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GRID CONNECTED PHOTOVOLTAIC ARRAY MAXIMUM POWER POINT TRACKING USING FUZZY FOR DC-DC BOOST CONVERTER AND THREE PHASE INVERTER

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ABSTRACT

Photovoltaic solar electricity and solar thermal has the highest potential of all the renewable energies, since solar energy is a practically unlimited resource and available everywhere. These days photovoltaic energy has the potential to play an important role in the transition towards a sustainable energy supply system, to cover a significant share of the electricity needs, and is expected to be one of the key energy technologies of this century. This paper presents a grid-connected photovoltaic (PV) system with the functionality of on-line Maximum Power Point Tracking (MPPT) at different irradiation and temperatures. The used Simulation data characteristics for climatic changes is similarly to the real Egyptian climatic data. The integration topology based on two-stage power conditioning modules, boost converter and three phase voltage source inverter. Therefore, the proposed MPPT algorithm implemented to the boost converter to enable PV arrays to operate at maximum power point during variable climate and irradiation conditions. Fuzzy logic algorithm (MPPT) technique control applied for on-line adapting the boost converter’s duty cycle. The Boost output is feeding the two level PWM inverter DC link. Accordingly, the Inverter modulation depth is tuning to have constant AC voltage and frequency for grid integration requirements. In addition, the three-phase output current is in phase with the voltage to optimize the PV power utilization .The results show that proposed on-line fuzzy algorithm performance has a fast response, stable and reliable to have MPP for the PV system during the different irradiation.

تعتبر الطاقة الشمسية سواء الكهربية منها او الحرارية من أكبر مصادر الطاقات الجديدة والمتجددة، نظرا لأن الطاقة الشمسية متاحة عمليا في كل الأماكن وبطاقة انتاجية غير محدودة وتلعب الطاقة الكهربية المولدة من الخلايا الضوئية هذه الايام دورا هاما في التحول في اتجاه زيادة مساهمة الطاقات الجديدة والمتجددة بنسبة بليغة في تلبية الاحتياجات من الطاقة الكهربية ومن المتوقع ان تكون هي أحد الطاقات الرئيسية في هذا القرن. وتقدم هذه الورقة نظام خلايا ضوئية متصلة بالشبكة الكهربية بخاصية تتبع متواصل للتشغيل عند أقصى نقطة تشغيل (MPPT) رغم التغير في شدة الإشعاع الضوئي ودرجة حرارة وقد تمت المحاكاة باستخدم تغيرات مناخية مشابهه لمنحني التغير للبيانات المناخية الحقيقية لمصر. وتمت عملية الدمج للخلايا الضوئية بالشبكة الكهربية في النظام المقترح على مرحلتين متتاليتين وهما محول تيار مستمرمن نوع الرافع Boost converterبالتوالي مع عاكس ثلاثي الأوجه من نوع مصدر الجهد الكهربي Voltage source inverter ذو مستويين. نظام التحكم المقترح للتشغيل لتتبع أقصى نقطة تشغيل يعتمد على تطبيق تقنية المنطق الخوارزمي Fuzzy logic لتغير دورة عمل محول التيار المستمر وبالتالي ضبط عمق التعديل للعاكس ثلاثي الأوجه للحصول علي خرج جهد تيار متغير ثلاثي الأوجه ثابت القيمة والتردد ليتمشى مع متطلبات الربط بالشبكة الكهربية. يضاف الي ذلك ان تيار الخرج ثلاثي الأوجه يكون في نفس الطور مع الجهد مما يتيح الحصول علي أقصي قدرة من الخلايا الضوئية. تظهر النتائج ان أداء النظام المقترح للتحكم يتميز بسرعة الاستجابة والاستقرار وكذلك الاعتمادية لتبع تشغيل نظم الخلايا الضوئية عند أقصي نقطة عند شدة إشعاع ضوئي متغير.

***Keywords*:** PV array, Maximum power point, DC/DC boost converter, Voltage source inverter.

1. INTRODUCTION

Distributed The growing energy demand coupled with the possibility of reduced supply of conventional fuels, along with growing concerns about environmental preservation, has driven research and development of alternative energy sources that are cleaner, renewable and produce little environmental impact [1]. Among the alternative resources, the electrical energy from PV currently being regarded as the natural energy source distributed over the earth and participates as a primary factor of all other processes of energy production on earth. Moreover, although the phenomena of reflection and absorption of sunlight by the atmosphere, it is estimated that solar
Energy incident on the surface of earth is of the order of ten thousand times greater than the world energy

Consumption [2]. In this context, the concept of distributed energy generation, became a real and present technical possibility, promotion various researches and standardizations in the world. Despite all the advantages presented by the generation of energy through the use of PV's, the efficiency of energy conversion is currently low and the initial cost for its implementation is still considered high, and thus it becomes necessary to use techniques to extract the maximum power from these panels, to achieve maximum efficiency in operation. It is noted that is only one point of maximum power (MPP) and this varies according to climatic conditions. The photovoltaic power characteristics is nonlinear, which vary with the level of solar irradiation and temperature, which make the extraction of maximum power a complex task, considering load variations. To overcome this problem, several methods for extracting the maximum power is been proposed in literature [3-4], and a careful comparison of these methods can result in important information for the design of these systems. There are a lot of techniques are used for MPPT such as Fixed Duty Cycle, Constant Voltage, Perturb and Observe (P&O) and Modified P&O, Incremental Conductance (IC) and Modified IC, Ripple Correlation and System Oscillation methods, which are briefly described in this section [5-6].

This paper, target is to have an on-line efficient optimization (MPPT) algorithm using fuzzy logic technique. In the studied power system PV, integration to grid has done using two stages; the PV array output connected to DC-DC converter followed by two level voltage source VSPWM inverter to the grid. Maximum power point tracking (MPPT) techniques is used to control the DC converter to extract maximum output power from under a given weather condition. The DC converter is on-line continuously controlled to have the maximum power point operation for the PV array in despite of the possible changes either on the climate condition and/or in the load impedance. To achieve this paper's target; the paper organized in the following sequences|:

- Modeling of PV - grid connected system with MPPT techniques facility using MATLAB.
- Simulation of PV–gird system during weather variation represented by an actual daily solar irradiation curve.
- Dynamic response of the algorithm characterized by driving the PV system into its MPP's operation while ensuring that the injected current remains in phase with the grid voltage to achieve a unity power factor.
- Investigate the interactions between the PV system outputs and the grid.

2. MODELING OF THE PV-GRID CONNECTED SYSTEM:

Power system under study single line diagram illustrated in Fig. 1. It consists of 22 kV-interconnected network. The studied PV array is poly crystalline silicon each cell power maximum of 56W and consists of 36 series cells per module with an open circuit 20.8V, 16 series connected modules and 123 parallel with total maximum power rating of 100 kW connected to the grid and to each other's. The PV arrays interconnected to the grid through DC/DC boost converter and DC/AC three-phase two-level inverter. After inversion, the arrays interfaced to the grid through a transformer 220V /22 kV of rated 125 kVA. A local load of active power of 50 kW has connected to the grid integration bus at PV point of common coupling.

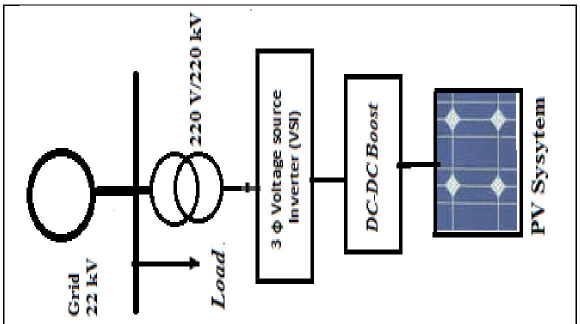


Fig.1: Studied PV grid connected single line diagram

2.1 PV Array:

The equivalent circuit model of a PV cell is been needed to simulate its real behavior using the physics of p-n junctions; a cell can be modeled as a DC current source in parallel with diode that represents the most effective current escaping due to diffusion and charge recombination mechanisms. Two resistances, series and shunt are included to m represent the contact resistances and the internal PV cell resistance respectively. These two resistance values are been usually obtained from measurements or applying the curve fitting technique based on the cell I-V characteristic [7]. The equivalent circuit model of a PV cell is essential to simulate its real behavior using the physics of p-n junctions. A cell can being modeled as a DC current source in parallel with diode that represents the most effective current escaping due to diffusion and charge recombination mechanisms. Two resistances, R_s and R_p are included to represent the contact resistances and the internal PV cell resistance respectively. These two resistance values are identifying from measurements or applying the curve fitting technique based on cell I-V characteristic. Current source I_{ph} represents PV cell current. The relationship between PV's output current and terminal voltage is given by [8]:

$$I = I_{ph} - I_{rs}\left[\exp\left(\frac{q(V+IR_s)}{AKT}\right)-1\right] - \frac{V+IR_s}{R_p} \qquad (1)$$

Where; A is the diode ideality factor, k is the Boltzmann constant (1.3806503 × 10^{-23} J/K), T is the cell temperature in Kelvin, q is the electron charge (1.60217646 × 10^{-19} C), I_{rs} is the reverse saturation currents of the diode, respectively. PV cells normally grouped in larger units called PV modules, which are interconnects in a parallel-series configuration to form PV arrays or PV generators. Assuming high value of R_p then for an array with N_s series and N_p parallel-connected cells, the array current related to the array voltage as:

$$I = N_p\left[I_{ph} - I_{rs}\left(\exp\left(\frac{q(V+IR_s)}{AKTN_s}\right)-1\right)\right] \qquad (2)$$

Where: $$I_{rs} = I_{rr}\left(\frac{T}{T_r}\right)^3 \exp\left[\frac{E_G}{AK}\left(\frac{1}{T_r}-\frac{1}{T}\right)\right] \qquad (3)$$

Where; I_{rs} is the cell reverse saturation current at temperature T, while T_r is the cell reference temperature, $I_{rr}$is the reverse saturation current at T_r and E_G is the band gap energy of the semiconductor used in the cell. The photo current I_{ph} depends on the cell's temperature and radiation as follows:

$$I_{ph} = [I_{SCR} + k_i(T - T_r)]\frac{S}{100} \qquad (4)$$

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.

A grid-connected PV solar system is to transfer the maximum power obtained from the PV panel into the grid independently of the climatic conditions. Therefore, the use of an appropriate electronic interface with maximum power point tracking (MPPT) capabilities is required. The output power of the PV cell has a nonlinear function with irradiance and temperature. Therefore, the power of the PV array changes continuously and consequently the PV operating point must change to maximize the energy produced by adjusting array voltage to its calculated maximum value at certain irradiation and temperature. Figure 2 shows the used power- voltage characteristics of the used PV array at different real climate Egyptian conditions and the target maximum power points for the proposed control system.

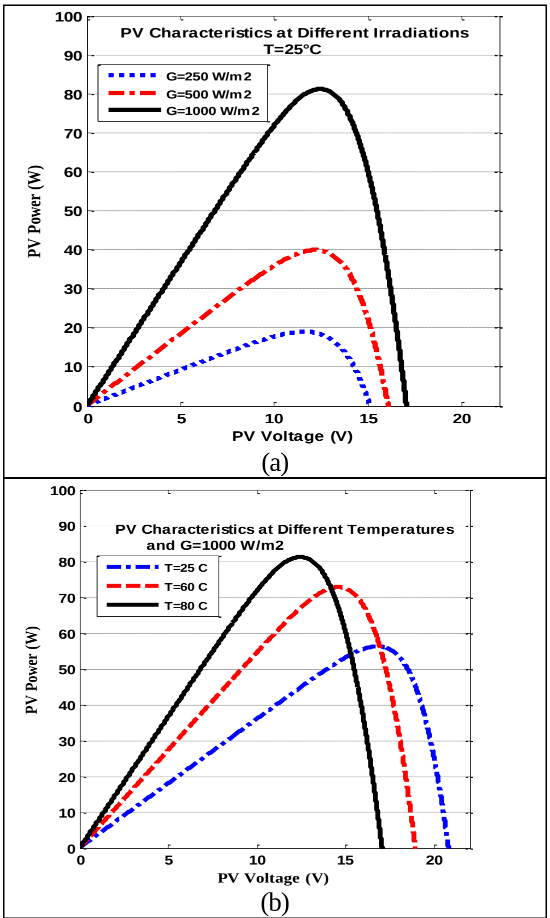


Fig.2: PV model characteristics at Different; a) radiation & b) temperature

2.2. Boost Chopper:

A buck boost converter is a power converter with an output DC voltage greater or less than its input DC voltage depending on its duty cycle (d). By implementing the PWM technique on the buck boost converter, a stable output voltage from a non-stable input voltage obtained by changing the duty cycle (d) of the switched input pulse. The buck boost converter with a switching period (Ts), and on-period of (Ton)the relationship between output V_o and V_{in} voltage is governed by [9];

$$\frac{V_o}{V_i} = \frac{1}{1-d}; \quad (5) \quad \text{Where; } d = \frac{T_{on}}{T_s} \quad (6)$$

After determining the value for V_{MPP}, the DC/DC buck boost converter being switched to quickly force the array terminal voltage to its MPP. As illustrated in Fig. (3), the difference between MPP fraction voltage and the array output represents the error of the PI controller. This PI controller regulates the PV array voltage by continuously switching on and off for the IGBTs at high frequency according to the varying duty cycle. The fast switching action of the boost converter decouples the dynamics of the PV array due its changes in voltage or current from that of the DC link capacitor, which offers good performance under changing weather conditions. The other advantage of using the boost converter is to increase the array voltage to higher levels suitable for grid interconnection.

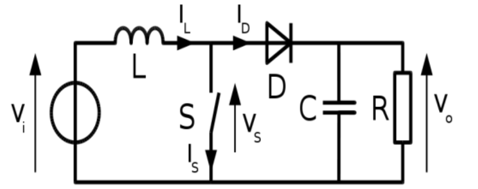


Fig. 3: Boost DC-DC converter

2.3. Three -Phase Voltage Source PWM Inverter:

Among various modulation techniques for MMI, PWM is an attractive candidate due to efficient DC link voltage utilization, reducing commutation losses and total harmonic distortion THD. The proposed inverter is a three-phase, two-level DC/AC inverter using IGBTs due to their lower switching losses. Depending on the gating signals, the output terminal voltage is either equal to capacitor voltage or zero, and expressed by [10]:

$$V_{inv} = N * V_{cap} \quad (7)$$

Where; V_{inv}, N, and V_{cap} are terminal voltage, gating signal and capacitor voltage, respectively. N takes the value of either one or zero. In the two-level inverter, the switching of the upper and lower IGBT generates the output voltages with positive and negative levels (+Vdc and -Vdc). The inverter connected to the network at the PCC through the equivalent inductance and resistance, which represent the impedance of the coupling transformer. The magnetizing inductance of the step-up transformer taken into consideration through a mutual equivalent inductance. The aim of the control strategy is to regulate the current output from the inverter to follow a specified reference value. This was been achieved by transforming the three phase output currents of the inverter to the rotating reference frame (dq0). The relation between the DC side voltage V_{dc} and the generated AC voltage V_{inv} described through the matrix in the *dq*-frame S_{av}, *dq*, as given by:

$$\begin{bmatrix} V_{inv,d} \\ V_{inv,q} \end{bmatrix} = S_{av,dq} V_{dc} \quad (8)$$

Where; $S_{av,dq} = 0.866\, m_i$ (9)

Where m_i is the inverter modulation index. A phase locked loop was been used to lock on the grid frequency in such a way that V_q was set to zero [11]. If the grid voltage is relatively constant, I_d and I_q can be used to control real and reactive power injections from the PV array. In order to inject real power from the inverter, I_d was controlled using PI controller to follow a specified reference signal I_{d_REF}, reactive power injection was set to zero and thus $I_q = 0$, as displayed in Fig.2. The I_{d_REF} was been extracted from the DC link capacitor. A constant DC voltage across the capacitor means that the power that goes into it from the PV array matches the power going out to the inverter [12]. As previously mentioned, the input power $P_{in}$to the capacitor controlled to be the MPP of the PV array output power by the DC-DC converter. The PI controller used to extract I_{d_REF} from the error mismatch between P_{in} and P_{out} according to the following relation:

$$I_{d\_REF} = \frac{1}{V_d}\left(K_p(P_{in} - P_{out}) + K_I \int (P_{in} - P_{out})dt\right) \quad (10)$$

Where; K_P and K_I are the proportional and integral controller constant, respectively and V_d is the direct component of the voltage at PCC. The output of the PI-Controller is Modulation index m, which feeds to PWM switching circuit.

3. PROPOSED CONTROL TOPOLOGY

This section describe two main parts the proposed global PV MPPT control scheme philosophy and secondly the proposed fuzzy logic algorithm to apply the MPPT concept. As shown in Figure (4), the block diagram of the global MPPT concept. A photovoltaic array used to convert sunlight into DC current. The output of the array connected to a boost DC converter that used to perform MPPT functions and increase the array terminal voltage to a higher value so it interfaced to the grid at 22 kV. The DC converter controller used to perform these two functions. A DC link capacitor used after the DC converter and acts as a temporary power storage device to provide the voltage source inverter with a steady flow of power. The capacitor's voltage regulated using a DC link controller that balances input and output powers of the capacitor. The voltage source inverter is controlled in the rotating *dq* frame is to inject a controllable three phase AC current into the grid. To have unity power factor operation; current is injected in phase with the grid voltage. A phase locked loop (PLL) is used to lock on the grid frequency and provide a stable reference synchronization signal for the inverter control system, which works to minimize the error between the actual injected current and the reference current obtained from the DC link controller. A load connected to the grid to simulate some of the loads that are been connected to a distribution system network.

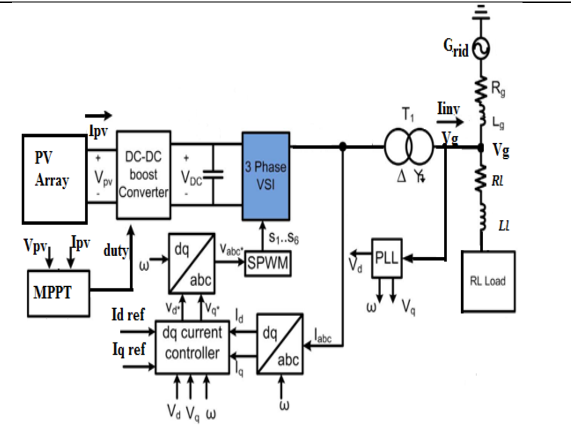


Fig. 4: PV grid connected control block diagram

3.1 Proposed MPPT Fuzzy Algorithm:

There are for Fuzzy logic MPPT's algorithm has three sequential stages; fuzzification, rule based on the look-up table and finally the defuzzification. During fuzzification process, control variable are been converted from a numerical value to a linguistic representation [13]. In this paper, Mamadani fuzzy type used as shown in Fig. (5.a) with two inputs. These inputs are the error between the actual PV power and the maximum reference power cross ponding to the synchronized irradiation and the change of this error. The fuzzy controller output is the DC boost duty cycle. The fuzzy surface to show the ranges and the relation between the inputs and the output memberships illustrated in Fig. (5.b). Twenty-one rules between the inputs to achieve the requested output target. This target is to minimize the error and the rate of error to zero to achieve the tracking for PV power equal to the MPP.

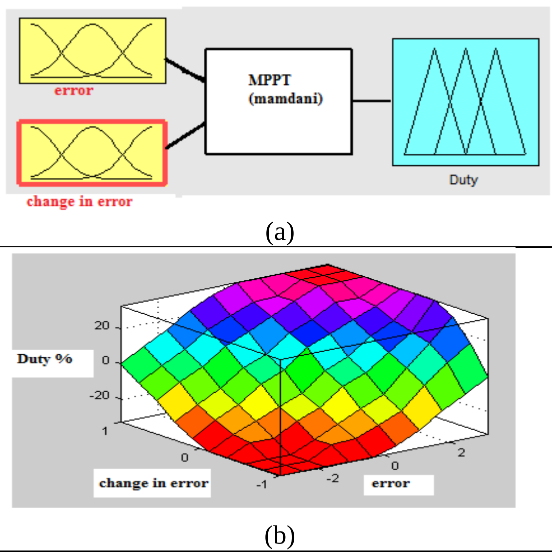
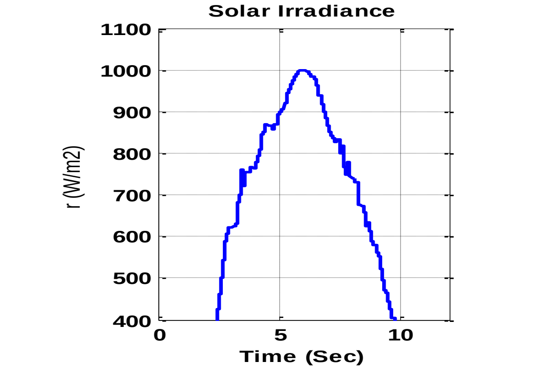


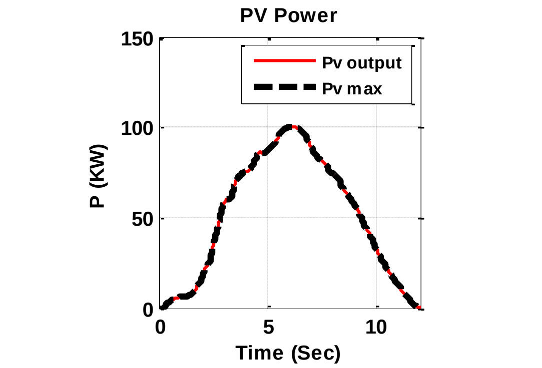
Fig.5: Fuzzy logic MPPT controller, a) Main structure, b) surface

4. SIMULATION RESULTS:

Studied power system for PV grid connected system at a daily irradiation and temperature of 25˚C using MATLAB /Simulink program simulated in this part to verify the dynamic and steady state response of the proposed fuzzy MPPT control system. In besides that monitoring of the DC and AC voltages and currents in the PV array and the associated power conditioning system. Figure (6.a) present the irradiation data which is typically get from the Arab Organization for Industrialization (AOI) Cairo irradiation records on summer 2011 at temperature of 25˚C to verify the performance at Cairo irradiation conditions[14]. Fig.(6.b) shows that the PV output after applying the proposed control to have MPPT is so closely and equal to the target calculated maximum power from the (Power /voltage) curve of the PV array at the different solar irradiation which already shown in Fig.(2.a). While Fig. (6.c) illustrates the PV array dc voltage changes during the different conditions of radiation. The DC-DC Boost converter performance illustrated in Figure (7). The duty cycle behavior is shown in Fig.(7.a) , it is changes to increase the Boost output voltage during the decreasing of the irradiation and its values ranged from 0.45 to o.6 . While Fig. (7.b) present the output Vdc with its reference values, it shows that the Vdc is follow the Vdc reference values that validate the proposed control technique. The second stage of voltage conditioning unit, three- phase voltage source inverter using pulse width modulation parameters have shown in Fig. (8). In Fig. (8.a) the modulation depth performances illustrated while the output three phase Voltage and current have shown in Fig. (8.b &8. c) respectively. It shows that the modulation depth is dynamically interacted with fast response to have a constant AC voltage output, which is essential for PV grid synchronizing. In addition, the three phase injected current is in phase with output voltage to have maximum utilization from the PV system. The three power components, load power, PV output and grid power sharing at the point of common coupling at the grid Bus in presented at Figure (9). As shown, the load power is constant while the way of supplying this load changed depending on the PV system output. When the irradiation is high; the PV power is greater than the load and the extra power is supplied to the grid. While if the irradiation decreased, and the PV output power is less than the load, in this case the load is complimentary supplied from both and the PV.



(a)



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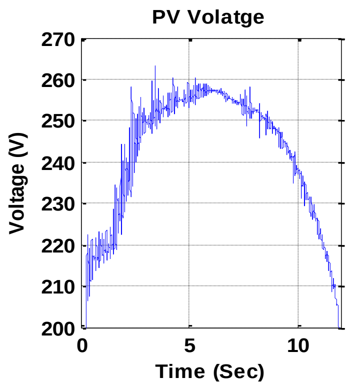
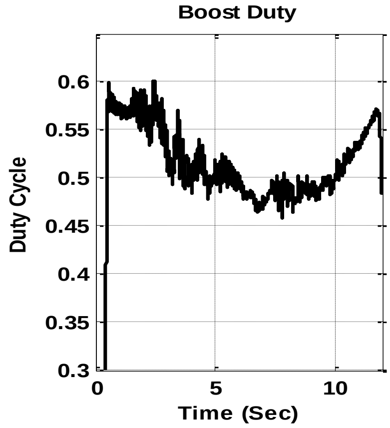
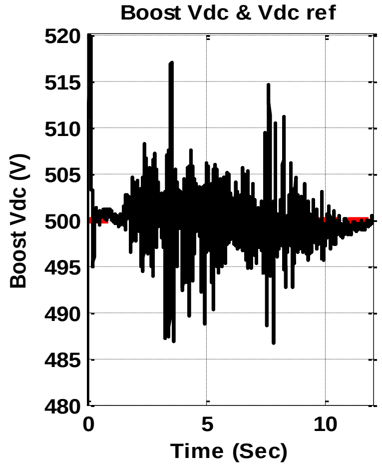


(C)

Fig.6: irradiation and PV array output; a) irradiation, b) PV power and C) PV voltage.



(a)



(b)

Fig.7: DC-DC Boost performance; a) Duty cycle, b) Vdc and Vdc reference

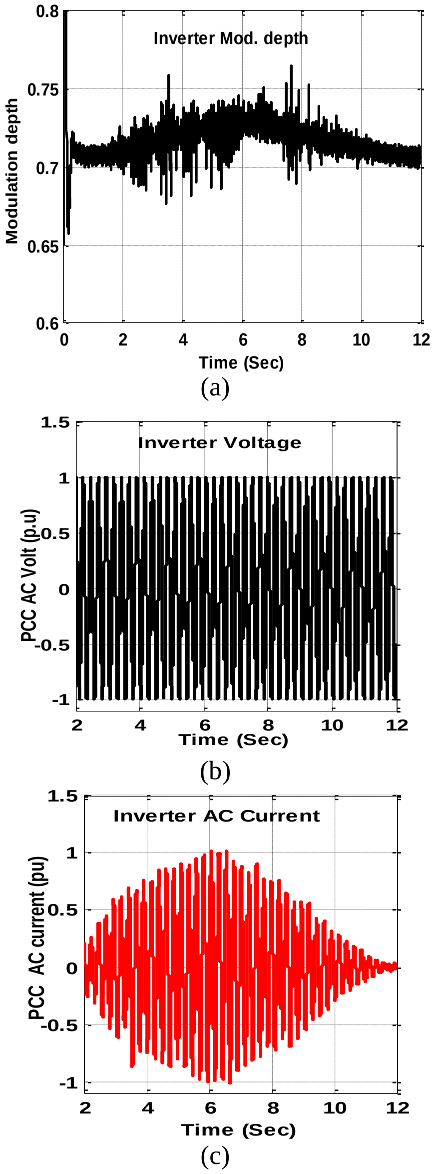


Fig.8: Three- Phase VSI Inverter; a) modulation depth, b) PCC AC Volt. and c) PCC AC current

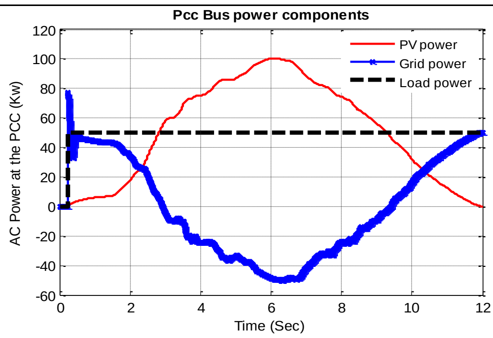


Fig.9: Power components at grid Bus.

5. CONCLUSIONS:

Modelling of grid connected photovoltaic system elements with two sequential stages of power electronic modules, DC-DC boost converter and three -phase two level voltage source PWM inverter had presented. Design of on-line control system to have Maximum power point tracking from the PV array using Fuzzy Logic Controller algorithms was been introduced. The results show that the proposed on-line fuzzy logic controller of the MPP offers clearly short settling time, accurate tracking the reference voltage during all the weather conditions. In addition, the proposed MPPT control algorithm performance is stable, fast, reliable and adaptive for implementation of PV micro grids and high voltage grid integration.

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