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Modified Grid Tied Inverter with Integrated Power Quality Improvement

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***Abstract*—This paper deals with a two stage grid tied PV system consisting of a boost converter and a full bridge inverter. The dc- dc stage helps to provide better decoupling as well as operation at maximum power point. The work is intended to address the problems created during the grid integration of Solar PV systems. The existing inverter control is modified to facilitate multifunctional operation of inverter which includes reactive power support to enable unity power factor operation and harmonics mitigation to improve quality of grid power. The addition of active power filtering capabilities to the existing grid feeding inverter reduces the need for installation of additional Custom Power Devices (CPDs) The system helps to address the problems created due to the nonlinear loads connected to grid. The given system does not use a PLL for grid synchronization which also helps to improve the dynamic response of the system.**

***Index Terms*— Harmonics, PLL Less, P&O MPPT**

I. Introduction

The rapid depletion of conventional energy sources like coal and the ever increasing energy demand has necessitated the shift to renewable energy resources like solar, wind etc. Among the various renewable energy sources solar is given more importance because of its immense potential. It is available in plenty and easier to tap for which inverters are used.

Inverters are of different types which includes CSI (Current Source Inverter) and VSI as their basic forms. CSI offers the advantage of low dc link capacitance which helps to increase the life span of inverters.[1] The comparison of these two topologies is presented in.[2]. Inspite of these reasons Voltage Source inverters are commonly used for grid interconnection. Currently a lot of research is being done on Single stage inverter topologies combining the advantages of both CSI and VSI.

One of the important challenges faced by researchers in this area is due to the moderate efficiency of the PV system. This limitation is being overcome by researchers by the use of MPPT (Maximum Power Point Tracking) techniques to extract maximum power from the PV panels. The dc- dc converter helps to extract maximum power from the PV panel by operating the system at MPP .Several MPPT techniques have been proposed till date which includes simple methods like P&O (Perturb and Observe)[3] ,Incremental Conductance,[4] .

Also there are more complex MPPT algorithms based on fuzzy logic controllers Sliding Mode controllers etc InC algorithm compares the incremental conductance with the conductance at MPP while P&O algorithm also known as Hill Climbing algorithm compares the voltage and power before perturbation to the voltage and power after perturbation to reach MPP.P&O algorithm is implemented in this paper due to its simplicity. Also it requires the sensing of less number of variables compared to other MPPT techniques.

There are different single stage topologies for grid tied inverters which includes ZSI (Z-Source Inverter),SBI (Switched Boost Inverters) etc that provides high gain in a single stage itself. A two stage topology is chosen in this paper for easy implementation of MPPT. Different control techniques have been proposed in different literatures for the extraction of reference current one of which is SRFT (Synchronous Reference Frame Theory).This technique faces two major problems (1) PLL makes the system response sluggish and (2) excessive dependence on PI controller tuning makes the system less reliable. An OCC based system for grid integration of single phase solar PV generation has been introduced. Christo Ananth et al.[5] presented a brief outline on Electronic Devices and Circuits which forms the basis of the Clampers and Diodes.The amount of power extracted by this single-stage system is

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highly dependent on the values of its operating parameters, which requires regular tuning in order to maximize the output power for different irradiance levels

The tremendous increase in nonlinear loads like that of LEDs Power Electronic Converters etc have led to the deterioration of quality of grid power. These loads causes harmonics that distorts the PCC(Point of Common Coupling) voltage and they do not contribute any active power transfer rather it increases the losses. It is required to maintain the quality of grid power by maintaining the THD (Total Harmonic distortion) of grid current within 5% as per IEEE 519 standard[6]

In this paper a multifunctional grid tied two stage VSI is presented. The inverter not only extracts and feeds the maximum power extracted from the solar panels to the grid but also provides reactive power and harmonic compensation. The two stage inverter is simulated in MATLAB Simulink platform to validate the results.

The paper is organized as follows Section II describes the Configuration of the System, Section III describes the modeling of PV panel and boost converter Section IV details the Control Strategy, Section V describes the Simulation Results and Section VI concludes the paper.

II CONFIGURATION OF THE SYSTEM

The two stage grid tied PV system presented in this paper is as shown in the Figure 1.The given system is composed of two power stages ie a dc-dc stage that is directly connected to a PV system and a dc-ac stage interfaced with grid.. The dc-dc stage is composed of a boost converter that helps to extract maximum power from the PV array using an MPPT algorithm. P&O algorithm is used in this paper Also dc- dc stage helps to achieve better decoupling The VSI section is interfaced to the grid through a ripple filter.

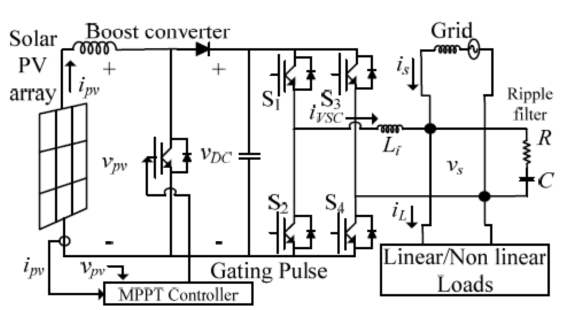

Fig. 1 Configuration of the double-stage single-phase grid connected solar PV generating system.

The variables 'V_{PV}' and 'I_{PV}' are the PV array voltage and current respectively. 'I_{VSC}' is the inverter current injected to the grid. i_L ,i_s and v_s are the load current, source current and source voltage respectively. The system features several advantages over conventional active power filtering sections in the sense that load power is not at all used in the generation of reference current. The reference current estimation using grid current suffers from the problem of sluggish response especially due to the low pass filter used to filter out the double frequency ripple components. The proposed method does not need dq0 transformations to generate quadrature and in phase components which in turn increases its simplicity of implementation. Also the system does not use a PLL for grid synchronization so the overall dynamic response of the system is improved. The system uses a Notch Filter [7] for generating in phase and quadrature components of PCC voltage which is based on a second order generalized integrator. The modeling of PV panel , design of dc- dc stage and control algorithm are presented in the subsequent sections

III MODELLING AND DESIGN

A *PV Array Model*

The PV module is modeling is done by considering it as a current source in parallel with an antiparallel diode. Taking into account the internal losses series and shunt resistances are also added as in Figure 2 The modeling is done as per the equations in [8].The relevant equations are given below.

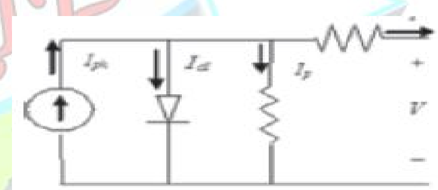

Figure 2 :Practical equivalent circuit of the solar cell

By applying Kirchhoff's law,

$$I = I_{ph} - I_d - I_p \tag{1}$$

Where I_{ph} is the photocurrent
I_d is the diode current and
I_p is the current leak in the parallel resistor

But
$$I_d = I_0 \left[\exp \left(\frac{V + IR_s}{a} \right) \right] \tag{2}$$

Where I_0 is the reverse saturation current
R_s is the series resistance
a is the modified ideality factor given by

$$a = \frac{AkT_c N_s}{q} \tag{3}$$

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Where A is the diode ideality factor(0.3 for Si)
k is the Boltzmann constant (1.381×10^{-23}J/K)
N_s is the number of series connected cells
T_c is is the cell temperature
q is the electron charge (1.602×10^{-19}C)
R_p is the parallel resistance

$$I_p = \frac{V + IR_s}{R_p} \qquad (4)$$

B Dc-Dc Stage Design

The dc-dc stage employs a boost converter to boost the low value of PV voltage to the value of required dc link voltage which should be higher than the peak value of grid voltage. The dc -dc stage helps to implement Maximum Power Point Tracking and enables better decoupling also. The relevant design equations are as given below

$$V_{DC} = \frac{V_{PV}}{1 - D} \qquad (5)$$

The inductance value is chosen by assuming Δi_L=10% generally

$$L = \frac{V_{PV} \times D}{\Delta i_L \times f_s} \qquad (6)$$

Where Δi_L is the ripple current

f_s is the switching frequency which is a design choice

D is the Duty Ratio & V_{DC} is the dc link voltage

IV CONTROL STRATEGY

The main objective of the VSC in this paper is to feed the maximum power extracted from the PV array to the grid
An overall unity power factor operation is achieved for the combination of VSC and selected local load. The reactive power and harmonics required for the selected load are supplied by the VSC. This is ensured by developing a control which allows the grid to meet only the real power demand of the local-loads along with losses of the VSC. The control strategy can be broadly divided into two parts, namely, the MPPT control block, and the VSC control block.

The MPPT controls the dc-dc stage which is composed of a boost converter whose duty ratio is modulated to achieve boost operation and extraction of maximum power .P&O Algorithm owing to its simplicity and robustness is being considered here.

The VSC control block employs an indirect current control strategy in order to generate the switching pulses for the inverter..The magnitude of real component of load power and VSC losses are only supplied by the grid The notch filter is used to generate a unit template for grid synchronization which ensures unity power factor operation

A MPPT Control

P&O Algorithm also called Hill Climbing algorithm is implemented in this paper as shown in the Figure 3

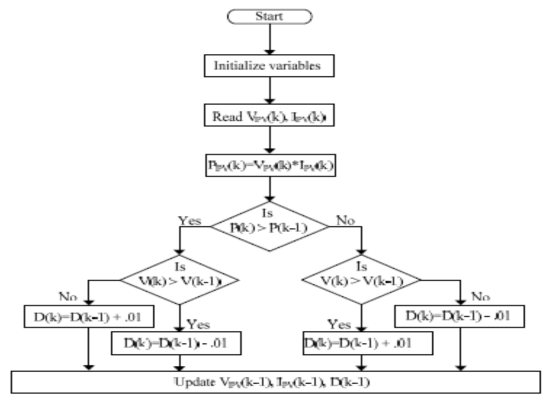

Figure 3:P&O MPPT

The MPPT algorithm was implemented using MATLAB Simulink Platform It involves the deliberate perturbation of PV array output voltage and Power. The controller compares the value before perturbation to that after perturbation to arrive at MPP. The relevant equations governing the controller are as given below

$$D(k) = D(k-1) - \Delta D \quad \text{if } dP_{PV}>0 \ \& \ dV_{PV}>0$$
$$\text{if } dP_{PV}<0 \ \& \ dV_{PV}<0 \qquad (7a)$$
$$D(k) = D(k-1) + \Delta D \quad \text{if } dP_{PV}>0 \ \& \ dV_{PV}<0$$
$$\text{if } dP_{PV}<0 \ \& \ dV_{PV}>0 \qquad (7b)$$

where ΔD is the perturbation duty ratio

B VSC Control

The Control algorithm for the VSC is as shown in the Figure 4 Here an indirect current control strategy is employed ie the source current is sensed for control purpose .The following parameters are determined for control purpose (a) In phase real component of load current I_{Lp} (b) Fundamental and 90^0 out of phase component of PCC voltage (c) Amplitude of PCC voltage and (d) VSC Losses Notch filter given in Figure 6 is used for extraction of in phase components of fundamental PCC voltage and in phase component of load current. I_{Lp} is extracted by using an

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ZCD and S/H circuit that detects the zero crossing of the quadrature component of voltage $V_{s\beta}$

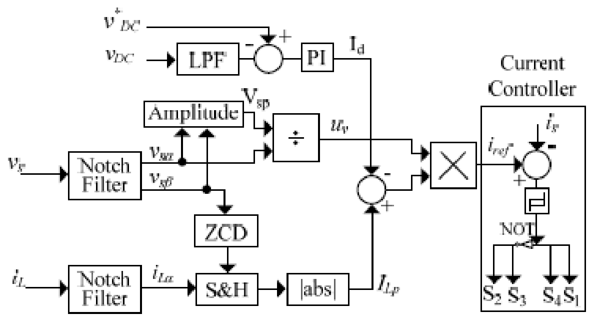


Figure 4:VSC Control

The unit synchronising template $u_v(k)$ is generated using the in phase component of PoC voltage $V_{s\alpha}$ and $V_{s\beta}$ as given below

$$V_{sp}(k) = \sqrt{V^2_{s\alpha} + V^2_{s\beta}} \quad (8)$$

$$u_v(k) = \frac{V_{s\alpha}(k)}{V_{sp}(k)} \quad (9)$$

The DC link voltage of the VSC is maintained at a predetermined voltage level using a PI controller. This facilitates active power transfer from the PV array and determination of VSC Losses. The compensating current signal is given by

$$i_d(k) = i_d(k-1) + k_p[e_{DC}(k) - e_{DC}(k-1)] + k_i e_{DC}(k)$$

$$e_{DC}(k) = v^*_{DC}(k) - v_{DC}(k) \quad (10)$$

Where k_p & k_i are the proportional and integral gains and is the V_{DC}^* reference dc voltage .of PI controller

The proposed system is designed so as to obtain a unity power factor operation by minimizing harmonics and necessary reactive power compensation for a selected nonlinear load. An indirect current control scheme is used here. One of the important advantages of this system is that this does not involve power calculations unlike the case of a traditional Shunt Active Power Filter.

A tuned Notch filter is used to extract the in phase harmonics free component of load current as well as in phase and 90^0 out of phase component source voltage. .Its transfer function is given by

$$G(s,\theta) = \frac{s^2 + \theta^2}{s^2 + \varsigma\theta s + \theta^2} \quad (11)$$

The block diagram representation of the scheme is as shown in the Figure 5.The system is adopted based on the assumption that there is not much variation in grid frequency. The consideration of varying grid frequency demands the adoption of a notch filtering scheme which increases the complexity of implementation and calculation burden. The notch filter adopts two integrators to enable the filtering of harmonics free current the parameter ς is to be chosen judiciously as a compromise between the band width and settling time so as to enable better harmonic elimination and less steady state error under frequency variations also .In this paper its value is chosen by trial and error method

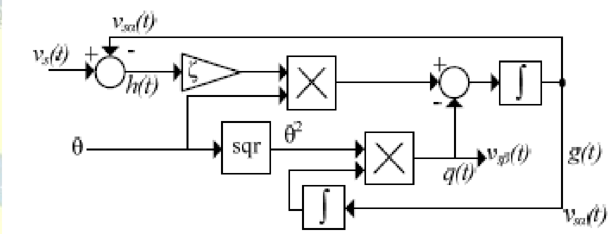


Figure 5: Schematic of Notch filter

The difference between the in phase real component of current that is extracted from the load current using Notch filter and the PI controller output which represents the VSC losses is taken to generate the compensating signal. The compensating signal is compared with the grid current to generate the error signal which is used to switch the inverter switches by passing through a hysteresis controller which limits the current error within a preset value .If the error goes beyond the upper limit S1 and S4 is turned ON if it goes below lower limit S2 and S3 is turned ON. The system is validated through simulations and the results are presented in the subsequent section.

V SIMULATION RESULTS

The entire system was simulated in MATLAB Simulink Platform and the diagram is as shown in the Figure.11 A 3.69kW Solar PV system was modelled and simulated in MATLAB and the P-V chara and I-V chara obtained under standard conditions of irradiance and temperature of $1000 W/m^2$ and 25^0 C are as shown in the Figure 6 The parameters used for simulation are given in the Appendix.

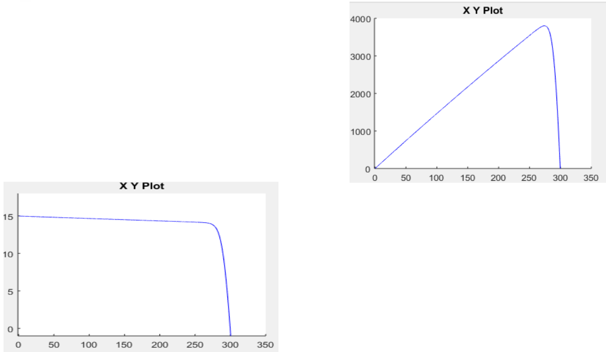


Figure 6:P-V chara and I-V chara of PV array

The waveforms of notch filter showing the extraction of in phase and 90^0 out of phase components of grid voltage is as shown in the Figure 7

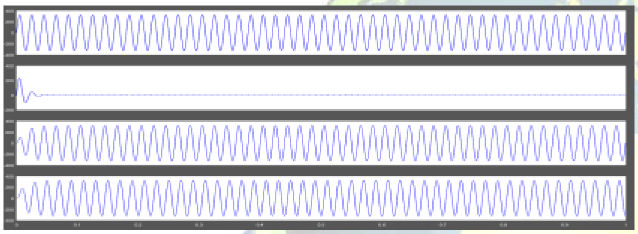
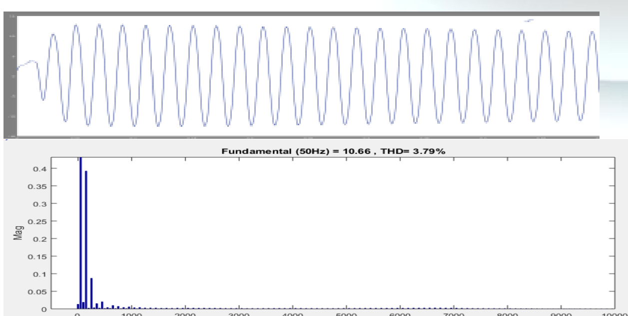


Figure:7(a) $V_{s(}$ (b) h(t) (c)In phase component of grid voltage (d) 90^0 out of phase component of grid voltage.

The given system was tested under the conditions of linear load, non linear load and, varying irradiance and temperature conditions and the relevant results are given below .Figure 8 shows the grid current under nonlinear load conditions. Figure 9 gives the THD analysis of grid current for step change in irradiance



..Figure 8:Grid current and THD results under nonlinear load

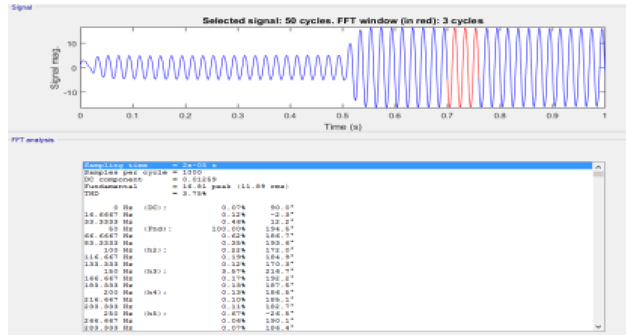


Figure 9: THD with step change in irradiation and temperature under nonlinear load condition

The performance was found to be satisfactory under the conditions of both linear and non linear load conditions .with THD below 5% as per IEEE 519 standard. The power factor at the point of coupling was found to be 0.989 which is near to unity under both linear and non linear load conditions. The grid current was found to be 180^0 out of phase with the grid voltage as in Figure 10 which indicates that power is being fed to the grid. The THD of the grid current was reduced from 28% to 3.79%.This means that the harmonics required by the local load is being supplied by the VSI.

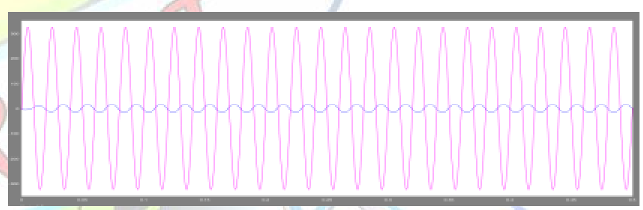


Figure:10: Grid voltage and grid current waveforms

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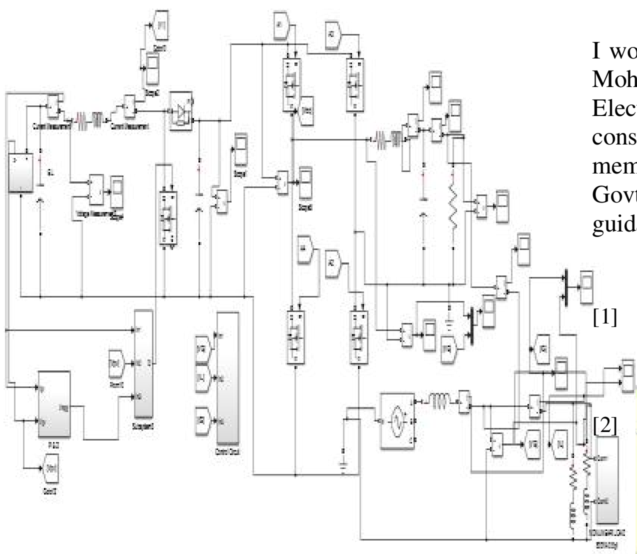

Figure 11:SIMULINK Model of the system

VI CONCLUSION

The modified voltage source converter capable of power quality improvement was designed and simulated. The simulation results showed a THD below 5% and DPF of 0.998 which is near to unity. This indicates the conformity of the system to the IEEE 519 standard The simulation results confirms the capability of the system to feed active power to the grid and compensate harmonics and reactive power requirement of selected load.

APPENDIX

System Parameters

Grid voltage and Grid frequency	230V and 50Hz
Kp and Ki	0.06 & 2 respectively
Boost Converter inductance	4mH
DC Link Capacitance	2000µF
PV Array Open circuit voltage and short circuit current at 1000W/m^2 & 25^0C	300V &15A
Switching frequency of boost converter	10kHz
Current controller thresholds for switching	±0.2 A.
Ripple filter parameters inductor and capacitor and resistor	10mH, 50µF and 10Ω ,1W

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