Modeling and Control of Grid-Connected by Photovoltaic System using Matlab

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Abstract:- In recent years, lack of adequate transmission capacity, limitations in constructing new transmission lines, growing concern to the environment and emerging electricity market structure have led to the increased use of Distributed Generation (DG), in the form of smaller size generators installed at the power distribution level close to the end users. Many DG systems employ renewable resources for electricity generation and, thus, help in mitigation of the adverse environmental impacts, being experienced due to the fossil fuel based centralized generating plants. Among the renewable DG systems, Photo-Voltaic (PV) solar systems have attracted considerable attention and investment in several countries. The installation of low (<10kW) and medium (<100kW) power PV generation systems is, particularly, increasing at the Low Voltage (LV) distribution networks. Power outputs of PV arrays depend on solar insolation, atmospheric temperature and the voltage level at which it is operating. The process of extracting maximum power from the PV array by adjusting its terminal voltage is called circule method of optimization techniques. In this thesis, low (5.6kW), and medium power (32.5kW) PV arrays have been considered for integration at the 1-Phase and 3-Phase lines of the LV system, respectively,using two-stage (DC-DC boost converter and DC-AC voltage source inverter) configuration of the PV system. The DC-DC boost converter is responsible for boosting the voltage andensuring circule method of optimization techniques of the PV array. The Voltage Source Inverter (VSI) controls its output current to remain in phase with the grid voltage to supply power at unity power factor.

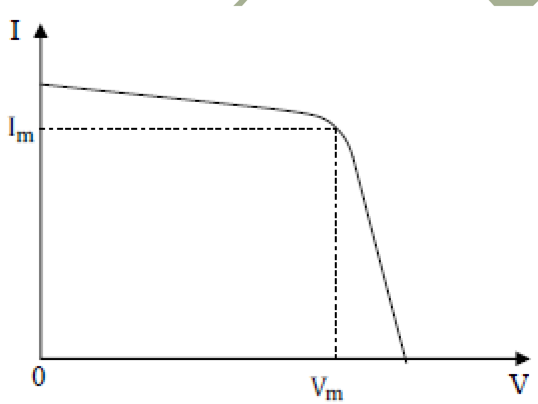
Introduction:-

Worldwide, there is a growing concern to the impending energy crisis, triggered by its ever increasing demand and rapid depletion of fossil fuels. Conventionally, the major sources of the electrical energy production are the fossil fuels such as coal and natural gas, which are under threat of reduced reserve left. The gap between supply and demand, specially being experienced by developing countries, is leading to frequent load shedding. Moreover, electrification of certain remotely located areas through extending the electrical power grids become infeasible due to economic and environmental reasons. On the other hand, greenhouse gases and hazardous wastes released from the use of fossil fuels in power plants have increased the threat of global warming, pollution of air, soil and water. Nuclear energy is one clean form of energy for bulk electricity production. However, it demands huge installation cost and involves several protection issues, in addition to the release of harmfulradioactive wastes, with no sustainable disposal mechanism. Of the above, alternative and renewable energy have drawn the attention of the whole world as sustainable form of energy sources and are their increased share in power generation is being planned in almost all the countries. Some of these sources, such as those based on solar radiation and wind, can never be exhausted, and, therefore, are called 'Renewable Energy Sources (RES)'. These are often described as clean and green forms of energy.

Photovoltaic System:-

The Photo Voltaic (PV) based solar system generates electrical energy, when certain semi conductor materials are exposed to light. It is one of the most important renewable sources as it is clean, pollution free, inexhaustible, and can be operated with minimal variable costs. Due to rapid growth in semiconductor and power electronics technologies, photovoltaic systems are gaining interest in electrical power applications. Solar cell (or

PV cell) is the basic building block of a PV source, semiconductor material. The output of a solar cell is rather low, about 2-3W at 0.5-0.7V.
Therefore, a single cell is not of much practical use, producing less than a volt. Several cells
on the power requirement, several such modules are connected in series and parallelcombination to form a solar (or PV) array.
PV systems operate with no moving parts, thus, requiring very low maintenance. PV
system sizes range from few watts to several megawatts. A major source of instability in
conventional energy sources arises out of the fact that the input energy must be immediately
consumed by the load. Unless the energy balance is maintained at that instant, it leads to undesirable situations, for instance frequency drift in an alternator of a thermal or hydro
power plant. However, PV sources do not require this balance to be maintained, since available energy, in excess of load demand, is not converted into electricity. Hence, a major source of instability, present in the conventional plants, is not present in the PV based systems. This results in more reliable operation and requires reduced operating complications.
Characteristics of a typical PV source are shown in Fig 1.1. From this figure,



which is a simple PN junction diode, formed by have to be connected in series to produce a useful voltage. Such strings are connected in
series and parallel in a sealed, weather proof package, which forms a PV module. Based

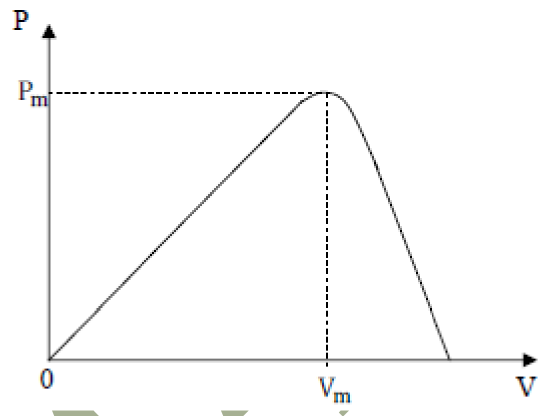


Fig 1.1: Current Vs voltage (IV) and Power vs Voltage (PV) characteristics of PV array

Few limiting factors, which restrict the usage of PV sources, are given below.

1. Photovoltaic energy system is more expensive than most of the other sources.
2. It requires large collection area for installation of the panels to get high power output.
3. PV energy is not available at night and is also affected in cloudy weather conditions.

This necessitates the use of storage system or alternate power system during these intervals of non-availability.

Photovoltaic Power System:-

PV modules are easy to transport and install. This enables easier expansion of generation and installation in remote areas. They can be designed to provide DC and/or AC power output, can operate interconnected with the utility grid or in isolation. Photovoltaic power systems are, generally, classified according to their functional and operational requirements, their component configurations, and how these are connected to other power sources and electrical loads. The two principle classifications are stand-alone system and grid-connected or utility-interactive systems.

Stand-alone PV systems:- In some of the countries, the electric grid is largely confined to feed the loads mainly in the urban areas and substantial proportion of the rural population does not have access to the electricity. In such cases, properly designed standalone PV system find potential application in

the rural electrification to generate electricity locally, diagram of a standalone PV system is shown in Fig 1.2. This
kind of power supply is immune to utility blackouts and do not rely on the penetration of

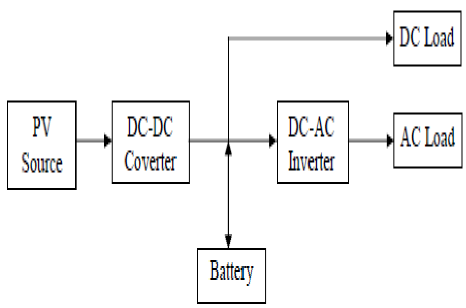


Fig 1.2 Block diagram of standalone PV system

Grid-connected PV systems:- Grid-connected PV systems, which are relatively more popular, can be interfaced to grid as shown in Fig.1.3. The interface requirements depend on the size and application. Small (<10kW) residential PV systems typically are interconnected with single-phase distribution lines. Intermediate size (>10 kW) industrial/commercial PV systems are usually interconnected with three-phase distribution systems. Large PV systems, with ratings of
100s of kW to a few MWs, are usually interconnected at either the distribution level or subtransmission level.

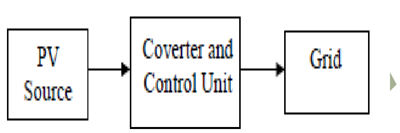


Fig 1.3: Schematic of Grid-connected PV application

Modeling of Photovoltaic Array:-

The basic building block of a photovoltaic (PV) array is the solar cell (PV cell), which is basically a p-n junction semiconductor device that directly converts light energy into electricity. The output current of the solar cell is directly proportional to the light falling on the cell and depends on the cell operating temperature. Hence, to understand the behavior of the solar cell, it is useful to create a model, which is electrically equivalent to the actual device and is based on

at the site where it is directly consumed. The block long distance transmission lines. As the PV source is not available during nights or cloudy
weather conditions, a battery can be used as a back up to these systems.

discrete electrical components, whose behavior is well known.
There are several ways to model a PV cell, module, or array for simulation . PV cell model can be coded by advanced software users. The resulting model may not be as robust or reliable as desired; troubleshooting and debugging can also potentially be time intensive. To overcome these problems, a circuit based PV array model is implemented in this thesis.
The simplified equivalent circuit of a PV cell can be obtained by a current source in
parallel with a diode as shown in Fig. 2.1. However, this circuit does not give an optimal
representation of the electrical process in the PV cell. A better equivalent circuit will include
a series resistance, *s R* and a parallel resistance *sh R* . Series resistance *s R* represents the contact resistance associated with the bond between the cell and its wire leads, and resistance of semiconductor, which leads to voltage loss of PV cell. *sh R* is representative of
the cell leakage current .The circuit considering all the elements mentioned are shown in Fig. 2.2

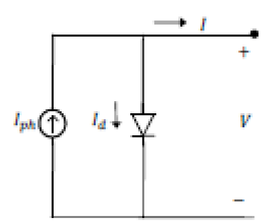


Fig 2.1: Simplified equivalent circuit of a PV cell

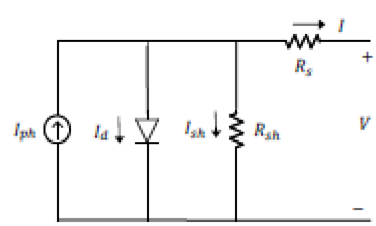


Fig 2.2: Equivalent circuit of PV cell

In this figures, I is the output current of the PV cell, V is the output voltage, *s R* is the
series resistance, *sh R* is the shunt resistance, *ph I* is the light generated current, *d I* is the diode current, and *sh I* is the leakage current. Voltage and current equations for the equivalent

circuit of the PV cell, shown in Fig 2.2, are as given below

$$I = I_{ph} - I_d - I_{sh}$$

$$I = I_{ph} - I_{sat}\left\{\exp\left[\frac{q}{AKT}(V+IR_s)\right]-1\right\} - \frac{V+IR_s}{R_{sh}}$$

$$I_{sat} = I_{sato}\left\{\frac{T}{T_r}\right\}^3 \exp\left[\frac{qE_{gap}}{KA}\left(\frac{1}{T_r}-\frac{1}{T}\right)\right]$$

Here,
sat I is the diode reverse saturation current (A)
sato I is *sat I* at standard test conditions (*S* = 1000*W* / *m*2 and *T* = 25°*C*)
ph I is the light generated current or short circuit current (A)
q is the electronic charge
A is the dimensionless deviation factor from the ideal p-n junction diode (=1~5)
K is Boltzmann's constant *T* is the cell operating temperature (K)
r T is the reference cell temperature (K)
gap E is the Energy of the band gap.

Simulation Results:-

GCPS response for varying atmospheric conditions :- Figs. 5.5 and 5.6 show the response of the Grid Connected Photovoltaic System (GCPS) for varying solar insolation, S. The step change in solar insolation is applied at t=l .5s and t= 2s. Initially, the PV array is operating at STC at its maximum power point. At t= 1.5s and 2s, solar insolation is changed from 1000 JF/m^2 to 400 W/m^2 and AOOWtm^2 to 60QW/m^2, respectively. The performance of the GCPS for changes in the solar insolation is explained below.

Case 1: S = 1000W/m^2(upto t=l.5s)

From Fig 5.5a, it can be observed that the PV array is operating at its maximum power point voltage, which is equal to 210V. ThePV array current (26.9A). power output (5630W), and power delivered to grid (5550W) are shown in Figs 5.5b, 5.5c and 5.53d, respectively. The d-axis (35A) and q-axis (OA) currents are shown in Figs 5.6a and 5.6b, respectively. The grid voltage and injected grid current are given in Fig 5.6c. The grid current is multiplied by a factor of 8 for better display. From this figure, it can be noted that the PV array is operating at unity power factor. The fundamental frequency component of grid current (24.4 A) is shown in Fig 5.6 d, which can be obtained by harmonic analysis using FFT, as explained in section 4.5.2 of chapter 4. Fig 5.6e shows the DC link voltage of the single phase inverter, and it can be observed that the voltage is maintained at 415V with 10V ripple in the DC link voltage.

Case2 : From S = JOOOWIm^1 to4WWlm^1 (at=1.5supto2s)

At time t=L5s, a step change in insolation is applied from l00JT/m^2 to 400W/m^2. The boost converter tracks the new MPP voltage, which is equal to 187V and the corresponding PV array power output is 2135W. The power delivered to the grid decreases to 2076 W. As the grid voltage is constant, the grid injected current decreases for a decrease in PV array output power. From Fig 5.6 c (a clear plot of Fig 5.6c is given in 5.7), it can be observed that the inverter is able to deliver power to the grid at unity power factor irrespective of the magnitude of the current. The corresponding changes in the GCPS operating parameters can be observed in Figs. 5.5 and 5.6.

Case 3 : From S = 4WW/m^2 to <500iVim^1 (at t= 2 s)

The GCPS is operating at new maximum power point voltage of 198 V and the corresponding power output is 3236W. From Fig 5.6c, ijt can be observed that the PV system operates at unity power factor irrespective of the value of solar irradiance. From the Figs 5.5 and 5.6, it can be observed that the GCPS control system is working well for varying atmospheric conditions.

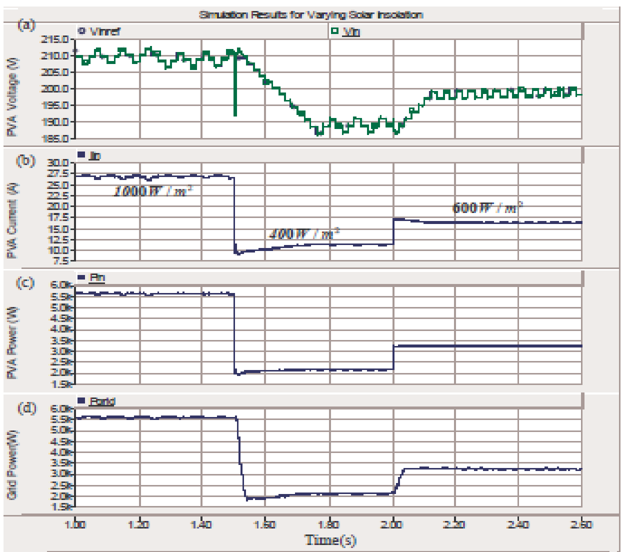


Fig 5.5 Performance of GCPS for varying solar insolation (a) PV array voltage output, (b) PV array output current, (c) PV array output power, (d) Power supplied by GCPS to Grid

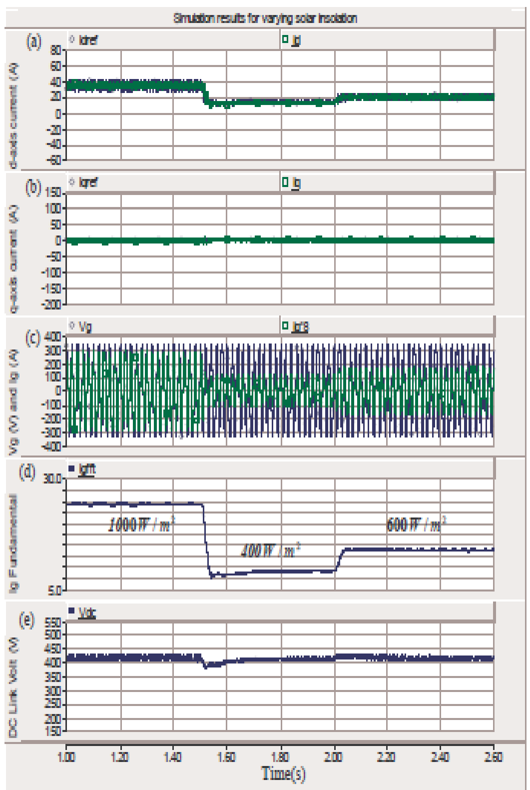


Fig 5.6 Performance of GCPS for varying solar insolation (a) d-axis current, (b) q-axis current (c) Grid Voltage and injected grid current, (d) Fundamental grid current, (e) DC-link voltage

Current harmonics (THD):-

The GCPS should supply the current to the grid at less Total Harmonic Distortion (THD). With the designed value of filter in section 5.5, the current harmonics of single phase inverter can be analyzed using FFT technique, similar to three phase inverter system explained in section 4.5.2, of chapter 4. Fig 5.8 shows the THD waveform for different solar irradiance levels, such as S= 1000W/m^2 S = 400W/m^2 and 600W/m^2, respectively and their values are about 6.26 % , 7.54%, and 6.87%, respectively.

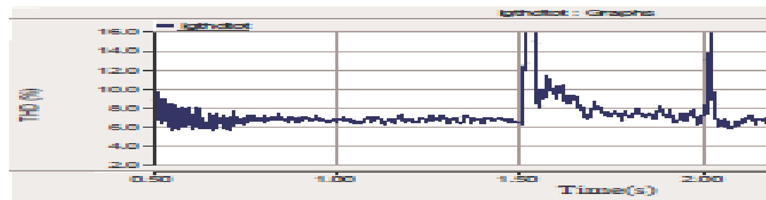


Fig 5.8: THD for a step change in solar irradiance, (from t=1.5s) and (from 400 W/m^2 to 600 W/

Simulation results for sag and swell in grid voltage:-

Similar to three phase system voltage sag and swell conditions explained in section 4.6, the performance of GCPS can be studied for 15% voltage sag and swell in the single phase line voltage. The performance of the PV system with 15 percent sag, and 15 percent swell in the grid voltage (from its nominal value of230 V RMS) from Is to 1.1 s is shown in Figs 5.9 and 5.10, respectively. It is observed from the plots that the PV system is injecting

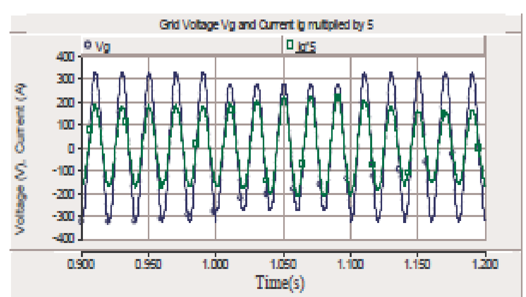


Fig 5.9 Grid Voltage(Vg) and Current (Ig) for 15 % sag in voltage from t= 1s to 1.1s

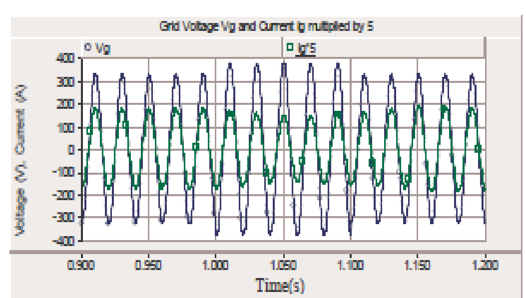


Fig 5.10 Grid Voltage (Vg) and Current (Ig) for 15 % swell in voltage from t= 1s to 1.1s

Concluding Remarks:-

In this chapter, single phase grid connected Voltage Source Inverter (VSI) control structures have been studied in detail. The proposed control strategy adopts an. inner current- control loop and an outer DC link voltage control loop. The single phase Phase Locked Loop (PLL) has been explained. The state space modeling of inverter current control and DC link voltage control are explained and the corresponding controllers have been designed using PI control. The developed control strategies are verified through simulation studies on 5.6 kW Grid Connected Photovoltaic System (GCPS). The L-filter has been designed and the current haimonics are calculated by EFT analysis. The effectiveness of the proposed control strategy under the important transients For GCPS, such as for grid voltage sag and swell, different solar insolaton levels, are evaluated through simulation studies conducted on a detailed switched model of the GCPS in the PSCAD/EMTDC (widely used power system simulation tool) software environment. The GCPS transient study provides the following conclusions.

- It is observed from the transients of1-Ph GCPS for voltage sag and swell that the PV system is injecting current into the gird at unity power even under voltage sag and swell and the inverter control is stable for the disturbance in the grid voltage.. The inverter current control adjusts its current output according to the grid voltage change i.e. the current is increased for voltage sag, and decreased for voltage swell
- The MPP voltage of l-Ph GCPS at solar irradiation S = 1000W/m^2 is 210V and at S = 600W/m^2 and 400W/m^2, it is 198V and 187V respectively. For the varying solar isolation, the 1-Ph GCPS control system is working well and it is delivering the power to the grid with variable power at unity power factor.
- With the designed L-filter (l0mH), the THD in the grid injected currents ale about 6.26%, 7.54%,and 6.87% ^respectively, for solar irradiation levels S = l000W/m^1, S m 400W / m^2 ,and 60QW / m^2.

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