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Modeling & Analysis of Power Management by Grid Connected PV System

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Now-a-days the DG system based on PV technology is becoming more popular with rang of power generation is between 1 KW to 50 KW because of its advantages like safe, clean, quiet to operate, reliable, maintenance free, flexible etc. Main objective of this paper is the Modeling of PV System components & Analysis of power management is carried out using the MATLAB/SIMULINK platform for different load & different insolation levels. In this paper it is presented that whenever load demand is less than PV capacity then remaining power is supplied to grid and whenever the load demand is more than PV capacity then load will consume the required power from the grid.

Keywords *Photovoltaic (PV), Power Management, MATLAB, Grid.*

1.0 INTRODUCTION

The word photovoltaic comes from "photo", meaning light, and "voltaic", which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight". Photovoltaic is often referred to as PV [1].

Major advantages of PV are: They are safe, clean and quiet to operate; They are highly reliable; They require virtually no maintenance; They operate cost-effectively in remote areas and for many residential and commercial applications; They are flexible and can be expanded at any time to meet your electrical needs; and They give you increased autonomy – independence from the grid or backup during outages; When the loads are located far from the grid, a PV system will be a great application to cut costs related to supplying power for this load(s); PV systems are reliable and last a long time with minimal maintenance. Disadvantages found in PV are: Unpredictable output; High capital cost; Since solar is minimally subsidized compared to polluting energy technologies, the initial cost of solar seems a bit high–when compared directly; Costumers don't always know about the potential of solar energy – It takes time to educate these clients. Its Conversion efficiency is around 12.8%.

PV systems are used for Cottages and Residences, for Mobile and Recreational applications, in Agriculture, for other applications like in calculators and watches. As well, tele communications equipment, highway construction signs, parking lights and navigational warning signals etc.

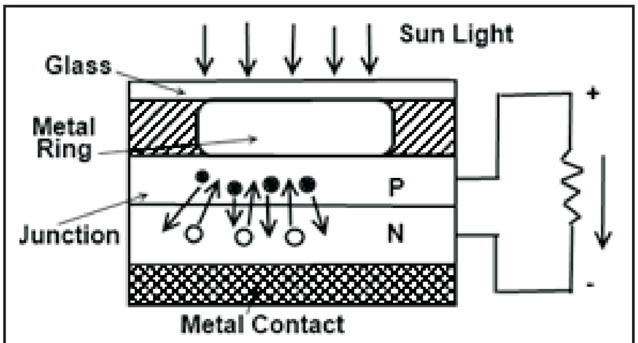

FIG. 1 BASIC SOLAR CELL CONSTRUCTION.

The basic construction of solar cell is shown in Figure 1. PV cells convert sunlight directly into electricity without creating any air or water

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pollution. PV cells are made of at least two layers of semiconductor material. One layer has a positive charge P, the other negative N. When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current [1].

For a PV system, the voltage output is a constant DC whose magnitude depends on the configuration in which the solar cells/modules are connected. On the other hand, the current output from the PV system primarily depends on the available solar irradiance. The main requirement of power electronic interfaces for the PV systems is to convert the generated DC voltage into a suitable AC for consumer use and utility connection. Generally, the DC voltage magnitude of the PV array is required to be boosted to a higher value by using DC-DC converters before converting them to the utility compatible AC. The DC-AC inverters are then utilized to convert the voltage to 50 Hz AC. The process of controlling the voltage and current output of the array must be optimized based on the weather conditions. Specialized control algorithms have been developed called maximum power point tracking (MPPT) to constantly extract the maximum amount of power from the array under varying conditions. The MPPT control process and the voltage boosting are usually implemented in the DC-DC converter, whereas the DC-AC inverter is used for grid-current control [2].

2.0 MODELING OF PV SYSTEM COMPONENTS

The block diagram of a PV grid-connected system is shown in Figure 2. The main objective from this interfacing is to feed all the collected energy at the PV plant to theload & remaining power into grid. Here two stage grid connected PV system is used. The modeling of PV system consist of mainly of five parts: the PV array, MPPT controller, Boost converter, Line side converter controller and LCL filter. Detailed modeling of this PV system is done using the references [3-6].

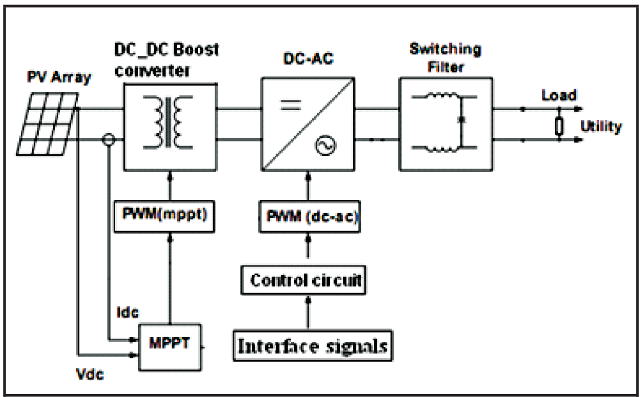


FIG. 2 GRID CONNECTED TWO STAGE PV SYSTEM

2.1 PV Array

Basically, PV cell is a P-N semiconductor junction that directly converts light energy into electricity. It has the equivalent circuit shown in Figure 3 [7].

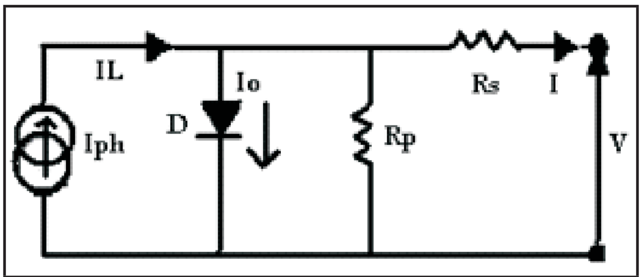


FIG. 3 EQUIVALENT PV CELL CIRCUIT.

Where,
I_o = Temp. dependence diode saturated current,
$I_{ph} = I_L$ = Temp. dependence photo current
R_s = series resistance &
R_p = shunt resistance parallel with diode.
(not used here)

The equations which describe the I-V characteristics of the cell are [8]:

$$I = I_L - Io\,(e^{q\,(V+IRs)/nkT}-1) \quad ....(1)$$

$$I_L = I_{L(T1)}\,(1+ Ko\,(T-T_1)) \quad ....(2)$$

$$I_{L(T1)} = G * Isc_{(T1,\,nom)} / G_{(nom)} \quad ....(3)$$

$$Ko = (Isc_{(T2)} - Isc_{(T1)}) / (T_2-T_1) \quad ....(4)$$

$$Io = Io\,(T_1) * (T/ T_1)^{3/n} * e^{-qVg/nk*(1/T\,-\,1/T_1)} \quad ....(5)$$

$$Io\,(T_1) = Isc_{(T1)} / (e^{qVoc\,(T1)\,/\,nkT1} -1) \quad ....(6)$$

$$Rs = -dV / dIvoc - 1/Xv \quad ....(7)$$

$$Xv = Io_{\,(T1)}*q/nkT1* e^{qVoc\,(T1)/nkT1} \quad ....(8)$$

Where,

k = 1.38e-23 J/K ; Boltzmann's const

q = 1.60e-19 coulomb; charge on an electron

G = num of Suns (1 Sun = 1000 W/m^2)

T = Temp in Deg C

A = 1.2 ; diode quality factor

Vg = 1.12 eV; band gap voltage

Ns = 36 ; number of series connected cells

Nsa = 32 ; No. of series modules in string

Npa = 25 ; No. of parallel modules in string

Pmax (array) = 47250 watt ; Maximum power output for Suns = 1

To increase the utility, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module.To achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV array. Here Solarex MSX60 PV module [8] is used to make an array where 32 modules are connected in series and 25 modules are connected in parallel to design a 47 kw PV array for 1 kw/ m^2 of insolation.

2.2 MPPT Algorithm

The power delivered by a PV system of one or more photovoltaic cells is dependent on the irradiance, temperature and the current drawn from the cells. Maximum Power Point Tracking (MPPT) is used to obtain the maximum power from these systems. Such applications as putting power on the grid, charging batteries, or powering an electric motor benefit from MPPT. In these applications, the load can demand more power than the PV system can deliver. In this case, a power conversion system is used to maximize the power from the PV system [9].

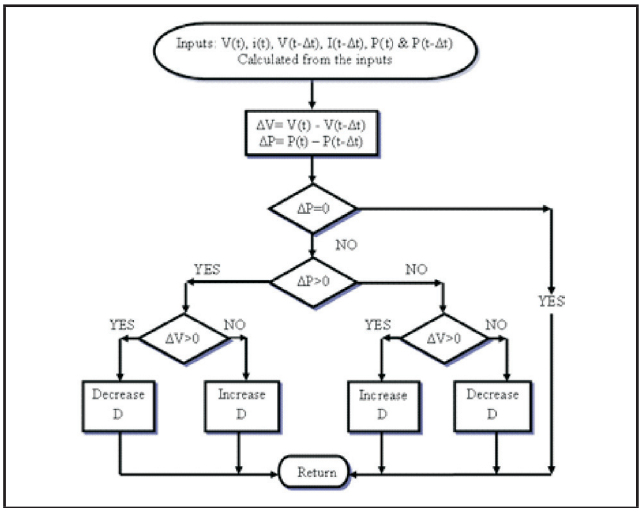


FIG. 4 THE FLOWCHART OF THE P & O ALGORITHM

Different MPPT methods include: Constant Voltage; Open Circuit Voltage; Short Circuit Current; Perturb and Observe; Incremental Conductance; Temperature Parametric; Fuzzy logic control; Neural network. Among these techniques, the Perturb and Observe (P&O) and Incremental conduction algorithms are the most common. Here in this paper Perturb and Observe MPPT method is used.The flowchart of the P & O Algorithm is shown in Figure 4

2.3 Line Side Converter Controller

This line side converter can operate in both isolated and grid connected mode. The main objective of this controller is to maintain the dc-link and load side voltage level constant.

Isolated mode:

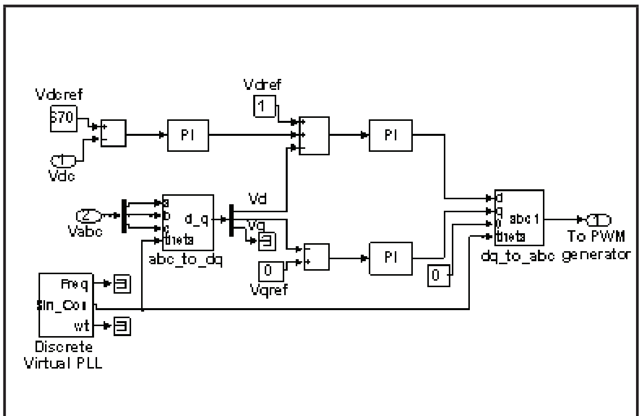


FIG. 5 SIMULINK/MATLAB MODEL OF LINE SIDE CONVERTER CONTROLLER FOR ISOLATED MODE

Figure 5 shows the simulink model of control scheme for line side converter for isolated mode. There is no grid connected in this mode so in terms of amplitude and frequency the output voltage need to be controlled and hence active and reactive power flow is controlled. A standard PI controller is used. The controller is consists of output voltage controller, which will control the output voltage with a minimal influence from the shape of the load current or load transients. And dc-link voltage controller, which operates only when the dc-link level is below the reference. Virtual PLL block is used to regulate the frequency [10].

Grid connected mode:

Figure 6 shows the simulink model of control scheme for line side converter for grid connected mode. There are two loops which use the standard PI controller to regulate the current and voltage.

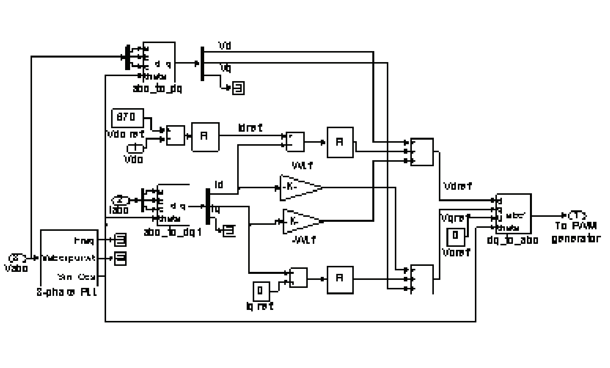


FIG. 6 SIMULINK/MATLAB MODEL OF LINE SIDE CONVERTER CONTROLLER FOR GRID CONNECTED MODE

Inner loop which regulates the grid current and outer loop which regulates the dc voltage. By imposing an i_d current component, PI controller regulates the DC bus voltage. Active and reactive component of the injected current are i_d and i_q respectively. i_q current reference is set to zero in order to obtain only a transfer of active power. For the independent control of both i_d and i_q, the decoupling terms are used. To synchronize the converter with grid, a 3 phase PLL is used. PLL reduces the difference between grid phase angle and the inverter phase angle to zero using PI controller and hence synchronize the line side inverter with grid [10].

2.4 LCL Filter

Figure 7 shows the Simulink model of LCL filter. The transfer function of the LCL filter designed by the output voltage to input current is given as follow.

$$G^{\alpha\beta}(s) = \frac{\frac{1}{L_1 + L_2 C}}{s[s^2 + \frac{L_1 + L_2}{L_1 L_2 C}]} \qquad ....(9)$$

The main function of this LCL filter is to filter out the high frequency component caused by the inverter switching operation. Also it affects the low order harmonic performance of the system. According to the attenuation needed in order to reduce high frequency components of line current, the LCL design depends. By taking properly designed inductor, current ripple can be reduced. Using the transfer function of the LCL filter and taking resonance frequency and low ripple current, the inductor values are determined. The capacitor value is rated with the accepted reactive power level of the capacitor for LCL filter [10]. L1 = 6.5 mH, L2= 1 mH, C = 3.5 kvar.

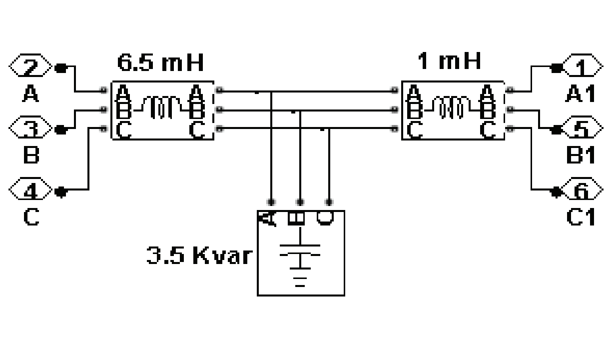


FIG. 7 SIMULINK/MATLAB MODEL OF LCL FILTER

3.0 MATLAB SIMULINK MODEL OF GRID CONNECTED PV SYSTEM

The simulink model used for grid connected PV system is shown in Figure 8. For the isolated mode the same model is used by disconnecting the 3 phase source (Grid) and using line side converter controller of Figure 5, instead of using that of Figure 6 The performance of the model is studied for different values of load. (35 kw, 20kw and 55 kw) and also under different insolation condition (for 0.8 , 0.6 and 1 kw/m^2). Table 1 shows the list of parameters used in PV system

Specifications

TABLE 1	
LIST OF PARAMETERS USED IN PV SYSTEM	
Photovoltaic array:	No. of series modules in string Nsa= 32; No. of parallel modules in string Npa=25; Output voltage rating = 540 V; Output current rating = 87.5 A; Maximum power output =47250 watt (for insolation level = 1 kW/m^2)
Boost converter:	C1=1000 µF , L= 0.5 mH, C2= 1000 µF
Grid parameter:	R =0.4 Ω, L=2 mH, 480 V, 50 Hz
LCL filter :	L1 = 6.5 mH, L2= 1 mH, C = 3.5 kVA_r
Load:	35, 20 & 55 kW
Insolation Level	0.8 , 0.6 & 1 kW/m^2

System Configuration

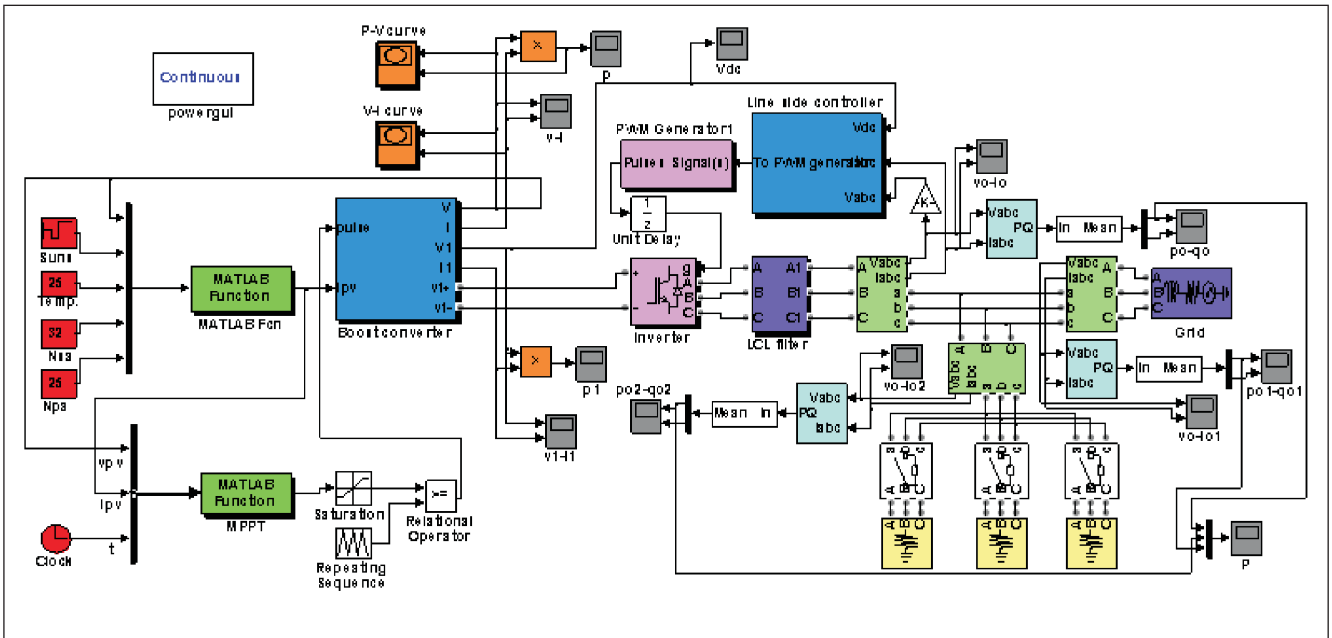
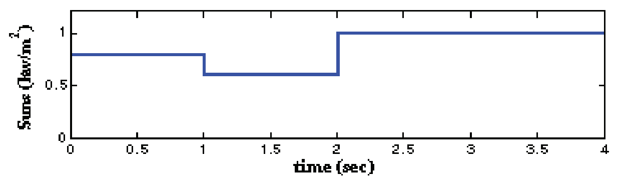
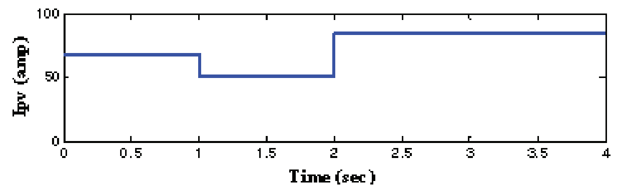


FIG. 8 SIMULINK/MATLAB MODEL OF PV SYSTEM WITH GRID CONNECTED MODE

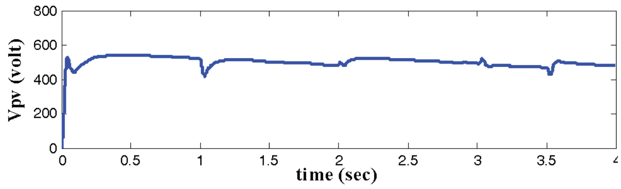
4.0 SIMULATION RESULTS



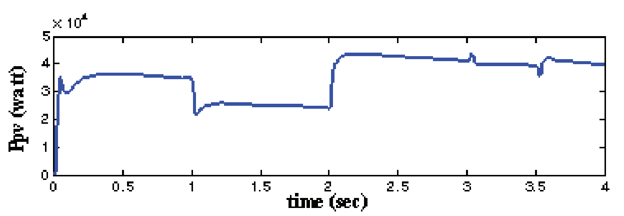
(A) DIFFERENT INSOLATION LEVEL



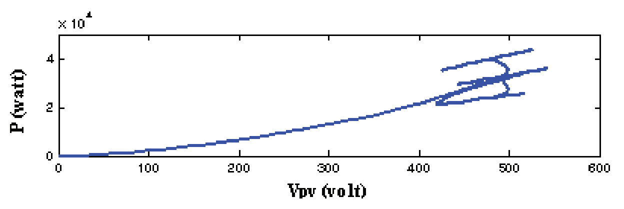
(B) PV CURRENT



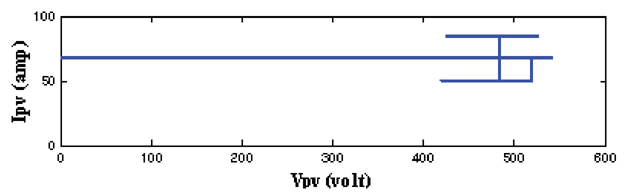
(C) PV VOLTAGE



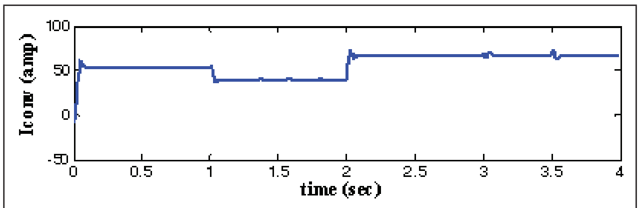
(D) OUTPUT POWER OF PV



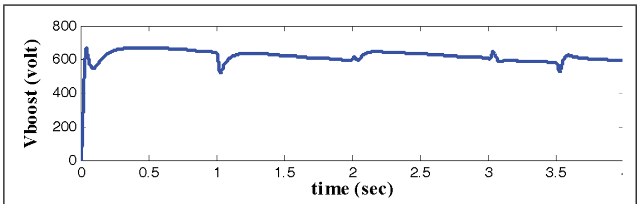
(E) P-V CURVE



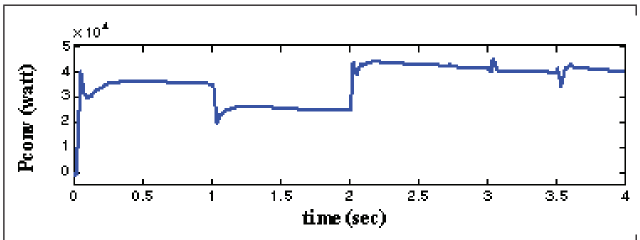
(F) V-I CURVE



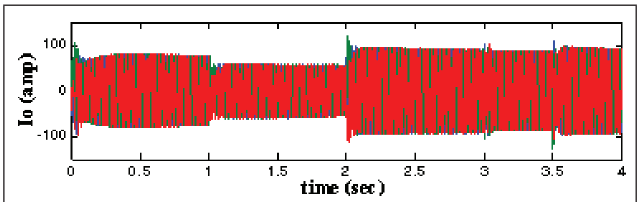
(G) OUTPUT CURRENT OF BOOST CONVERTER



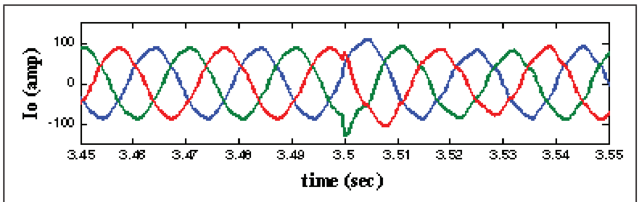
(H) OUTPUT VOLTAGE OF BOOST CONVERTER



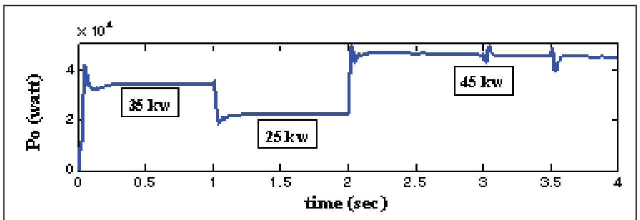
(I) OUTPUT POWER OF BOOST CONVERTER



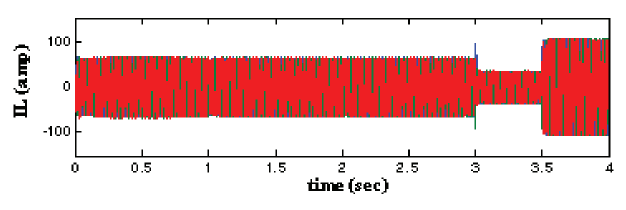
(J) OUTPUT CURRENT OF PV INVERTER



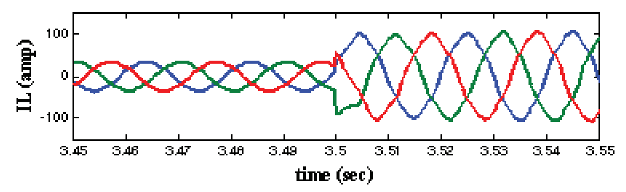
(K) ENLARGED VIEW OF OUTPUT CURRENT OF PV INVERTER



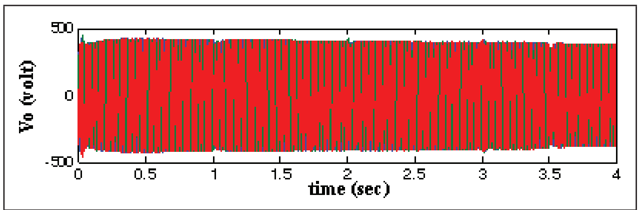
(L) OUTPUT POWER OF PV INVERTER



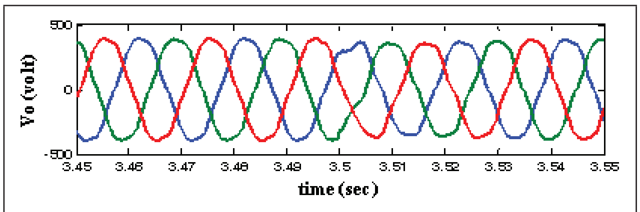
(M) LOAD END SIDE CURRENT



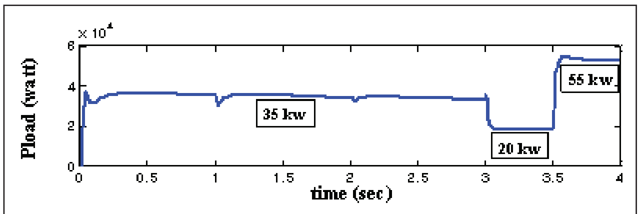
(N) ENLARGED VIEW OF LOAD END SIDE CURRENT



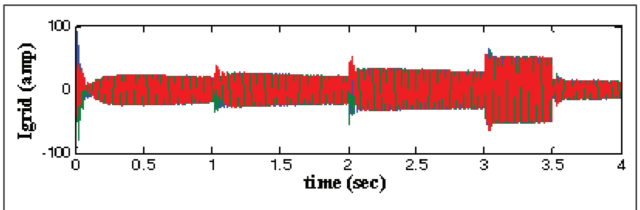
(O) LOAD END SIDE VOLTAGE



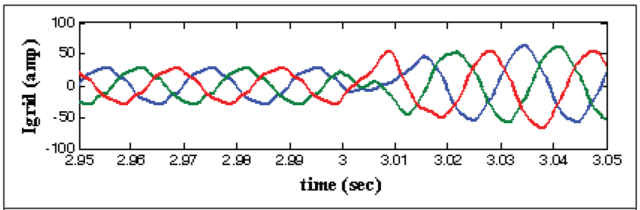
(P) ENLARGED VIEW OF LOAD END SIDE VOLTAGE



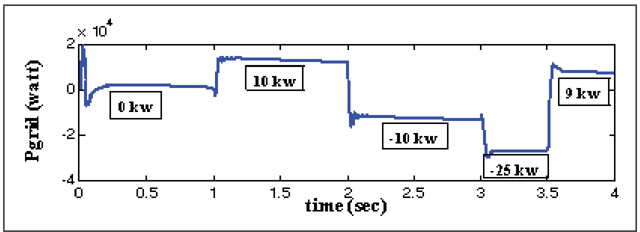
(Q) REQUIRED LOAD POWER



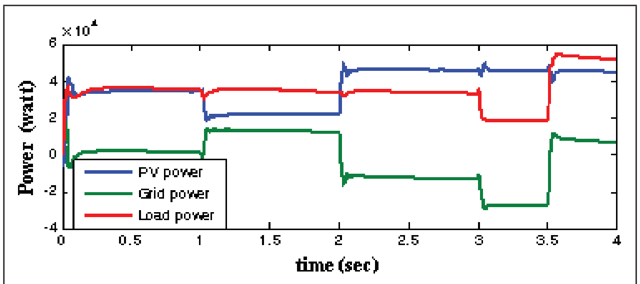
(R) GRID CURRENT



(S) ENLARGED VIEW OF GRID CURRENT



(T) GRID POWER



(U) COMPARISON BETWEEN DIFFERENT POWER VARIATION

FIG. 9 SIMULATION RESULTS OF PV SYSTEM FOR GRID CONNECTED MODE.

5.0 ANALYSIS OF MATLAB SIMULATION RESULTS

The results of the simulation are shown in Figure 9 for different load and insolation levels. Here different insolation level is shown in Figure 9 (a). according to that level PV current, voltage and power variation is as shown in Figure 9 (b), (c) and (d) respectively. Voltage level remains almost constant during the different insolation level according to its V-I characteristics. P-V curve and V-I curve for different insolation level is as shown in Figure 9 (e) and (f). From the Figure 9 (e) it is concluded that PV system is working at its maximum output power according to its insoltion level.

Boost converter output current, voltage and power is as shown in Figure 9 (g), (h) and (i) respectively. Figure 9 (j) and (k) shows the output current variation of PV inverter for both different load and insolation condition. Output power variation of PV inverter power is as shown in Figure 9 (l).

Load end side current, voltage and there enlarge view are shown in Figure 9 (m),(n),(o) and (p) respectively. Figure 9 (q) shows the required load power demand i.e 35, 20 & 55 kw.

Grid current variation and it's enlarge view is shown in Figure 9 (r) and (s). Also power injected into the grid and consume from the grid is shown in Figure 9 (t). At last the Figure 9 (u) shows the comparison of PV inverter power, required load power and grid power. During the period t= 0-3 sec load demand is constant and insolation level is changing. Whereas during t= 3-4 sec insolation level is constant & load demand is changing. From the waveform it is clear that whenever load demand is less than PV capacity then remaining power is supplied to grid and whenever the load demand is more than PV capacity then load will consume the required power from the grid. This way bidirectional power flow is possible.

6.0 CONCLUSION

The analysis on PV system suggests the role of the PV system as a reliable energy source and the suitability of developed model for power management. In this paper the ability of the PV in picking up the load whenever sufficient insolation is available, and the ability of the Grid (working as a backup) in meeting the load demand whenever there is not sufficient insolation, are presented. Also the results of MATLAB simulation show the power management achieved with this PV system model is very well.

7.0 REFERENCES

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