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An Efficient Constant Current Controller for PV Solar Power Generator Integrated with the Grid

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ABSTRACT

Photovoltaic (PV) systems proposes attractive alternative source of generation because these can be placed near to the load centers when compared with other renewable source of generation. Most of renewable energy systems works in conjunction with the existing electrical grids. Also, inverter technology has an important role to have a safe and reliable grid interconnection operation of renewable energy systems. It is also necessary to generate a high quality power to the grid with reasonable cost. They also must be capable of provide high efficiency conversion with high power factor and low harmonic distortion. For this reason, the control policy must be considered. Therefore, The most important current control techniques are investigated in this paper.

Keywords:— *PV system design, modeling, DC-DC Boost Converter, PWM inverter, PLL constant current control.*

I. INTRODUCTION

World is moving towards the greener sources of energy to make the planet pollution free and environment friendly. The major utilization of these sources with grid integration is the challenging task. It is therefore Distribution Generation particularly single phase rooftop Photo Voltaic system are major research area for grid integration, since these sources have huge opportunity of generation near load terminal. The rooftop application involving single phase Distribution Generation's fed with Photo Voltaic source can be not only utilized for household use but the excess energy can be transferred to the grid through proper control scheme and adequate hardware.

Photo Voltaic systems can generate high voltages. Safety is therefore very important in order to avoid accidents and damage of expensive components and equipment. For safety reasons, solar arrays are normally earthed, either by placing a matrix of metal in the ground under the array, or by using conventional earth rods. It is normally not necessary to protect solar array from direct lightning strikes, provided that their mounting structure is well earthed. However, inverters or other electronics controls connected to the array should be protected. Blocking diodes are installed in solar arrays to prevent reverse current flows into the modules, which may damage the modules and cause energy losses. By-pass diodes are incorporated into modules to prevent damage of arrays when some cells or modules become shaded.

Photo Voltaic system requires regular maintenance to ensure proper operation and the full life of components. Some of the most important maintenance tasks are cleaning of modules front, Removal obstacles, tree branches, etc. Which cause shadowing of the modules, Battery charge check, if it remains very low the system should be re-designed, topping of battery electrolyte.

The rest of components of PV systems require little or no maintenance. The decentralized renewable energy production needs the continuous increase in the electrical energy with the clean environment. The increasing energy consumption may overload the distribution grid as well as power station and may cause the negative impact on power availability, security and quality.

The only solution to overcome this problem is integrating the utility grid with the renewable energy systems like solar energy, wind energy or hydro energy. As per the availability of renewable energy sources the grid can be connected to the renewable energy system. Because of abundant availability of solar energy recently the solar power generation systems are getting more attention, more efficient and more environment friendly as compared to the conventional power generation systems such as fossil fuel, coal or nuclear energy. Photovoltaic cells are devices that absorb sunlight and convert that solar energy into electrical energy.

In this paper proposes the modeling of the grid connected PV system with the constant current controller (CCC), which controls the solar inverter for interfacing the grid. The voltage level of DC voltage generated by the PV array is increased using the boost converter and then applied to the 3-phase, 2 level Solar inverter. The control of the solar inverter is provide through the constant current controller.

This controller uses the Phase Locked Loop (PLL) and PI controllers. The PLL is used for tracking the phase angle of the grid voltage. The PI controller gains are chosen such that the CCC generates the pulses for solar inverter according to the grid voltage. The proposed model is able to supply the 2 MW resistive loads and 30 MW, 2 MVAr load the applicable criteria that follow.

II. PROPOSED DRIVE SYSTEM

The PV array is the combination of series and parallel connected PV module. Each PV module has series connected PV cell according to the voltage requirements. Figure 1 shows the configuration of the grid integrated PV system. The MPPT technique is applied for operating the PV array at the maximum power point. The Vref generated by the MPPT is the desired DC voltage of the PV array and compared with the actual voltage of the PV array. The error signal is processed by the PI controller for minimizing the error. That control signal is compared with the triangular waveform for obtaining the switching pulses for the switch SW1. This arrangement controls the duty ratio for varying the load according to the MPPT. The boost converter stepping up the voltage level of the PV array.

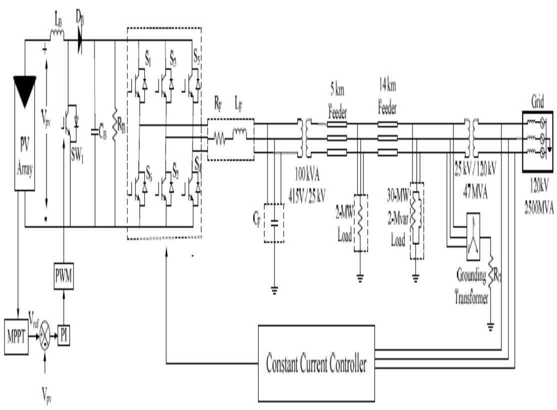

Figure 1: Configuration of the Grid Integrated PV System

The 2-level inverter is inverting the DC voltage 600 V into the sinusoidal AC signal 415 V. A constant current controller is providing the switching pulses to the inverter. This controller senses the phase angle of the grid voltage and generates the switching pulses such that the inverter can output the voltage with the same frequency of the grid voltage. If there is phase distortion in the grid voltage, this controller is able to track the distorted phase and controls the inverter to give the same output. The harmonics generated by the inverter is reduced by the 3-phase LC filter. For integrating the PV system into the grid the voltage level should be same. Hence the 100 kVA, 415/25 kV transformer is used. The 120 kV, 2500 MVA utility grid is integrated with the solar system. The grid voltage level has been changed from 120 kV to the 25 kV using the step down transformer. The 30MW, 2-MVAr load is connected at the grid side. At the distance of 14 km resistive load of 2 MW is connected.

3. MODELLING OF PV ARRAY And PV Cell

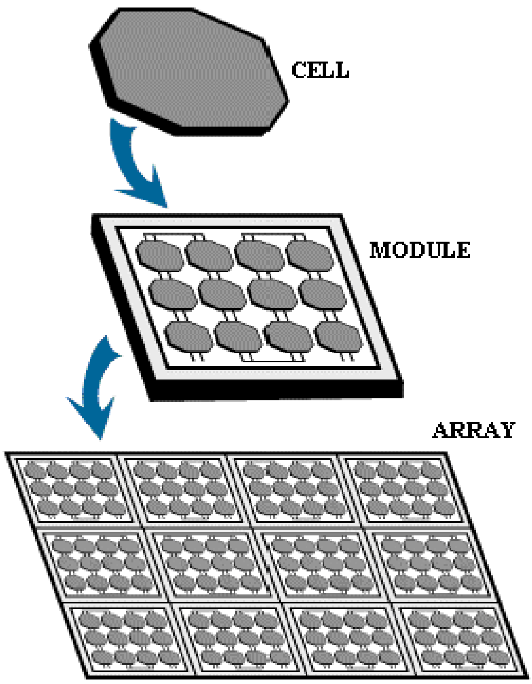

Figure 2: PV Cell, Module and Array

A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module'. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on the intensity of light reaching the module. Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

A PV array consists of a number of PV modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The PV array can be of any size from a few hundred watts to hundreds of kilowatts, although the larger systems are often divided into several electrically independent sub arrays each feeding into their own power conditioning system.

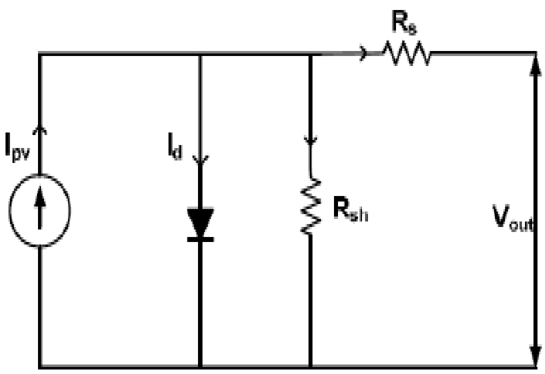

Figure 3: Equivalent Circuit Model of PV Cell

The Solar cells are to convert solar energy into the electrical power. These cells are made up of semiconductor materials, when sun beam is absorbed with these material electrons emits and releases the current and thus electric power is produced. The equivalent circuit for obtaining the V-I characteristic of the PV cell.

The desired high power numerous solar cells are connected in series and parallel. For the high voltage requirement cells are connected in series and for high current application cells are connected in parallel to form a panel. The group of these panels is known as PV array.

The Mathematical modeling of the PV array can be given as:

$$I = NpIph - NpId\left[\exp\left(\frac{q}{kTA} * \frac{VPV}{Ns}\right) - 1\right] \quad \text{.........(1)}$$

Where,

I=The PV array output current
Np=No.of cells connected in parallel
Iph=Light generated current or photo current
Id=Diode reverse saturation current
q=($1.6*10^{-19}$ C) is electron charge

$$k = \left(1.38 * \frac{10^{-23} J}{K}\right) \text{ is a Boltzmanns Constant}$$

T=The cell of temperature in Kelvin
A=Ideal factor
Ns=No.of cells connected in series
Rs=Shunt resistance
Rse=Series resistance

When the diode is reverse saturation current Id varies with the temperature according to the following equation is,

$$Id = Irr\left[\frac{T}{Tr}\right]\exp\left(\frac{qEg}{kA}\left[\frac{1}{Tr} - \frac{1}{T}\right]\right) \quad \text{.................(2)}$$

Where,
Irr=The cell reverse saturation current at reference temperature
Tr=The reference temperature
Eg=The band gap energy of the semiconductor used in the solar cell
The energy gap of the semiconductor used in the PV cell
dependent on the temperature is given as:

The energy gap of the semiconductor used in the PV cell dependent on the temperature is given as:

$$Eg = Eg(0) - \frac{\alpha T^2}{T + \beta} \quad \text{........................(3)}$$

The light generated current or photo current Iph depends on the solar radiation and Cell temperature is given as:

$$Iph = [Iscr + Ki(T - Tr)]\frac{S}{100} \quad \text{.....................(4)}$$

Where,

Iscr=The short circuit current at reference temperature

Ki=The short circuit temperature coefficient

$$S = \text{The incident solar radiation in } \frac{mW}{cm^2}$$

The total PV power can be calculated using the following expression,

$$P = IV = NpIph\left[\left(\frac{q}{kAT} * \frac{V}{Ns}\right) - 1\right] \quad \text{................(5)}$$

In the Solar irradiation and temperature plays an important for predicting the behavior of the PV cell and effects of both the factors have to be considered while designing the PV system.

The solar irradiation affects the output and the temperature affects the terminal voltage.

IV. Boost Converter Model and Its Control

In the Boost Converter the output voltage of the PV cell is very limited, which is very low for the application. The series and parallel combination also does not provide the required output. Hence the boost converter is necessary to enable the low voltage PV array to be used. A capacitor is also connected for reducing the high frequency harmonics between the PV array and boost converter.

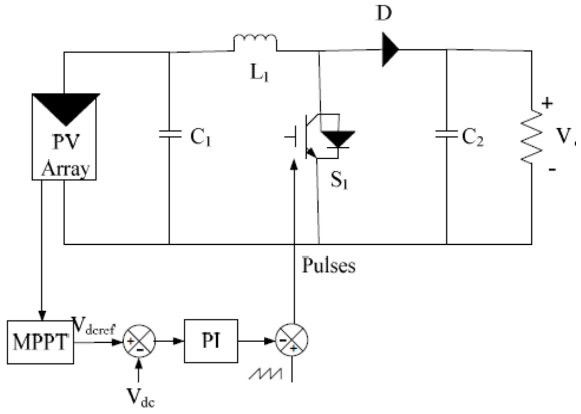

Figure 4: Closed Loop Controller for Boost Converter

When the switch S1 is in ON state, the inductor L1 is charged from the voltage (Vpv) generated by the PV array and the capacitor C1 discharges across the load. The duty cycle D

is $\left(\frac{Ton}{T}\right)$ and. $\left(T = \frac{1}{f}\right)$ The boost converter operates in CCM (Continuous Conducting mode).

The current supplied to the output RC circuit is discontinuous. Thus a large filter capacitor (C_2) is used to limit the output voltage ripple. The filter capacitor must provide the output dc current to the load when the diode D is in OFF state.

The Boost Converter with interfacing PV panel or array and the load. The designed equations for the boost converter are given as,

$$\frac{Vo}{Vg} = \frac{1}{1-D} \quad \text{…………………..…………...…(6)}$$

The duty ratio of the Boost Converter is given as:

$$D = 1 - \frac{Vg}{Vo} \quad \text{…………………………...……..(7)}$$

Where,
Vg=Input voltage
Vo=Output voltage
D=Duty cycle

The control of the boost converter is provided through the PWM signal. The output of the filter which is the control signal is compared with the reference voltage. The PI controller attempts to minimize the error by adjusting the process control inputs. Then it is compared with the saw-tooth waveform to generate the PWM signal which is fed as gate signal to the IGBT switch. The control circuit regulating the reference voltage, (Vdcref) which is calculated by the MPPT techniques. Thus the PV array can be controlled by controlling the duty ratio for operating at the maximum power point.

5. Maximum Power Point Tracking System

The objective of the project was to design a Maximum Power Point Tracker (MPPT) for a solar-powered vehicle. This component optimized the amount of power obtained from the photovoltaic array and charged the power supply. The solar car will be constructed by the 2003/2004 Nerd Girls Team and will incorporate the Maximum Power Point Tracker unit into the final design.

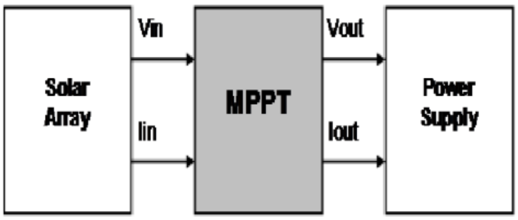

Figure 5: Block Diagram of MPPT

The inputs of the MPPT consisted of the photovoltaic voltage and current outputs. The adjusted voltage and current output of the MPPT of charges power supply. A microcontroller was utilized to regulate the integrated circuits (ICs) and calculate the maximum power point, given the output from the solar array. Hardware and software integration was necessary for the completion of this component.

VI. Controller for Solar Inverter for Interfacing Grid

In a solar or PV inverter is interfacing the utility grid. It is also converts the variable direct current output of a photovoltaic (PV) solar panel into a utility frequency alternating current that can be fed into a commercial electrical grid. It is a critical component in a photovoltaic system and its control should be such that its output can interface the voltage of the utility grid.

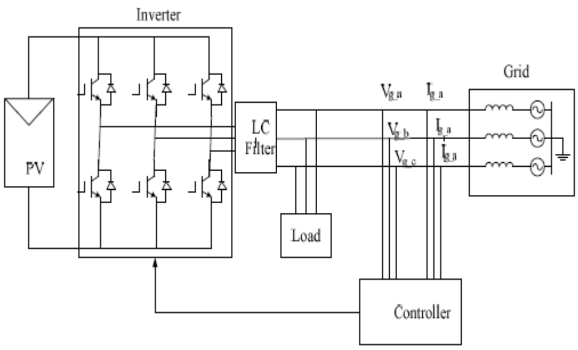

Figure 6: Switching Model of Solar Inverter

There are two basic control modes for the grid connected inverters. One constant-current-control and the other is constant-power-control. In this proposed model, the control of the solar inverter is provided through the Constant Current Controller using the 3-Phase Locked Loop (PLL). In constant current control, the inverter output currents are regulated to the reference grid current. In this figure 3 the switching model of the solar inverter.

VII. Block Diagram of Constant Current Controller

In the detailed block diagram of the constant current controller for generating the controlled switching pulses for the solar inverter such that the output voltage should be able to interface the grid. The 3-Phase Locked Loop calculates the phase angle of the utility grid and also gives the information about the frequency variation. According to the phase angle of the utility grid voltage, the constant current controller is modeled such that the controller is able to generate the switching pulses for solar inverter for tracking the phase of the grid voltage.

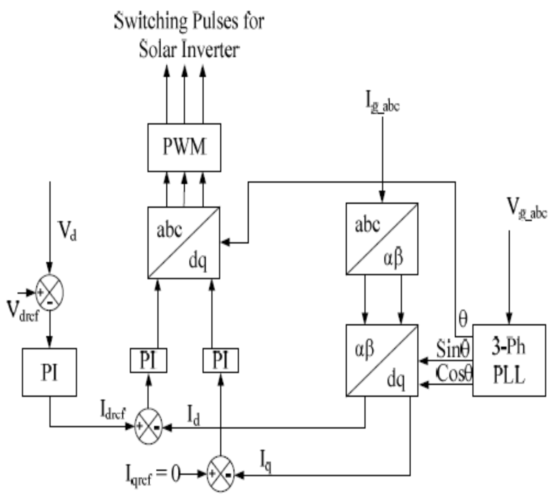

Figure 7: Block Diagram of Constant Current Controller

The 3-phasegrid current Ig_abc is converted into variable using the Clarke transformation. The variables are transformed into the dq variables. The current Id and Iq are compared with the Idref and Iqref for processing in the PI controller to minimize the errors. These signals are transformed into 3Ø signal using the inverse park's transform and then compared with the triangular waveform for generating the PWM switching pulse for the solar inverter. The Vdc and Vdcref is the DC link voltage of the PV array and expected DC voltage of the PV array.

8. Simulation Result and Discussion

The simulation result are shows the concept of Comparison of Constant Current and Hysteresis Controlling techniques for PV system Integrated with Grid. The flowing figure represents simulink model for PV system integrated with grid using constant current controller. The following figure 5 represents simulink model for PV system integrated with grid using hysteresis controller. The following figure 6 represents simulink model of hysteresis controller to reduce the harmonics. The following figure 7 represents simulink design for hysteresis controller design. The following figure 8 represents simulation of proposed scheme at boost converter output. The following figure 9 represents simulation of proposed scheme at with filter. The following figure 10 represents simulation of proposed scheme at 2MW load. The following figure 11 represents simulation of proposed scheme at 30MW load. The following figure 12 represents simulation of proposed scheme at without filter. The following figure 13 represents simulation results using hysteresis controller.

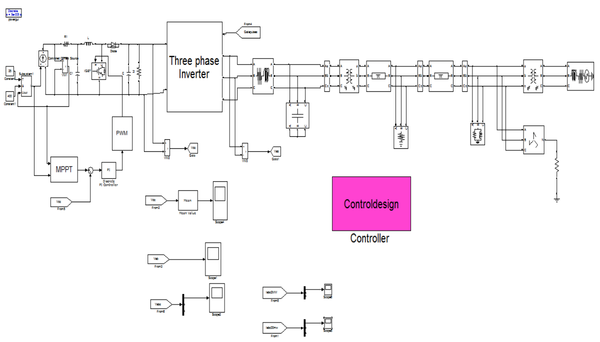

Figure 8: Simulink Model for PV System Integrated with Grid using Constant Current Controller

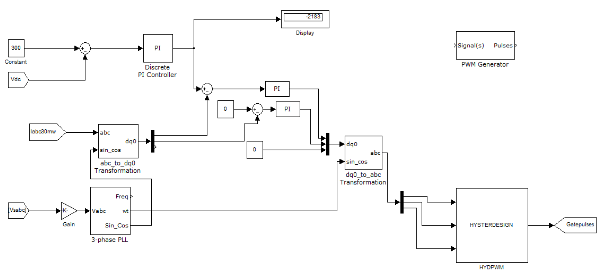

Figure 9: Simulink Model of Hysteresis Controller to Reduce the Harmonics

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. Models are hierarchical, so we can build models using both top-down and bottom-up approaches. We can view the system at a high level, then double-click on blocks to go down through the levels to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact. After we define a model, we can simulate it, using a choice of integration methods, either from the Simulink menus or by entering commands in MATLAB's command window. Using scopes and other display blocks, we can see the simulation results while the simulation is running. In addition, we can change parameters and immediately see what happens, for "what if" exploration.

The simulation results can be put in the MATLAB workspace for post processing and visualization. Simulink can be used to explore the behavior of a wide range of real -world dynamic systems, including electrical circuits, shock absorbers, braking systems, and many other electrical, mechanical, and thermodynamic systems.

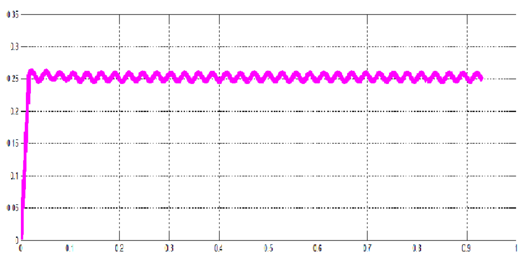

Figure 10: Inverter Output Voltage After Filtering using Hysteresis Controller

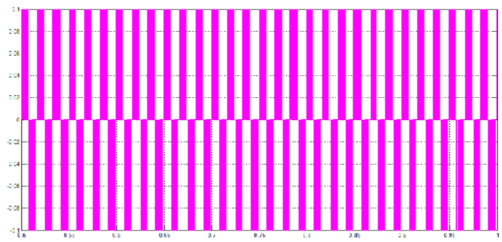

Figure 11: Inverter Output Voltage After Filtering using Constant Current Controller

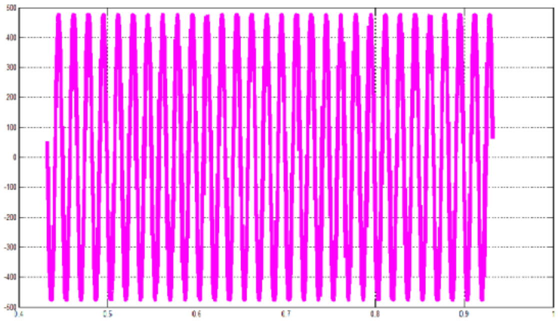

Figure 12: Inverter output voltage before filtering

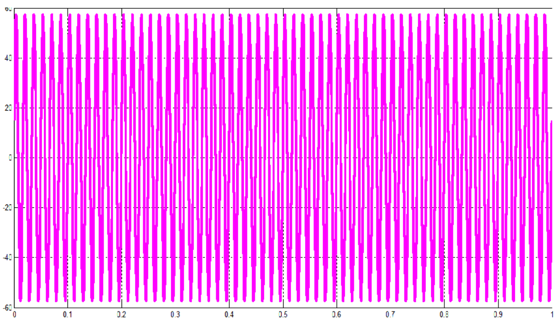

Figure 13: Load current for supplying 2MW load

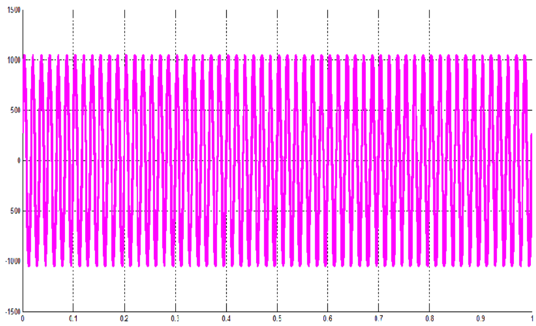

Figure 14: Load current for supplying 30MW load, 2 MVAr

IX. CONCLUSION

This paper proposes the comparison of constant current and hysteresis controlling techniques for PV system integrated with Grid. Here while comparing two controllers ie constant current controller and hysteresis controller, to integrate the PV system with grid. All results will be same for both hysteresis controller and constant current controller, the only difference is in without filter results. When compared with constant current controller, by using hysteresis controller high efficiency conversion with high power factor and low harmonic distortion can be obtained. Hence From the above both constant current and hysteresis controlling techniques can be used to interface the PV system with grid but by using advanced hysteresis controller harmonic content can be reduced.

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