SIMULATION AND ANALYSIS OF STAND ALONE PV SYSTEM WITH SINGLE PHASE AND THREE PHASE LOADS

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Abstract:

Demand has increased for renewable sources of energy to be utilized along with conventional systems to meet the energy demand. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. Solar systems, including thermal and photovoltaics, offer environmental advantages over electricity generation using conventional energy sources. Solar energy is abundantly available, so we have to extract and utilize in a very efficient way. In this thesis Stand-alone photovoltaic (PV) systems are presented because they are becoming increasingly viable and cost-effective for remote and/or off- utility grid power requirements. Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. These types of systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as an auxiliary power source in what is called a PV-hybrid system. In grid-connected applications, the solar arrays are used in large capacities of the order of MW for the generation of bulk power at the solar farms, which are coupled through an inverter to the grid and feed in power that synchronises with the conventional power in the grid. In this thesis the PV system with an inverter with controller and conversion of energy under three phase and single phase load is presented along with the charging, discharging and state of charge of the battery

Key Words: **PV module, Inverter, PID controller, single phase and 3-phase supply, Battery state of charge**

1. INTRODUCTION

Solar power is an important of the renewable energy mix in the world today but several factor have limited its widespread use and adoption. One of the major issue is the relatively costlier installation of PV array .That has rendered it uncompetitive is the energy market. So need of ours is more research into making solar cheaper modelling and simulation of PV arrays is done to estimate its characteristics better and extract maximum power possible. The basic objective would be to study PV system observing the battery charging and discharging characteristics and successfully implementing controlled grid connected inverter to the PV system using Simulink models. Modelling the inverter and PV system in Simulink and observing the battery characteristics would be of prime importance.

1.1 MODELLING OF A PV CELL

A PV cell or a solar cell is the smallest block of PV system. Since a PV cell can generate very small current (nearly 30mA) and voltage (0.6V), a PV module is designed with series and parallel connection of PV cells to increase voltage and current respectively and panel contains large numbers of array of such a combination. The solar energy is converted to electrical energy in PV panel having semiconductor materials. When solar energy is more than critical energy semiconductor, photo current is generated due to photo effect. Electrons are emitted and connected with load constitutes electric current

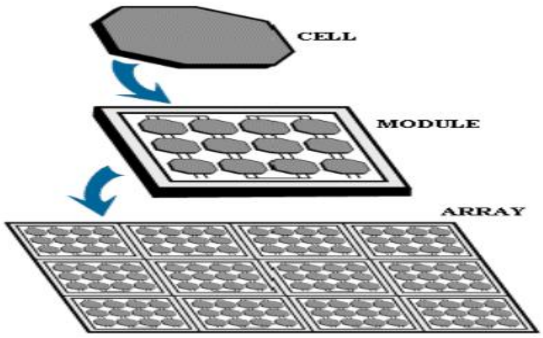
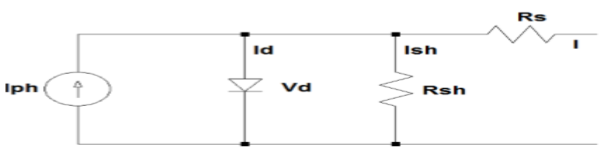


Fig 1.Formation of Solar Module and Solar PV Array

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel.



The characteristic equation for a photovoltaic cell is given by [1], [2], [4], [7], [9] and [10],

$$I = Ilg - Ios * \left[\exp\left\{q * \frac{V + I * R_s}{A * k * T}\right\} - 1\right] - \frac{V + I * R_s}{Rsh} \quad (1)$$

Where,

$$Ios = Ior * \left(\frac{T}{T_r}\right)^3 * \left[\exp\left\{q * Ego * \frac{\frac{1}{Tr} - \frac{1}{T}}{A * k}\right\}\right]$$

$$Ilg = \{Iscr + Ki * (T - 25)\} * \lambda$$

I & V : Cell output current and voltage;

Ios : Cell reverse saturation current;

T : Cell temperature in Celsius;

k : Boltzmann's constant, 1.38 * 10-19 J/K;

q : Electron charge, 1.6*10-23 C;

Ki : Short circuit current temperature coefficient at Iscr;

Lambda : Solar irradiation in W/m^2;

Iscr : Short circuit current at 25 degree Celsius;

Ilg : Light-generated current;

Ego : Band gap for silicon;

A : Ideality factor;

Tr : Reference temperature;

Ior : Cell saturation current at Tr;

Rsh : Shunt resistance;

Rs : Series resistance;

The characteristic equation of a solar module is dependent on the number of cells in parallel and number of cells in series. It is observed from experimental results that the current variation is less dependent on the shunt resistance and is more dependent on the series resistance [7].

$$I = Np * Ilg - Np * Ios * \left[\exp\left\{q * \frac{\frac{V}{Ns} + I * \frac{Rs}{Np}}{A * k * T}\right\} - 1\right] - \frac{V * \left(\frac{Np}{Ns}\right) + I * Rs}{Rsh}$$

The I-V and P-V curves for a solar cell are given in the following figure. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current.

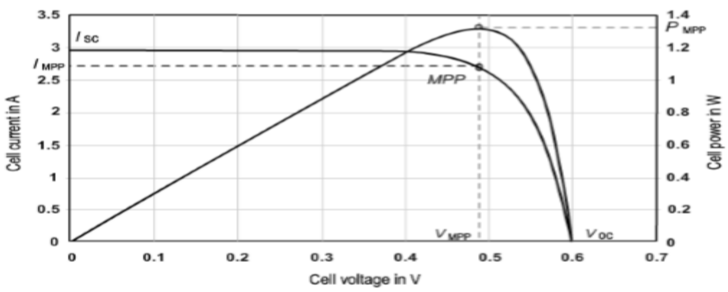


Fig **2 Proposed PV Modelling:**

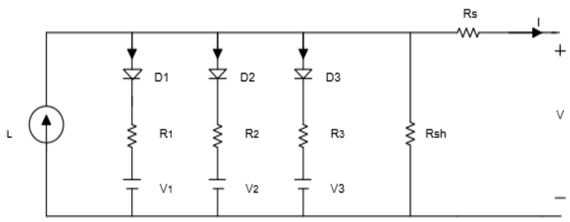


Fig 3 Proposed Piece Wise Linear Model

$$I = I_L - I_{d1} - I_{d2} - I_{d3} - \left(\frac{V + IR_S}{R_{SH}}\right)$$

Where

I_{d1} = current through diode 1

I_{d2} = current through diode 2

I_{d3} = current through diode 3

To control the power (constant power) voltage controlled resistor in series with diodes is used near the maximum power point voltage ($Vmax$) although there is little change in voltage near the $Vmax$ (between.9Vmax to 1.1 Vmax with 0.1 Vmax interval) by suitable switching ON and OFF of the diodes connected in parallel rather than switching of all the diodes at the same time. The detailed analysis of switching ON and OFF of the diodes connected in parallel and determination of the value of the voltage controlled register are given below. The switching voltages are taken at V 1= 0.9Vmax, V2 = Vmax, V3 =1.1Vmax

1.3CHARGE CONTROLLERS:

A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may prevent against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. To protect battery life, charge controller may prevent battery from deep discharging or it will perform controlled discharges, depending on the battery technology. Charge controller is an essential part in stand-alone PV systems. However there are special circumstances where a charge controller may not be needed in small systems with well-defined loads. By eliminating the need for the sensitive electronic charge controller, the design is simplified, at lower cost and with improved reliability. There are two cases where battery charge regulation may not be required: (1) when a low voltage "self-regulating module" is used in the proper climate; and (2) when the battery is very large compared to the array.

2. CHARACTERSTICS OF THE BATTERY

The energy output from the Solar PV systems is generally stored in a battery or in a battery bank deepening upon the requirements of the system. Mostly batteries or used in the stand-alone system and in the case of grid connected system, batteries are used as a backup system

2.1 BATTERY CHARGING:

The battery charging in PV systems consists of three modes of battery charging; normal or bulk charge, finishing or float charge and equalizing charge [5], [6]. To charge lead-acid battery safe, faster and full charging, the manufacture recommended charge lead acid battery with four charging steps [2] that are called:

(1) Trickle charging

(2) Constant current charging

(3) Constant voltage charging

(4) Float charging

2.2 BATTERY DISCHARGING

2.2.1 Depth of Discharge (DOD):

The battery DOD is defined as the percentage of capacity that has been withdrawn from a battery compared to the total fully charged capacity

2.3 State of Charge (SOC):

The state of charge (SOC) is defined as the amount of energy as a percentage of the energy stored in a fully charged battery. Discharging a battery results ina decrease in state of charge, while charging results in an increase in state of charge

3. INVERTER

The function of a solar or PV inverter is to convert the variable direct current (DC) output of a PV solar panel into a utility frequency alternating current (AC) which can be fed to a commercial electrical grid or can be used by a local, off-grid electrical network. . The final choice of one inverter instead of the other better depends on the application. In our application of stand-alone renewable energy systems (SARES), multilevel inverters have great potential with its reliability, surge power capacity and efficiency.

3.1Modelling of a grid connected inverter:

Figure 4 shows a whole configuration of three-phase grid-connected inverter with an L filter. The analyses for current controller in inverter with an L filter are still valid for the case with LCL filter as long as the control bandwidth is kept below resonant frequency of LCL filter. Considering the filter inductance of L and the filter resistance of R, the voltage equations of a grid-connected inverter are expressed in the synchronous reference frame as follows:

$$v_q = R i_q + L\frac{di_q}{dt} + \omega L i_d + e_q \quad (1)$$

$$v_d = R i_d + L\frac{di_d}{dt} - \omega L i_q + e_d \quad (2)$$

where i_q and i_d are the q-axis and d-axis inverter currents, respectively; e_q and e_d are the q-axis and d-axis grid voltages, respectively; v_q and v_d are the q-axis and d-axis inverter output voltages, respectively; and ω is the grid angular frequency.

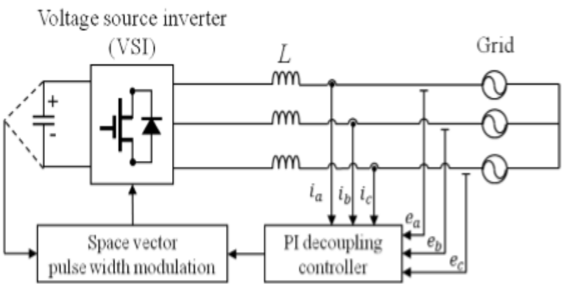


Fig 4 Block diagram of 3 phase grid connected inverter

When phase voltages and currents include harmonic components, the transformed variables into the synchronous reference frame are not in pure direct current (DC)-quantity. Instead, they contain the harmonic components as well as DC-quantity. To apply the decomposition method, the voltage and current variables can be expressed with DC-quantity and sinusoidal harmonic terms as follows:

$$v_{qd} = V_{qd} + v_{qdh} \quad (3)$$

$$i_{qd} = I_{qd} + i_{qdh} \quad (4)$$

$$e_{qd} = E_{qd} + e_{qdh} \quad (5)$$

where the capital letter V, I, and E denote the inverter voltages, inverter currents, and grid voltages having DC-quantity, respectively, the subscript "qd" denotes the variables on the q-axis and d-axis in the synchronous reference frame, the subscripts "h" denotes harmonic quantities.

The decomposed models for the voltage equations of a grid-connected inverter are derived by substituting Equations (3), (4), and (5) into Equations (1) and (2) as follows:

$$V_q + v_{qh} = R(I_q + i_{qh}) + L\frac{d(I_q + i_{qh})}{dt} + \omega L(I_d + i_{dh}) + (E_q + e_{qh}) \quad (6)$$

$$V_d + v_{dh} = R(I_d + i_{dh}) + L\frac{d(I_d + i_{dh})}{dt} - \omega L(I_q + i_{qh}) + (E_d + e_{dh}) \quad (7)$$

Voltage equations in Equations (6) and (7) can be rewritten with respect to the DC-quantities and harmonic components as follows:

$$V_q = RI_q + L\frac{dI_{qs}}{dt} + \quad (8)$$

$$V_d = RI_d + L\frac{dI_d}{dt} - \omega L I_q + E_d \quad (9)$$

$$v_{qh} = Ri_{qh} + L\frac{di_{qh}}{dt} + \omega L i_{dh} + e_{qh} \quad (10)$$

$$v_{dh} = Ri_{dh} + L\frac{di_{dh}}{dt} - \omega L i_{qh} + e_{dh} \quad (11)$$

For convenience, Equations (8) and (9) are referred to the fundamental voltage equations because theyareobtainedthroughthePark'stransformationofphasevariablesinthefundamentalcomponents. Similarly, Equations (10) and (11) are referred to the harmonic voltage equations.

3.2 CURRENT CONTROLLER

There are various methods to control the current. Controlled current is the inverter output current , which flows into the low-pass AC filter. Each controller generates a control signal which contains the information on whether needs to be increased or decreased. Together with the information on the mode of operation of the inverter, the control signal is required to derive the switching signals for the individual switches of the inverter. The PI control method is a common control method in grid- connected PV systems [19]. With this control method the frequency of the ripple on is the same as the frequency of the triangular waveform, which is constant, hence enabling better and easier AC filter design. However, simulation studies implementing the PI control method for the cascaded inverter showed that as the mode changes, the control is lost due to non-linear behavior of the system. The method has therefore not been investigated further for hardware implementation with the cascaded converter.

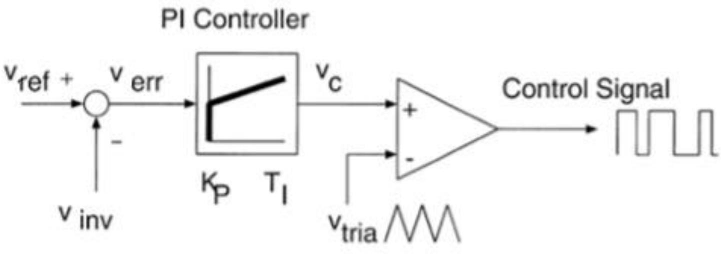


Fig 5. PI Controller

And PID controller can also be used along with our proposed PV module and inverter.

4. SINGLE-PHASE GRID CONNECTED INVERTER

Power inverter is an important part of many DC to AC conversion equipment's such as uninterruptible power supply (UPS), induction motor drive and automatic voltage regulator (AVR) systems. In these systems, it is the major requirement for the power inverter to be capable of producing and maintaining a stable and clean sinusoidal output voltage waveform regardless of the type of load connected to it. The main key to successfully maintain this ability is to have a feedback controller.

DYNAMIC MODEL OF SINGLE-PHASE INVERTER

Fig. 6, shows the equivalent circuit of a single-phase full bridge inverter with connected load. In this study, control based on the linear strategy theory is presented. Solid-state switches and connected rectifier are nonlinearity source of a system, so for proper control design, the system must be linearized around its operating point. If the designed controller is robust enough, the system can work around its operating point with high performance which means a wide range of bandwidth is required [2]. In this work, a nominal resistive load of 10 Ω is set as the operating point for linearization.

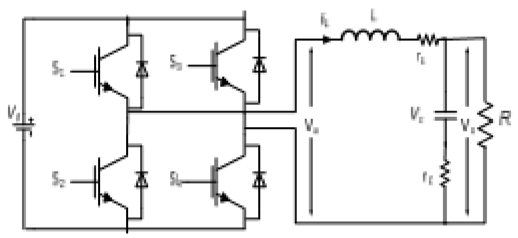


Fig 6 Full-bridge Single-phase Inverter

State-Space Model

The resistive load and its related filter operate as a continuous time second-order system. The state variables of the system are capacitor voltage and inductor current.

$$\begin{pmatrix} i_L' \\ V_c' \end{pmatrix} = \begin{pmatrix} -\frac{r_L r_c + R(r_L + r_c)}{L(R+r_c)} & -\frac{R}{L(R+r_c)} \\ \frac{1}{C(1+r_c/R)} & \frac{1}{RC(1+r_c/R)} \end{pmatrix} \begin{pmatrix} i_L \\ V_c \end{pmatrix} + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} V_a$$

$$V_o = \begin{pmatrix} \frac{r_c}{r_c+R} & \frac{R}{R+r_c} \end{pmatrix} \begin{pmatrix} i_L \\ V_c \end{pmatrix}$$

One of the important factors of load effect on the inverter is output impedance which in this case as rectifier is a load with nonlinear nature; the output voltage will be highly distorted**.**

By ignoring the internal resistance of the filter capacitor and solving, the equations can be simplified as

$$\begin{pmatrix} i_L' \\ V_c' \end{pmatrix} = \begin{pmatrix} -\frac{r_L}{L} & -\frac{1}{L} \\ \frac{1}{C} & \frac{1}{RC} \end{pmatrix} \begin{pmatrix} i_L \\ V_c \end{pmatrix} + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} V_a$$

$$V_o = \begin{pmatrix} 0 & 1 \end{pmatrix} \begin{pmatrix} i_L \\ V_c \end{pmatrix}$$

Analysis of multiple feedback loop control

A DC motor has some similarity to an inverter in terms of using cascade control (multi-loop control). In a DC motor system, the armature current and stator voltage are used as current and voltage feedback loop for achieving sufficient steady-state and good transient performance. A single-phase inverter has the same scenario. The inductor current of the filter acts as an inner loop parameter while the output voltage is the outer loop parameter.

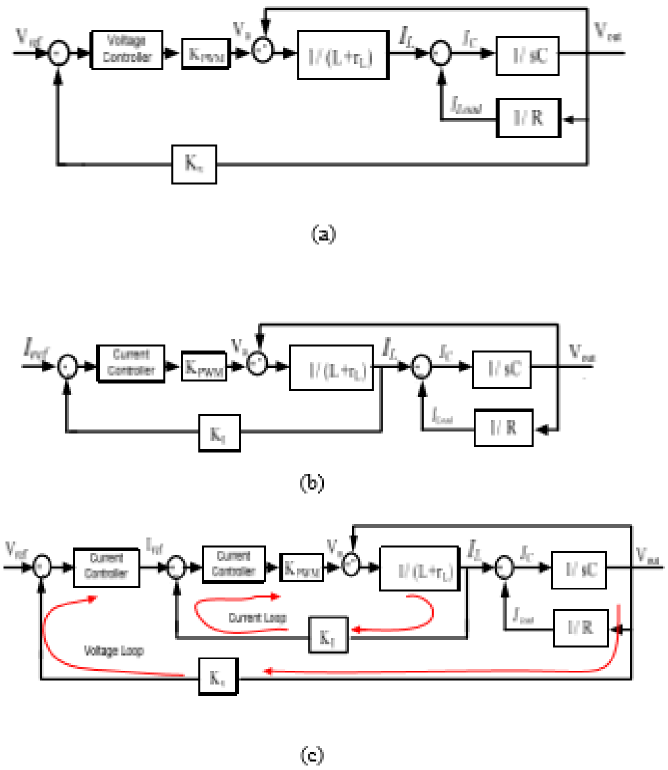


Fig 7 a),b),c) Control Schemes for single phase inverter

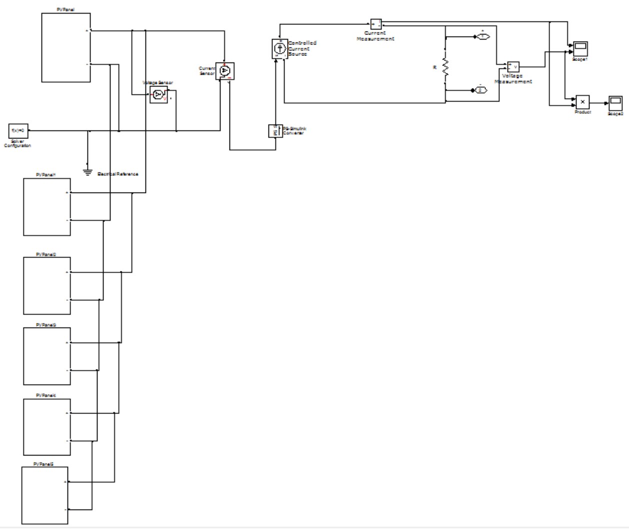
5. PROPOSED MODEL

Our proposed model with PV array, Inverter, controller with single phase and 3-phase A.C load is

5.1 PV Array or Solar Array

It consists of 6 solar panels.

Load: - R=10.5ohm



5.2 PV Panel:

Each panel consists of 36 solar cells.

Panel Parameters:-

Short Circuit Current (I_{sc}) = 2.54A

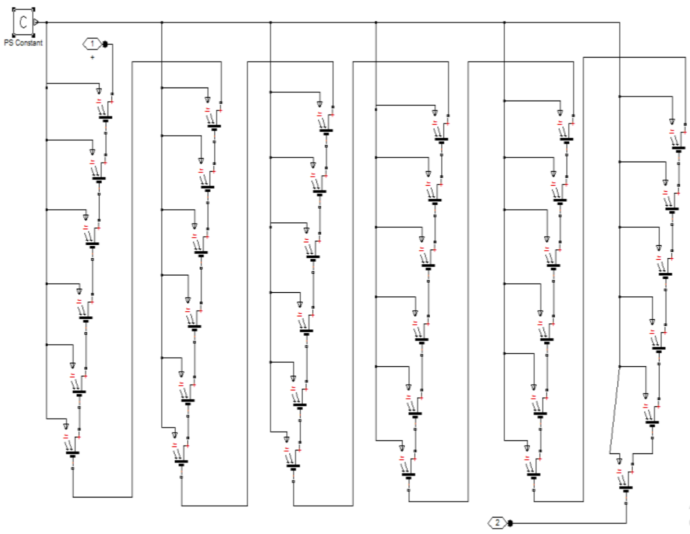
Open Circuit Voltage (V_{oc})= 21.8V

Irradiance (Ir0) = 1000 W/m^2

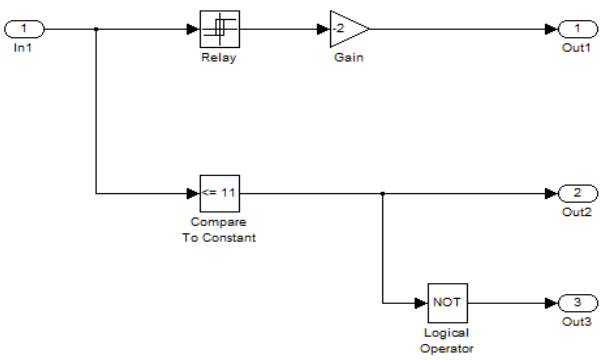
Quality factor (N) = 1.6

Series Resistance R_s) = 5.1e-3

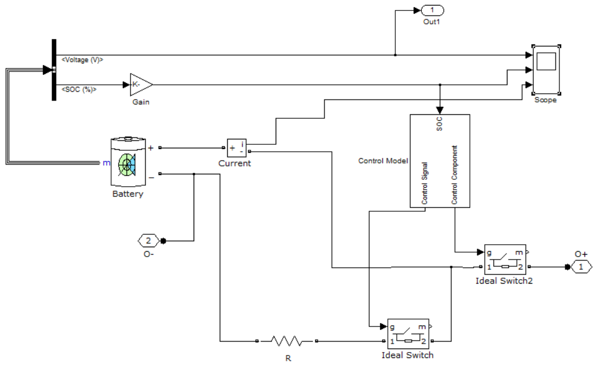
Fixed Temperature = 25 C



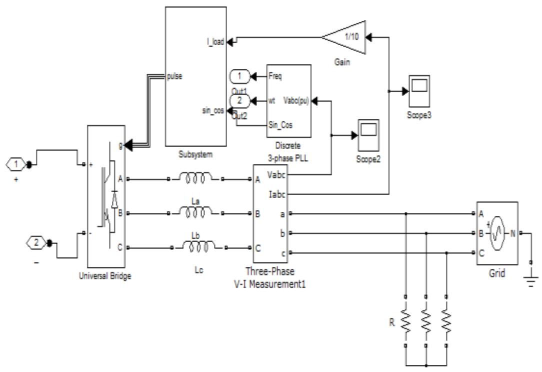
5.3 Charge Controller:



5.4 Battery



5.5 Three-phase grid connected inverter



Parameters:

LC Filter

La = Lb = Lc = 20e-3H and 1F

R1 = R2 = R3 = R = 1 ohm

Discrete 3-phase PLL Loop parameters:

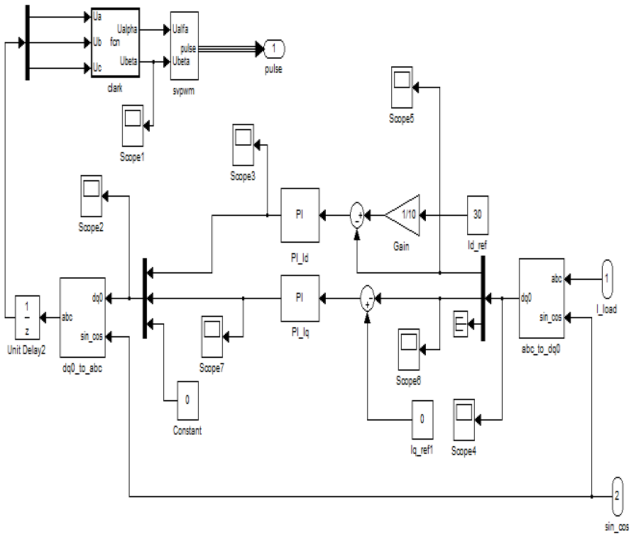
Minimum Frequency = 45Hz

Initial Inputs: - 1) Phase = 0 2) Frequency = 50Hz

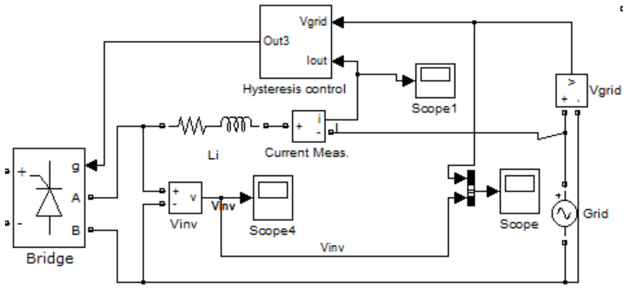
Regulator gains: - 1)Kp = 0.18 2)Ki = 3.2 3)Kd = 0

Sample time = 2e-6

5.6 Subsystem



5.7 Single-phase Grid Connected Inverter



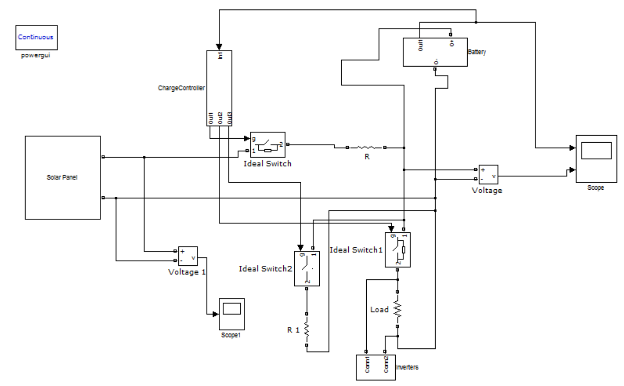
Inductance = 12e-3 Resistance = 0.001Ω

1-phase PLL

Initial Inputs: - 1) Phase = 0 2) Frequency = 50Hz

Regulator gains: - 1)Kp = 180 2)Ki = 3200 3)Kd = 1

5.8 Overall Simulink Model



Load=20ohm R1=20ohm R=10ohm

6. CONCLUSIONS AND RESULTS:

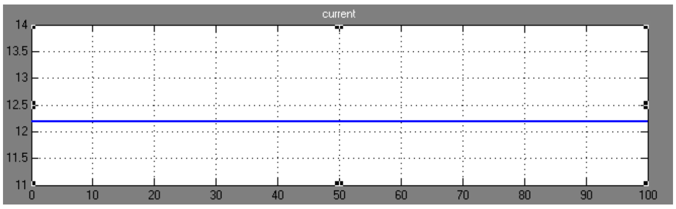


Fig 6.1 Current waveform of Solar Panel

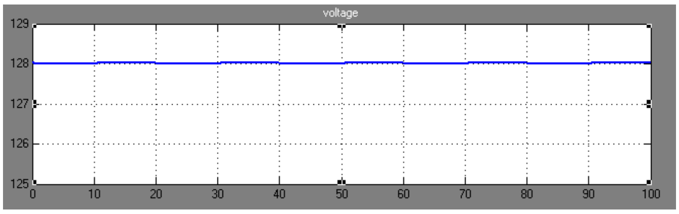


Fig 6.2 Voltage waveform of Solar Panel

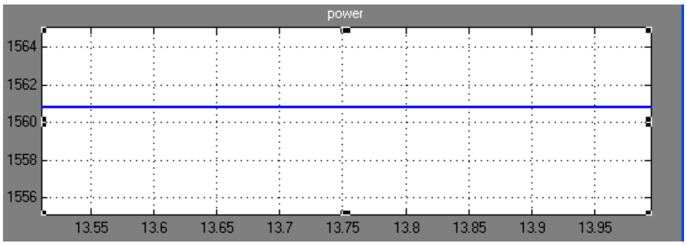


Fig 6.3 Output power of Solar Panel

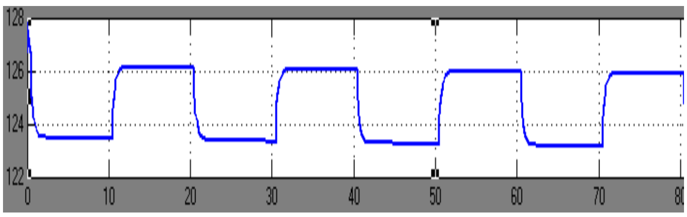


Fig 6.4 Battery Voltage

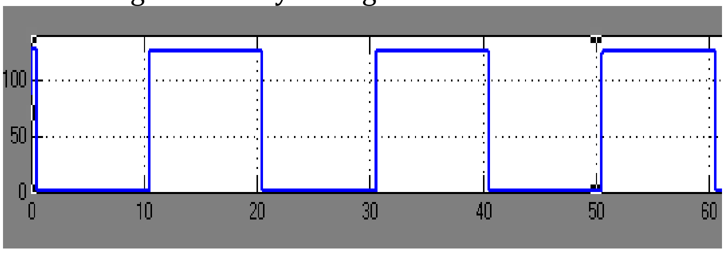


Fig 6.5 Load Voltage

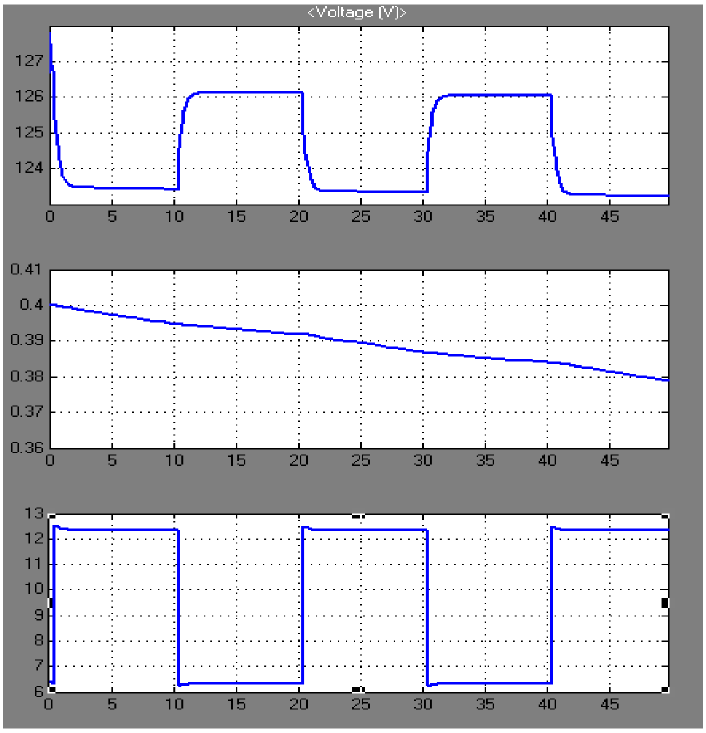


Fig 6.6 Battery Charging Discharging Characteristics

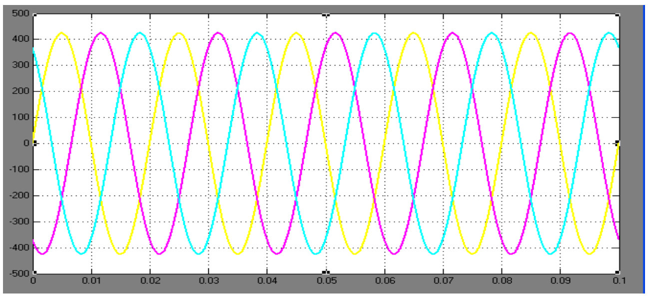


Fig 6.7 Output Phase Voltage

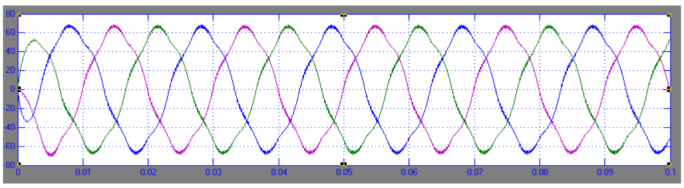


Fig 6.8 Output Phase Current

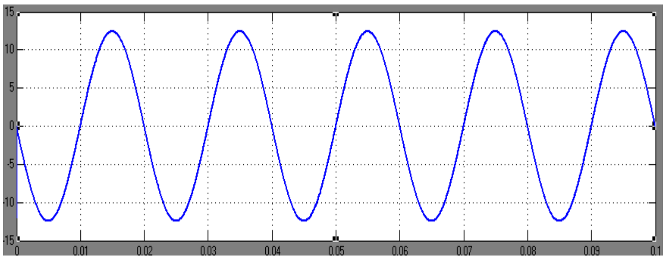


Fig 6.9 Single phase current

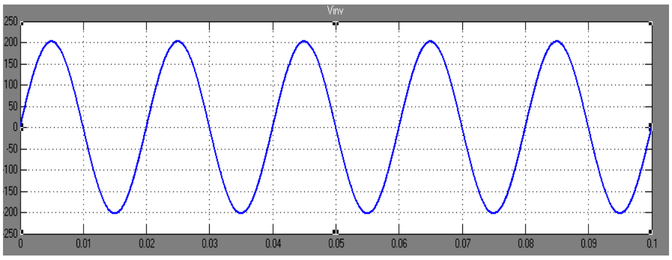


Fig 6.10 Single phase voltage

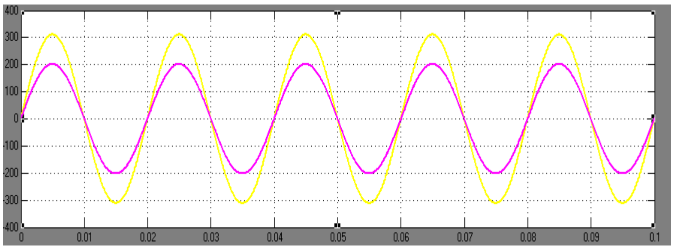


Fig 6.11 Single phase voltage along with grid voltage

From the results we can say that our proposed model is an efficient way for extraction of solar radiation like a stand-alone system and with grid connected inverters it can be used in grid connected applications also.

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