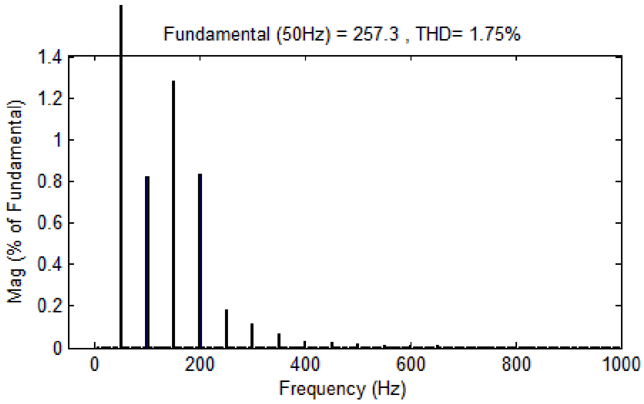

Fig 12: FFT analysis of output voltage

VI. PERFORMANCE ASSESSMENT OF 100 KW PV SYSTEM IN AMAL JYOTHI COLLEGE OF ENGG

Amal jyothi college of engineering has established 100KW capacity of grid connected solar photovoltaic plant in the college campus. The plant was fully commissioned on 28th April 2013. . The solar plant is located at a latitude of 9.36 N and a longitude of 76.36 E. The overall area occupied by photovoltaic modules is 15 Sq ft. The total installed capacity of the plant is 100KW. There are 432 panels with 40 cells parallel in each panel. A string contains 18 panel which is connected in series.4 such strings are connected to form a array junction box (AJB). 6 array junction box constitute main junction box(MJB).Output of main junction box is given to inverter. The solar photovoltaic modules are connected such that a voltage of 415 volts is generated at the output of inverter. The simple block diagram of the Plant is shown in figure 13.

The analysis was carried out for 15 days dated from 24 th july to 15 th august. In india especially in kerala july – august month is rainy season and this analysis give brief idea of grid connected PV plant in rainy season. The solar panels are located on roof top of automobile block and inverter in the ground floor. The solar irradiation, module temperature, ambient temperature, inverter output voltage , inverter output current, inverter output power were measured every one hour interval from 9 am to 4 pm. The inverter placed in the ground floor gives readings such as total energy, DC link voltage, AC voltage, DC voltage, output temperature. Separate monitoring systems are not provided with solar plant. So measurements have to taken manually.

Graphical analysis methods are used to identify the energy distribution and to explain the operational system behaviour, of the inverter in particular. The performance ratio is analysed at identical climatic conditions by extracting data with identical module temperatures and irradiances to detect small shifts of system performance.

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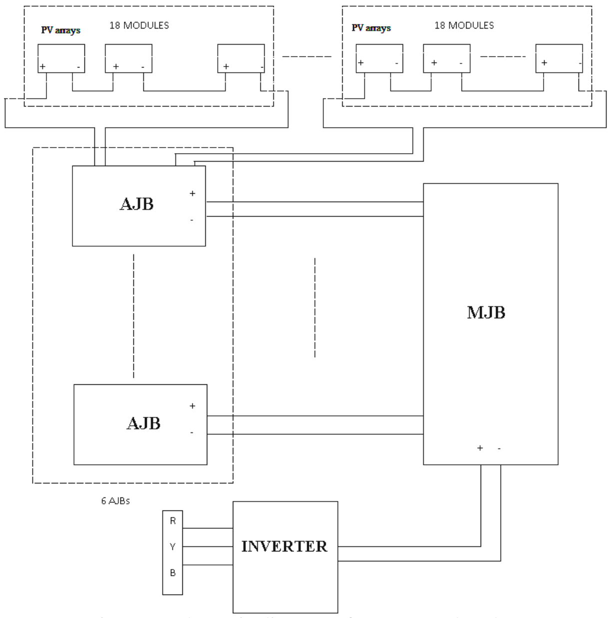


Fig. 13 : Schematic diagram of 100 KW solar plant

The performance of PV array is illustrated in the following figures. The DC output power generated by the PV modules is linearly dependent on the in-plane irradiance, except for lower irradiance values. At irradiance values lower than W/m2, the output power was found to be approximately zero. As the irradiance increases, the DC power generated by PV array correspondingly increases[13].

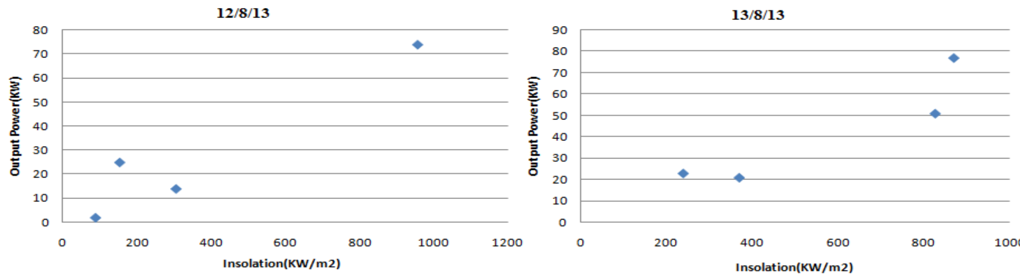
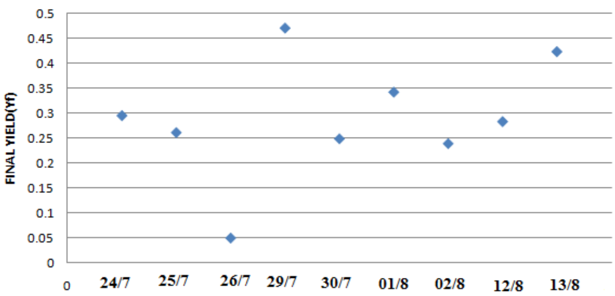


Fig 14: The relationship between the output power of PV array and the irradiance



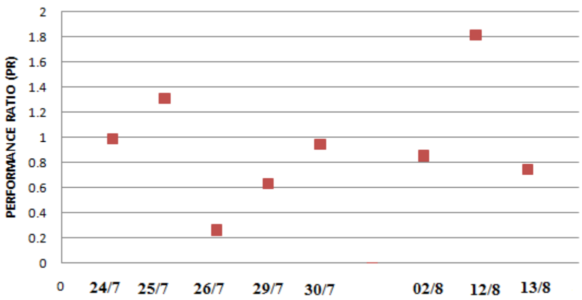


Fig. 15: Average Final Yield

Fig. 16: Average performance ratio

VII. CONCLUSION

Photovoltaic (PV) sources are used nowadays in many applications as they own the advantage of being maintenance and pollution free. A major application of PV is in the area of distributed or dispersed generation. Regarding practical

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problems associated with the interaction of the PV system with the grid .One of the major problems is the increase in the Total Harmonic Distortion (THD) of current injected into the grid during low solar radiation periods. A review of conventional methods for THD reduction for grid connected PV system is done. This thesis described a new scheme for controlling the line current THD in grid connected PV systems. Fixed band hysteresis control, sinusoidal band hysteresis control and fuzzy logic control of inverter is has been analysed. A MATLAB/SIMULINK model of Fixed band hysteresis control, sinusoidal band hysteresis control and fuzzy logic control of inverter were developed. Simulation results shows that a fuzzy logic control can provide a better performance and a reduced THD when compared to other controls. The performance of the 100 KW solar photovoltaic power plant has been analysed for 15 days. The total electrical energy generated by the plant till 13th august is 27567 kWh and the maximum output recorded was 77 KW. This is lower than expected for a solar power plant and is on account of teething trouble associated with inverters and since the analysis were carried out in rainy season. It was found that failure in inverters were the most frequent incidents. This is mostly caused by lack of experience in the initial production stage and some unexplained inverter failures might be caused by disturbance from the grid and other interconnected issues. The daily plots showing the variation of solar insolation with output power have been plotted for different days. Final yield and performance ratio of the system has been presented to assess the system performance based on the monitored data.

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