MODELING & ANALYSIS OF STANDALONE PHOTOVOLTAIC SYSTEM

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Abstract

This paper represents the three phase Photovoltaic system connected with variable load in a standalone mode's mathematical modeling using MATLAB/ Simulink environment. The system consist of a PV Array, Boost converter, three phase inverter and its control to maintain load in standalone mode. The 40 kW systems at the college site is under the study with a variable inductive load of 30kW which has to be fed by PV system in continuous mode .This paper gives analysis of each components of system while maintaining the load. The constant and boosted DC voltage is obtained with the help of boost converter from PV Array. The three phase IGBT inverter PWM control scheme is proposed here to normalize the voltage imbalance during variable load.

Keywords: Photovoltaic System, Boost Converter, IGBT Inverter, and PI Controller etc…

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1. INTRODUCTION

This paper represents modeling and simulation of standalone Photovoltaic system. The work has been carried out on a 40 kW PV system. The main structure of PV Array system is shown in the Fig. 1.It consists of PV Array of capacity 40 kW, DC to DC boost converter, three phase IGBT Inverter, three Phase variable load and PWM controller for inverter. In the standalone mode normally for low range application inverter is directly connected with utility mains. In this type of configuration boost converter is connected before inverter to maintain the input voltage. Due to the variation of solar radiation throughout the day or season, variable voltage and power is obtained from Array [3]. So we have employed DC to DC boost converter which boost up the voltage as well as it makes the voltage level constant. In domestic installation it is called charge controller, feeds required voltage for smooth operation of inverter.

Fig -1 : Block diagram of three phase variable load connected PV Array System

The power conditioner devices are most important for this application [2]. The smooth output waveform is needed therefore proper firing pulse generation must be controlled carefully. This paper represents the PWM control of inverter which is having PI controller integration that is capable of producing the smooth output voltage and current waveform. Moreover it also maintains the unbalancing of the load. This paper also gives the idea about balancing the load represented by suitable wave forms of 40kW standalone system.

2. MODELING OF PV ARRAY

The PV cell comes in mono crystalline, polycrystalline and amorphous material built. Here polycrystalline cell structure is selected 100 W module connected in series and parallel combination so that an array made from this configuration can produce output power 1.2kW [4]. Total 40 array system is taken to achieve 40kW of power with suitable series and parallel configuration. In a single module 36 cells are connected in series to get 22 V open circuit cell voltage. The mathematical model of PV cell is represented by a current source with a diode connected in parallel as shown in Fig. 2. The intrinsic series resistance R_S whose value is very small .The equivalent shunt resistance which has a very high value is R_P. Applying Kirchhoff's law to the node where I_{ph}, diode, R_P and R_S meet, we get the following equation for the photovoltaic current:
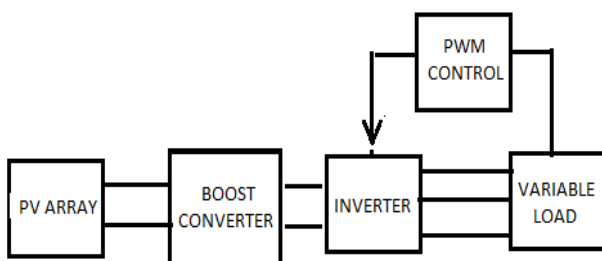
$$I = I_D - IR_P - I_{ph} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (1)}$$

$$I = Iph - Io\left[exp\left(\frac{V+IR_S}{V_T}\right) - 1\right] - \left[\left(\frac{V+IR_S}{R_P}\right)\right] \dots\dots\dots \text{ (2)}$$
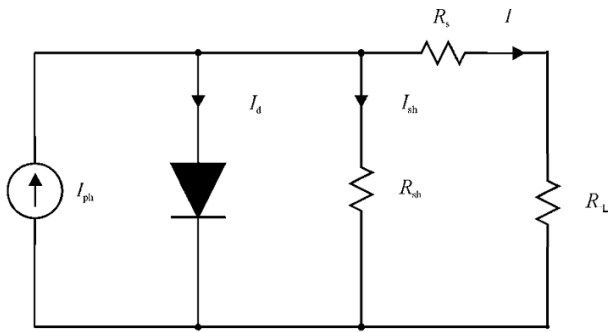
Fig -2 : PV Cell model

$$I = n_p I_{ph} - n_p I_{Rs}\left[exp\left(\frac{q}{KTA} * \frac{V}{n_s}\right) - 1\right] \dots\dots\dots\dots\dots (3)$$

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 exp\left(\frac{qE_G}{KA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \dots\dots\dots\dots\dots\dots\dots (4)$$

$$E_G = E_G(0) - \frac{\alpha T^2}{T+\beta} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

$$I_{ph} = [I_{scr} + K_i(T - T_r)]\frac{S}{1000} \dots\dots\dots\dots\dots\dots\dots\dots\dots (6)$$

Where, Iph is the Insolation current, I is the Cell current, I_0 is the Reverse saturation current, V is the Cell voltage, Rs is the Series resistance, Rp is the Parallel 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 an electron[1]. On the basis of above equation the simulink model is prepared shown below:
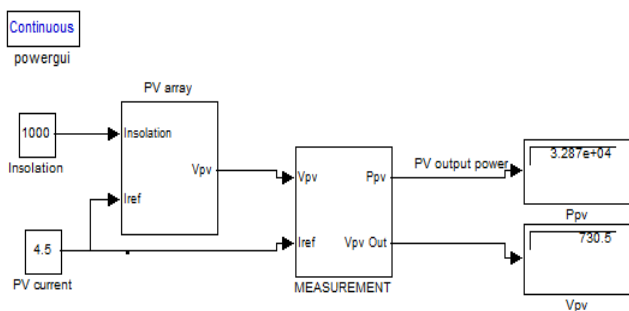

Fig -3 : Simulink Model for PV Array

3. BOOST CONVERTER

The module generates dc voltage under all condition of solar radiation. The generated voltage is low moreover its must be constant at the input level of inverter [7]. So we need a boost converter device which boost the voltage as well as it tries to maintain constant boosted voltage. The PWM at a fixed frequency is the main key to get regulated supply. The generally used switching devices are BJT, MOSFET or IGBT.

The minimum oscillator frequency should be about 100 times longer than the transistor switching time to maximize efficiency.
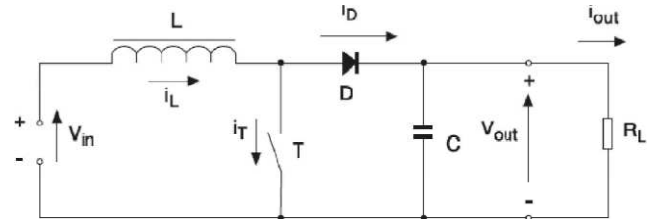

Fig -4 : Circuit Diagram of Boost Converter

The Fig. 4 shows a step up or PWM boost converter. It consists of a dc input voltage source Vin; boost inductor L, controlled switch T, diode D, filter capacitor C, and the load resistance R_L. When the switch S is in the on state, the current in the boost inductor increases linearly and the diode D is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit. The transfer function for boost converter is

$$G(s) = \frac{V_0}{1-D} * \frac{1 - \frac{Ls}{(1-D)^2 * R}}{\frac{LCs^2}{(1-D)^2} + \frac{Ls}{(1-D)^2 R} + 1} \dots\dots\dots\dots\dots\dots\dots (7)$$

The equation (7) shows transfer function of the boost converter model. The load current feedback to the inductor switching helps to maintain the output at required level based on this technique boost DC-DC model is represented below.
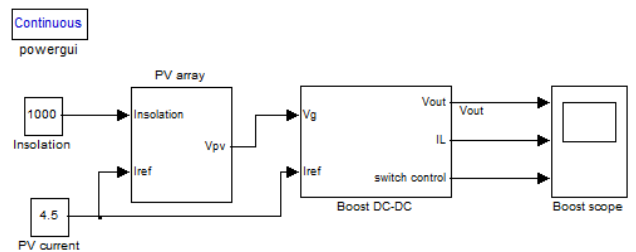

Fig -5 : Simulink Model for DC to DC Boost Converter

4. INVERTER MODELING

The new technology now a day's using module connected inverter which has gained good popularity but in our model it is centralized power inverter [9]. The PV array produces DC power and therefore when a standalone system contains an AC load. So needs conversion of AC power which is achieved by power inverter. For producing desired voltage waveform gate triggering of inverter must be controlled in accurate mode [11]. For producing PWM output we require a modulating signal, which is sinusoidal wave and triangular wave as carrier that controls the switching frequency of switches used for

conversion control. The PWM Generator block, which generates pulses for the carrier-based pulse width modulation (PWM) systems. It fires the self-commuted devices (FETs, GTOs, or IGBTs) of any phase, or a combination of two three-phase bridges.
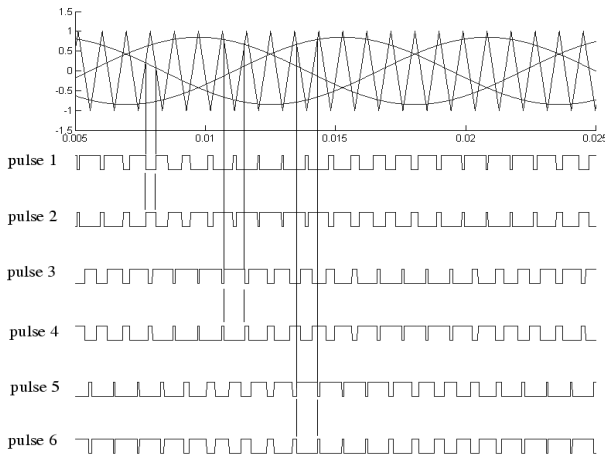

Fig -6: Gate Pulse Generation

The number of bridge arms that we want to control actually decides the number of pulses generated by the PWM Generator block. For three Arm Bridge we have to generate pulse 1, 3 and 5 to fire upper devices and pulses 2, 4 and 6 fire the lower devices. Therefore six pulses are generated for a three-arm bridge.

First we compare the triangular wave with reference waveform accordingly that pulses are generated as shown in Fig. 6.The reference signal can also be generated from a signal connected at the input of the PWM block. Using this option we can fed the error voltage (obtained by comparing load bus voltage with reference voltage) of load side which is to be balanced. The PWM Generator needs one reference signal to generate the pulses for a single- or a two-arm bridge, or it needs a three-phase reference signal to generate the pulses for a three-phase bridge (single or double bridge). The proposed model uses this technique. The variable load is connected at the output of inverter, hence there is variation in voltage, this can be normalised with the inductor current and voltage control methodology purposed. For controlling the output of inverter R-L branch is added at output side helps to control voltage feedback through inverter gating control [11].

The voltage at the output of inverter is fed back to the controller, where it is compared with reference bus voltage. The error is then controlled and normalised through PI controller. The proper tuning of the proportional and integrator gain is done by initial assumption. There are two types of waveform generation control schemes used for grid-connected inverters Voltage control and Current control [12]. Voltage and current controlled inverters look quite different on a sub 20ms time scale. On a longer time scale (i.e. seconds) however, inverters used for injection of energy from a PV array directly into the grid are controlled as power sources i.e. they inject "constant" power into the grid at close to unity power factor. The control systems constantly monitor incoming power from the PV array and adjust the magnitude and phase of the ac voltage (voltage controlled) or current (current controlled) to export the power extracted from the PV array[13]. The output from PI controller is within the unit tolerance band and to make it alternate proportional to bus voltage the PLL Block is used with zero angles set to generate unity power factor output from inverter helps to set it in maximum active power delivering mode. Since this is the unit reference signal generated given to the PWM generator block which then produces firing pulses accordingly.

From Fig. 6 we can observe Pulse 2,4and 6 are complements of pulses 1, 3 and 5 respectively. Note that, unlike the pulses generated by the Synchronized 6-Pulse Generator block, the pulses generated by the PWM Generator block are of variable width. The inverter Simulink model contains three phase IGBT Inverter connected with three phase variable load. The Simulink model is made with the help of SimPower system tool box. As Shown in the Fig. below inverter is connected with three phase inductive branch which is further connected with load. In this control scheme the Line voltage value of load is taken first with the help of voltage measurement block to give input to the inverter control system.
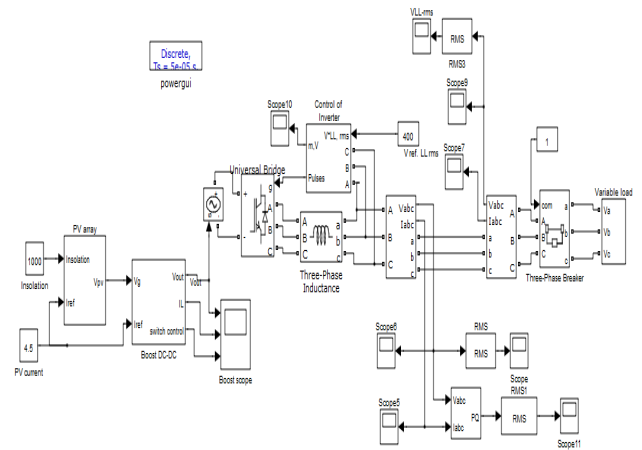

Fig -7: PV Inverter Connected with Three Phase Variable Load

The subsystem of inverter consists of three main portions first part is voltage measurement block system. This voltage measurement block system has three phase voltage measured from load side as the load varies our voltage magnitude varies.
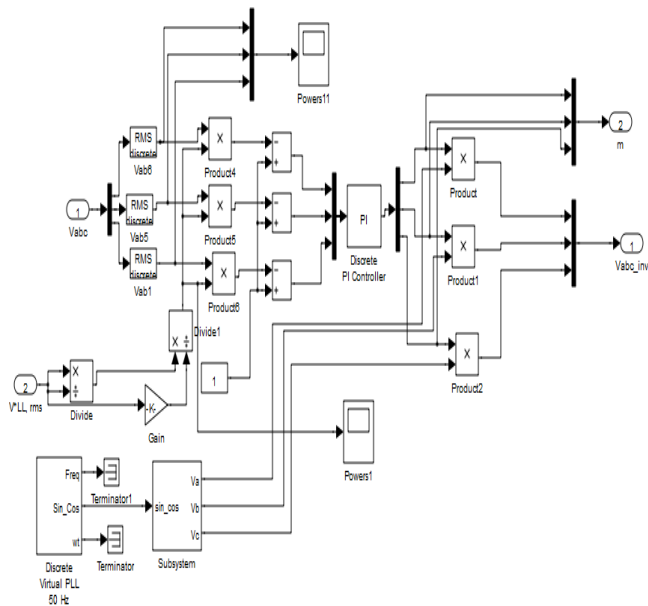
Fig -8: PI Controller of Inverter Controller Subsystem

This voltage measurement block system has three phase voltage measured from load side as the load varies our voltage magnitude varies. This measured voltage is divided in form of phase voltage, line to line voltage and RMS values of phase voltage. The line to line values of the voltage is used here to measure the voltage variation of load and the RMS values are used for maintaining the magnitude as per the required condition. The second block is controller; it is the heart of the inverter scheme employed. The detailed description is shown below. The V*LL rms gives the value of reference voltage line to line, which we have to maintain across the grid and load .The V*LL is taken from the grid side, which is then multiplied with the RMS value of the Load side phase voltage. The obtained value is again compared with the unit value. The obtained signal is then given to three phase PI controller. The values of proportion gain and integral gain is set to normalise the values of voltage, which is compared with unit input signals sothat it will help to maintain the output of the inverter. The PI controller produces unit reference signals whose output is limited between1 to 1.5. The signal obtained from the PI controller is DC value, which doesn't contain the sinusoidal component. In order to make this a perfect sinusoidal values of unit magnitude, a PLL block is taken to match the bus sinusoidal voltage and frequency. The PLL is set to 50 Hz and zero degree so that it can produce unity power factor active power. Therefore, we can say that our inverter produces the maximum power in this mode. The discrete PWM generator compares the unit ref sinusoidal signal with the triangular wave which then helpful to generate the firing pulses as describe in the above PWM Modulation article.

5. MODELING OF VARIABLE LOAD

The charge controller and inverter model proposed here needs to be investigated for variable load condition. Normally in standalone mode it is quite difficult to manage large fluctuation of voltage to control. The three phase variable model is proposed here to investigate the behavior of PV system in case of variable load condition. The three phase load model is made here with the help of three phases R-L load connected with the help of three phase circuit breaker. Each load consists of 10 KW, 1000 VARs load. The switching time of breaker is set according to the requirement in this way we obtain the three phase variable load. So the controller designed for proposed system has to be tuned for this kind of variable load by properly managing the reactive power. The model is simulated for 5 sec the timings for breaker one is set to 0.1 to 0.2sec so the load of 10KW, 100VARs is disconnected in this time event. Similarly for breaker two is set to 1 to 2 sec and for breaker three it is set to 3 to 4 seconds.
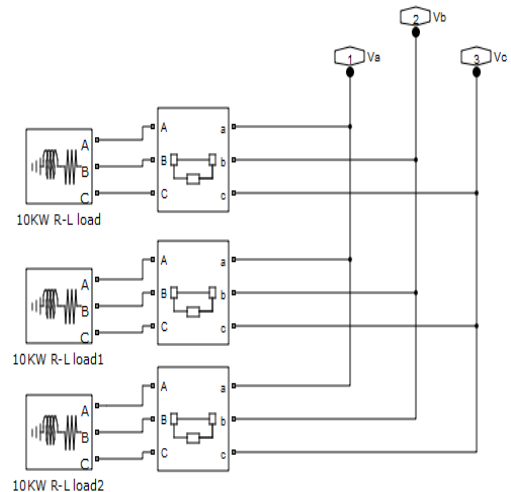

Fig -9: Three Phase Variable Load Subsystem

6. RESULTS AND DISCUSSION

6.1 PV Module

The PV module generates DC voltage under varying condition of solar radiation. For Fig. 3 showing the value of solar radiation at different solar radiation condition, we can obtain the desired output for I-V and P-V curve. The different parameters of PV module is short circuit current 5.14 A, open circuit voltage 22.2V, current at Pmax 4.95A, voltage at Pmax 17.2V. From the Fig.10 we can observe that when solar radiation is increased the output values of voltage and power is increased. The power level is increasing as the solar radiation is increased as graph shown in Fig. 10 Similarly the current output is also increasing to maximum value side at maximum radiation level.
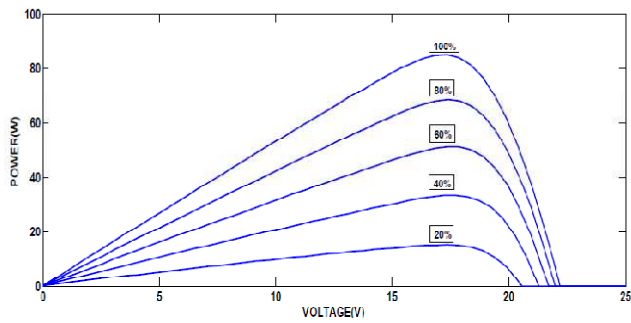
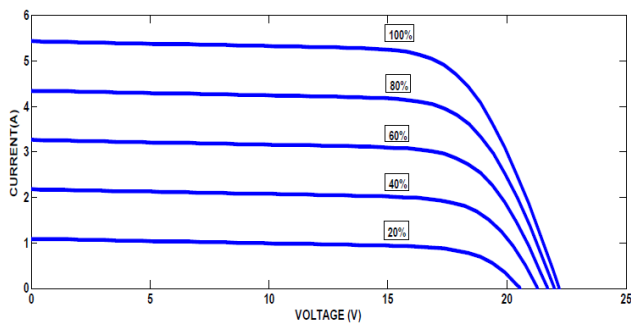**Fig -10**: P-V Characteristic of PV Module

Fig -11: I-V Characteristic of PV Module

Fig. 12 shown below is obtained in the condition when solar radiation is at its peak the charge controller gives fixed voltage 800 V. The fixed level of voltage is desired for proper operation of inverter. Therefore we get constant power of 32kW approx. This voltage helps to generate the desired output from inverter.
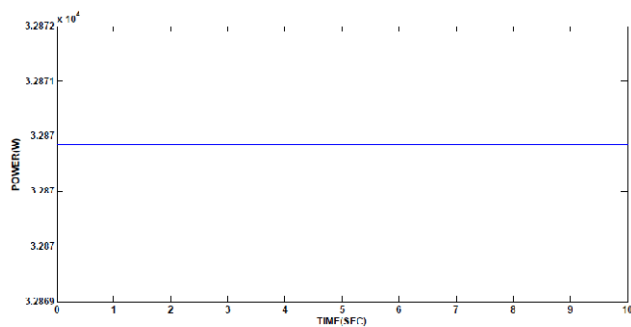

Fig -12: Power Output from Charge Controller

6.2 Simulation of Boost Converter

The output voltage from module is variable dc as solar radiation changing in nature. The boost converter shown in Fig. 5 having different values of input given as inductance 10 mH, capacitance 1µF, initial capacitor voltage 800V, input voltage 735.5 V and reference current is 4.5 A. For the above given values we have obtain Fig. 13 in which the boosted

voltage obtain 800V. The graph is Linearly increasing within narrow range of voltage magnitude which shows that our voltage is boosted and will be remaining stable within that range of magnitude means 800V.The inductor current control is employed the graph we get 4.5A inductor switching current and the plot for Switching control is given in Fig.14&15.
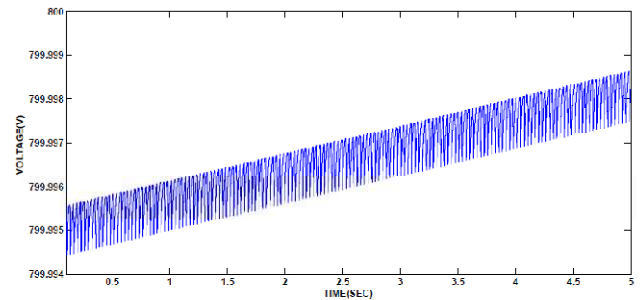

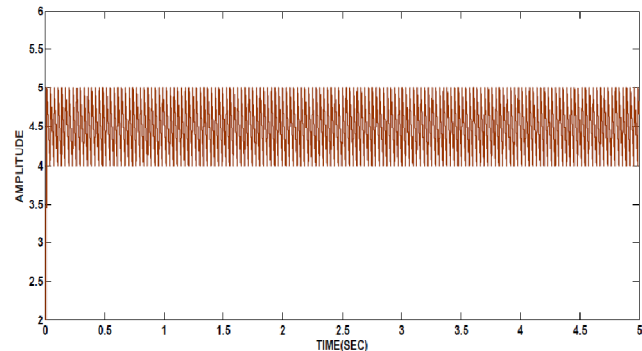**Fig -13**: Voltage Output from Charge Controller

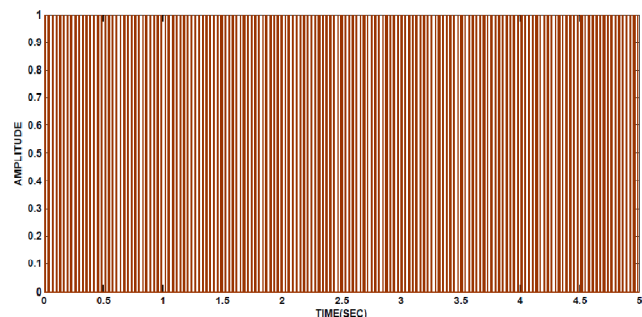**Fig -14**: Inductor Current Control of Charge Controller

Fig -15: Switching Control Signal of Boost Converter

6.3 Inverter Simulation Results

We are using three phase IGBT inverter connected with three phase variable load of 30kW. The inverter has its own controller as discussed above which maintains the output .The IGBT is used for inverter has various values for it are No of bridges arm is 3, snubber resistance 10000 ohms, inf capacitance, Ron 1e-4, Forward voltage 1V, the values for

PWM generator are carrier frequency is 4000 Hz, sample time 20e-6, modulation index 0.85and input voltage is 800V.We have simulated it in discrete time simulation mode for time 5e-5 sec and obtain the various plots as shown below the output can be varied according to switching frequency setting. The PV Array system can produce power of 40 kW. We have connected 30 kW load. We are getting 25kW of active power and 1kVARs reactive power from the simulation. We are getting this kind of result because we have used here three phases R-L load connected with the help of three phase circuit breaker. Each load consists of 10 KW, 1000 VARs load.
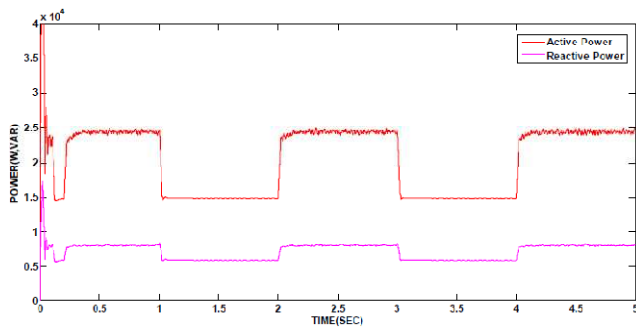

Fig -16: Active and Reactive power from PV inverter to load

The switching time of breaker is set according to the requirement in this way we obtain the three phase variable load. The model is simulated for 5 sec the timings for breaker one is set to 0.1 to 0.2sec so the load of 10KW, 100VARs is disconnected in this time event. Similarly for breaker two is set to 1 to 2 sec and for breaker three it is set to 3 to 4 seconds.
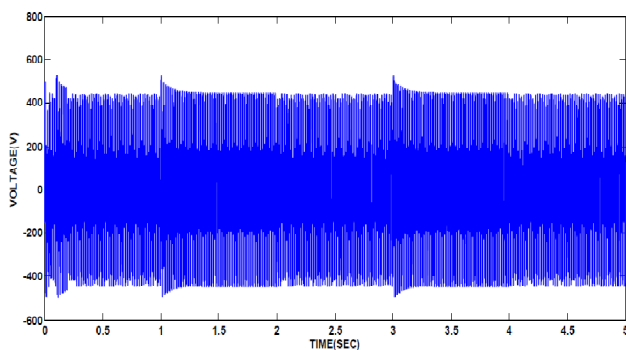

Fig -17: Voltage from Inverter to Load.

Fig. 17 shows the voltage output from inverter we see some spike in the voltage wave form at switching instants when load are thrown by operating the breaker. When sudden rejection of load occurs at that particular switching instant for very less time (in microseconds) voltage rises. The voltage wavform is smooth throughout the rest of the region shows controller is giving good performance.
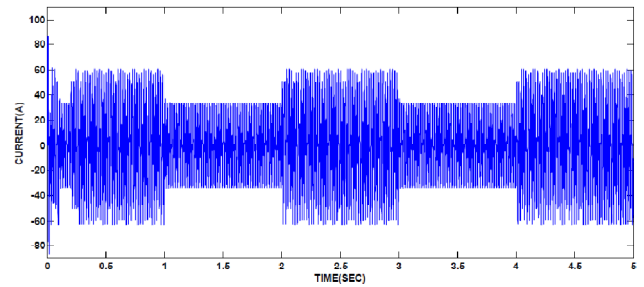

Fig -18: Current from Inverter to Load

Similarly we are getting the corresponding Current waveform Fig. (18) we get sag at the same instant i.e. due to the sudden rejection of load of 10kW at a time normal value of current is 60A but when load is cut off the magnitude of current is reduced by 25A.
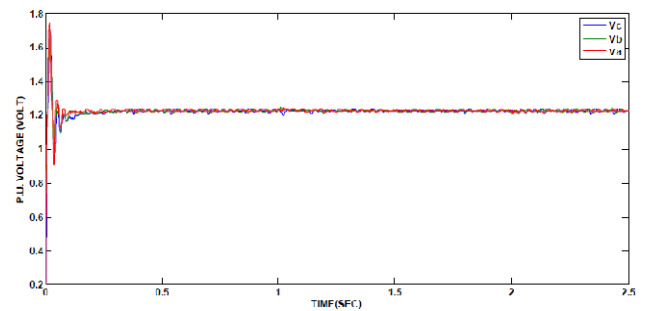

Fig -19: Voltage Output from Inverter under Varying Load Condition

In the varying load condition when the load varies the magnitude of voltage and current varies for stable operation of system the voltage magnitude must stable in 1 P.U. Here we are getting voltage that goes on stabling at 1.2 P.U.

CONCLUSIONS

The aim of this paper is to provide insight into the modelling of a standalone PV system. The model of PV array, Boost converter, Inverter & its control, Variable load is represented. The simulation result of each system is discussed at same discrete simulation time specified. In this model maximum power should be achieved by getting maximum solar radiation condition. In conventional system a single PV module is connected to a dc - dc converter and the output of the dc – dc converter is connected to the inverter finally inverter feeds the Load. The control scheme given here can be a good solution of economic model. It offers a simple way to study the performance for utility interface applications. It is simple to implement and capable of producing satisfactory sinusoidal current and voltage waveforms. This paper includes switching control of the system according to inverter control using PI controller to track the maximum power point according to the

variation of load. The proposed system components models are implemented in Matlab/Simulink environment and interfaced with SimPower System toolbox. The system has very good behaviour for three phase variable load mode.

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