A Grid Connected PV Module Having MPPT and VSC

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***Abstract*-** *PV array is used with MPPT to attain maximum power while the radiation is changed frequently. MPPT is controlled via incremental conductance method Algorithm. A 3-phase voltage source converter is used to convert DC from MPPT to AC which is connected to the Grid through Transformers. The inverter is controlled using vector control scheme to have an independent control on active and reactive power. Capacitive Banks have also been installed prior to Grid to provide reactive power supply and improve Active power performance. The proposed system is analysed with the help of MATLAB/SIMULINK.*

Keywords- Voltage source inverter (VSI), photovoltaic(PV), maximum power point tracking (MPPT), grid-connected.

I. INTRODUCTION

As the increasing environmental pollution and the gradual depletion of fossil fuels, people incrementally turn their concentration to the non-conventionally energy generation. In future time Large scale solar plants are gaining recognition as huge capability of energy sources. Due to the increasing demand and environmental issues, renewable energy sources have attracted the attention of researchers and investors. Among the available renewable energy sources, the photovoltaic (PV) system is considered to be a most promising technology, because of its suitability in distributed generation, satellite systems, and transportation [1]. The main benefits of solar energy is that it can be easily utilized by both home and commercial users as it does not require any huge set-up as much as wind and geothermal power stations. The generation and control of electrical power supplied to the grid have change drastically due to improvement in power electronics and development of new technologies. We use solar photovoltaic cells for powering the grid connected inverters. The role of inverter in grid connected system not only integration of renewable energy sources to ac grid but it also provides power factor correction, reducing harmonics drawn from grid and improving quality of voltage at load terminals. While an inverter performs above functions, it also injects switching frequency ripples in the grid, therefore it must be insured that frequency ripples injected in the grid are within specified safety limits of the grid. For this we need a properly designed filter at the output of the inverter. Further a grid-connected inverter is expected to undergo common grid disturbances like voltage sags, voltage swells, which require control mechanism to ensure operation under these excursions. Also the operating power of solar power plants have elevated from few KWs to MWs, so to assure the seemly performance of grid connected to such plants we require good control of active and reactive power generated by the inverter. This require deep research on general issues related to grid-connected inverters and on specific issues related to their operation at higher power levels.The PV system operates in two different modes: grid-connected mode and island mode [2].In the grid-connected mode, maximum power is extracted from the PV system to supply maximum available power into the grid. In single and three phase PV applications we used commonly Single- and two-stage grid-connected [5], [6]. grid connected PV systems have become very favourable because they do not require battery back-ups to assure MPPT. If Stand-alone systems can also attain MPPT, but they would need suitable battery back-ups for this purpose. grid connected PV systems usually employ two stages systems and single stage systems [3].The foremost stage is used for Maximum Power Point Tracking (MPPT) and boosting the PV voltage. The next stage inverts the first stage DC output to AC at grid frequency. The first stage consists of a boost or buck-boost converter (DC-DC) and the secondstage consists of the inverter (DC-AC).The block diagram of the grid connected PV system basically can be represented as shown in Figure[4]:[ttthisdd][[[

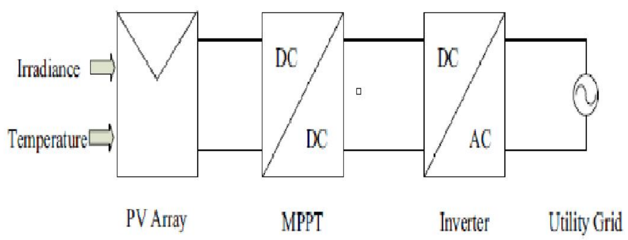

Fig. 1 The block diagram of grid-connected PV system

This paper is organised as follows: section II describes the modelling of grid connected photovoltaic system. Section III describes the control strategy. Section IV describes modelling of the inverter. In section V we discussed simulation validation, conclusions are drawn in section VI.

II. MODELLING OF GRID CONNECTED PHOTOVOLTAIC SYSTEM

a. Photovoltaic Array

Themathematical model of PV array is modeled by considering a single diode equivalent circuit of a PV cell as is shown in Fig (2). By applying KCL for ideal photovoltaic cell, the generated output current of the cell is difference of photon current and diode current and is given in (1). And practical PV cell is represented by adding series and shunt resistance to the ideal cell. A PV array mathematical model is formed by (2) -(4) considering the number of parallel and series cells and its corresponding losses in terms of resistances. Where Id- diode current, Iph- the photon current, Icell-individual cell current, Is-the saturation current Np number of modules connected in parallel, Ns- number of cells connected in series, q- electrical charge, N-ideality factor, k - Boltzmann constant, VA - terminal voltage of the array and IA - PV array current, Rs -series resistance, Rsh- shunt resistance. A practical PV array configured by series parallel combination of PV module and each module is constructed by number of PV cells connected in series [3].

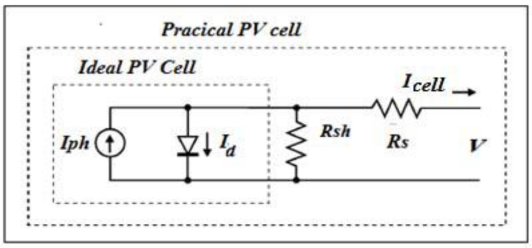

Fig. 2 Equivalent Circuit of PV cell [5]

$$I_{cell} = I_{ph} - I_d \quad (1)$$

$$I_d = I_s\left(e^{\frac{qV}{NKT}} - 1\right) \quad (2)$$

$$I_{cell} = I_{ph} - I_d - I_{sh} \quad (3)$$

$$I_A = I_{ph}N_p - N_p\left[I_s\left(e^{\frac{\left(V_A + I_A R_S \frac{N_S}{N_p}\right)}{N_S V_t}} - 1\right)\right] - \frac{\left(V_A + I_A R_S \frac{N_S}{N_p}\right)}{R_{sh}\frac{N_S}{N_p}} \quad (4)$$

b. Maximum Power Point Tracker

In practice, the PV array is connected to the MPPT in order to allow the PV array to produce maximum power it is capable of by varying the electrical operating point of the PV array. [4] The converter changes the operating voltage level of the PV array to enable it operates at *Vmp*in order to produce the maximum power. The operating voltage level is controlled by changing the duty cycle of the converter. A pulse width modulation (PWM) control signal is applied to the gate of the transistor in the DC-DC converter. The generation of the PWM control signal is controlled automatically by an algorithm. The photovoltaic power characteristics is nonlinear, as shown in *Figure*, which vary with the level of solar irradiation and temperature, which make the extraction of maximum power a difficult task, considering load variations. To overcome this problem, several algorithms for extracting the maximum power have been proposed, however in this dissertation the incremental conductance method has been used.

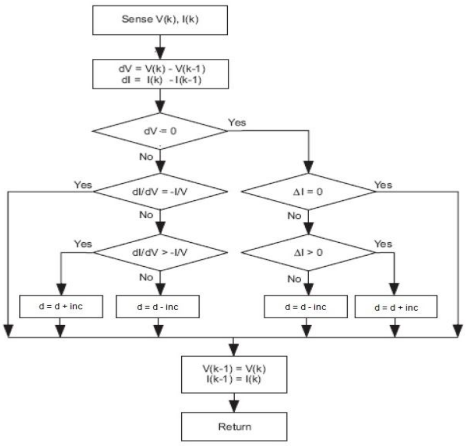

Fig. 3. *Flowchart of Incremental Conductance Algorithm*

c. Converter

Inverters are the power electronic circuit, which converts the DC voltage into AC voltage. The output voltage can be controlled with the help of drives of the switches. The pulse width modulation techniques are most commonly used to control the output voltage of inverter. However, the output voltage of the inverter contains harmonics whenever it is not sinusoidal. By using proper control scheme harmonics can be reduced.Inverters can be broadly classified into two types.

Voltage Source Inverter (VSI)
Current Source Inverter (CSI)

In voltage inverter (VSI) or voltage fed inverter (VFI)the DC voltage remains constant. in current source inverter (CSI) or current fed inverter (CFI)input current is maintained constant. occasionally, the DC input voltage to the inverter is controlled to adjust the output. these type inverters are called variable DC link inverters. inverters can have singlephase or three-phase output.

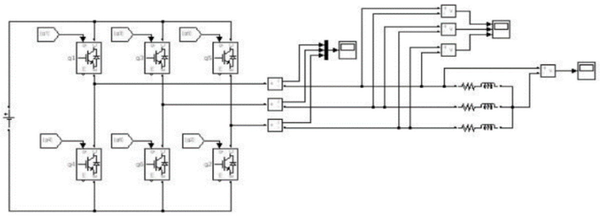

fig.4simulation of 2 level inverter

III. CONTROL STRATEGY

Vector control is a popular method known for converting the three-phase quantities in to synchronously rotating reference frame. The basic idea of vector control is to control the flux producing component (direct axis current) and the torque producing component (quadrature axis current) in a decoupled manner, keeping analogy with the above convention, in this work, the grid current is separated in to direct and quadrature axis currents and the vector control scheme is implemented in a decoupled manner in the synchronously rotating reference frame.

A. Clarke Transformation

using Clarke transformation The balanced three-phase quantities are transformed from the three-phase reference frame to the balanced two-axis orthogonal stationary reference frame. The Clarke transformation can be expressed as follows;

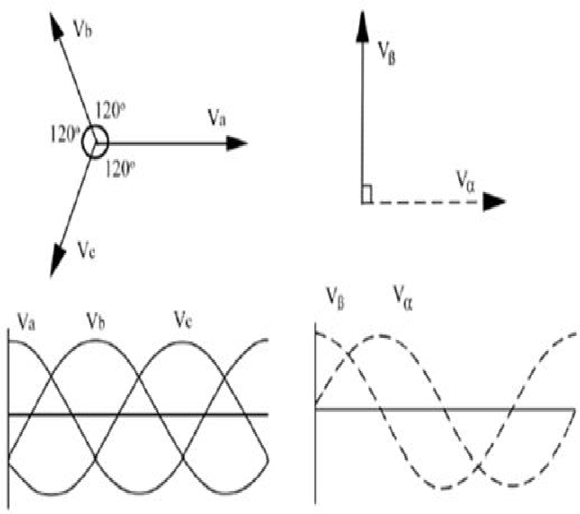

Fig.5. Different reference frames for Three-phase andTwo-phase

$$\begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{pmatrix} \begin{pmatrix} V_\alpha \\ V_\beta \\ V_o \end{pmatrix}$$

B. Vector Control Scheme

The overall block diagram of a vector control scheme is shown in The grid voltages and the line currents are transformed into dq reference frame, and are used as feedback variables for the controller. The control calculations are performed in the dq reference frame. After performing all such calculations, these quantities are again converted back to abc reference from the dq reference frame and which will be used in the PWM stage for the three-level inverter switches.In this project the active and reactive power flow from the inverter to the grid is controlled in decoupled manner by implementing the vector control approach.The overall control scheme consists of the following stages;

i. Grid Synchronization with PLL
ii. Current Control
iii. Decoupling
iv. PWM Scheme

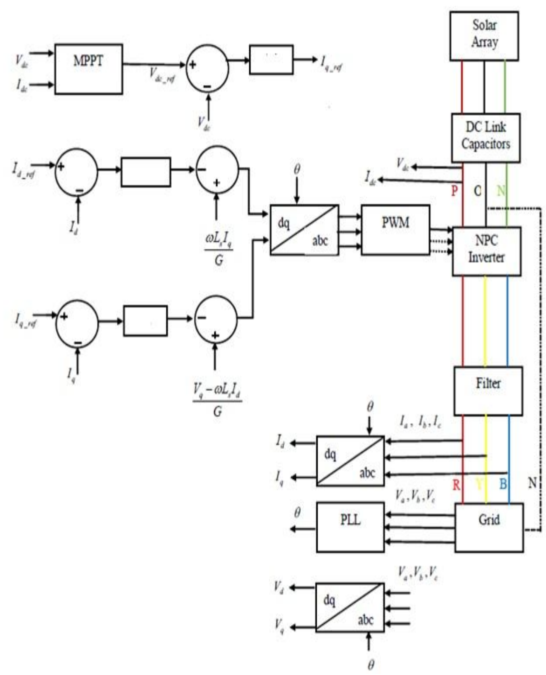

Fig.6. *Structure of control scheme*

IV. MODELLING OF INVERTER

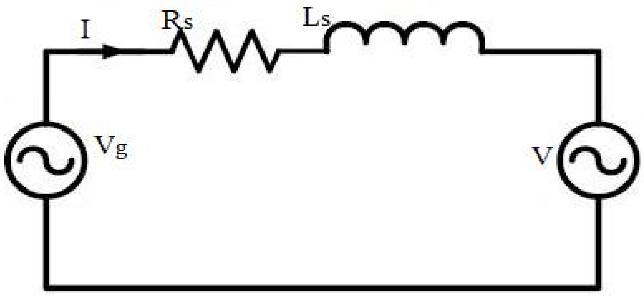

Fig.7. Single phase equivalent circuit of grid connected inverter

The single phase equivalent circuit of a three-phase three - level grid connected NPC inverter is shown in *Figure* Where V is the inverter pole voltage and V_g is the grid voltage. R_s and L_s are resistance and inductance of the line. The differential equations for the above system can be expressed as,

$$\begin{pmatrix} V_{ga} \\ V_{gb} \\ V_{gc} \end{pmatrix} = R_s \begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} + L_s \frac{d}{dt} \begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} + \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \quad (1)$$

$$L_s \frac{dI_{abc}}{dt} + R_s I_{abc} = \Delta U_{abc} \quad (2)$$

Where $\Delta U_{abc} = V_{gabc} - V_{abc}$

The grid currents in synchronously rotating reference frame can be expressed as equation (3)and (4) respectively

$$I_d = \frac{2}{3}\left[I_a \cos\omega t + I_b \cos\left(\omega t - \frac{2\pi}{3}\right) + I_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right]$$

$$I_q = -\frac{2}{3}\left[I_a \sin\omega t + I_b \sin\left(\omega t - \frac{2\pi}{3}\right) + I_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right]$$

In a similar way the voltages can be expressed as follows,

$$\Delta U_d = \frac{2}{3}\left[\Delta U_a \cos\omega t + \Delta U_b \cos\left(\omega t - \frac{2\pi}{3}\right) + \Delta U_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right]$$

$$\Delta U_q = -\frac{2}{3}\left[\Delta U_a \sin\omega t + \Delta U_b \sin\left(\omega t - \frac{2\pi}{3}\right) + \Delta U_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right]$$

On differentiating equations *(3)*and *(4)*From equation *(10),*

$$\frac{dI_a}{dt} = \frac{\Delta U_a}{L_s} - \frac{R_s}{L_s} I_a \quad (5)$$

$$\frac{dI_b}{dt} = \frac{\Delta U_b}{L_s} - \frac{R_s}{L_s} I_b \quad (6)$$

$$\frac{dI_c}{dt} = \frac{\Delta U_c}{L_s} - \frac{R_s}{L_s} I_c \quad (7)$$

On substituting equations(5*)* , *(6)* and *(7)* in $\frac{dI_q}{dt}$ and $\frac{dI_d}{dt}$

$$\frac{dI_d}{dt} = \frac{\Delta U_d}{L_s} - \frac{R_s}{L_s} I_d + \omega I_q \quad (8)$$

$$\frac{dI_q}{dt} = \frac{\Delta U_q}{L_s} - \frac{R_s}{L_s} I_q - \omega I_d \quad (9)$$

$$\Delta U_d = V_{gd} - V_d \quad (10)$$

$$\Delta U_q = V_{gq} - V_q \quad (11)$$

Which can be further arranged as,

$$V_d = V_{gd} - (R_s I_d + L_s \frac{dI_d}{dt} - \omega L_s I_q) \quad (12)$$

$$V_q = V_{gq} - (R_s I_q + L_s \frac{dI_q}{dt} + \omega L_s I_d) \quad (13)$$

Equations *(12)* and *(13)* reveals that there is a cross coupling exists between the direct and quadrature axis quantities. To separate the direct and quadrature axis quantities decoupling terms have to be added in both direct and quadrature axis.The decoupled control can be ensured by adding two feed forward terms V_{dff} and V_{qff} to the output of the direct and quadrature axis current controllers respectively.

$$V_{dff} = \frac{\omega L_s I_q}{G} \quad (14)$$

$$V_{qff} = \frac{V_q - \omega L_s I_d}{G} \quad (15)$$

Thus after implementing the decoupled control as mentioned the active and reactive power in the dq-reference frame is given by *(14)* and *(15)*.

$$P = \frac{2}{3}\left(V_d I_d + V_q I_q\right) = \frac{2}{3}\left(V_q I_q\right) \quad (16)$$

$$Q = \frac{2}{3}(V_q I_d - V_d I_q) = \frac{2}{3}(V_q I_d) \quad (17)$$

Where P is the active power and Q is the reactive power.

V. SIMULATION VALIDATION

In this paper we discuss the PV array of three phase grid connected 100kWp PV system.the given model when implemented using MATLAB Simulink gives the following waveforms of different entities. We can validate our theory concept while observing the match between the theoretical and simulated waveforms of the output voltages, current, power etc.as the solar irradiance changes output power of delivered by the PV array also changes. output voltage of PV array is boosted by boost converter. The proposed MPPT scheme will help the system to operate at that voltage where the power output will be the maximum depending upon the solar irradiance changing throughout the day time. inverter is connected to a transformer and transformer connected to the utility grid.

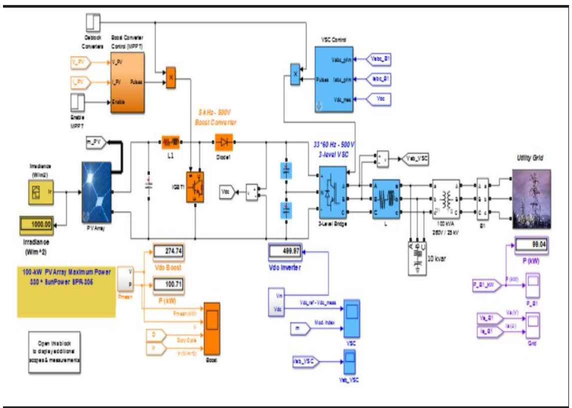

Fig.8MATLAB/SIMULINK grid connected PV system

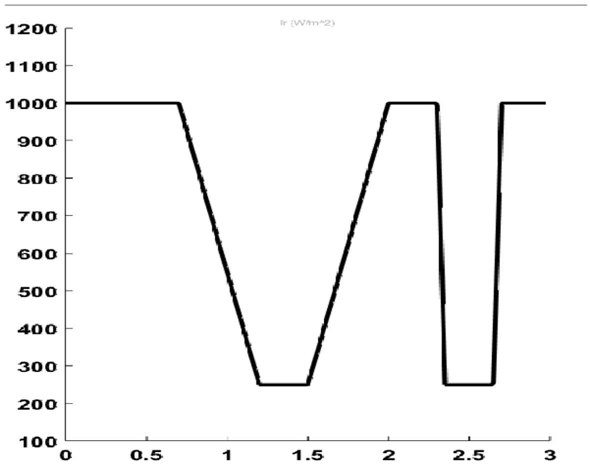

Fig.9Irradiance delivered to PV array

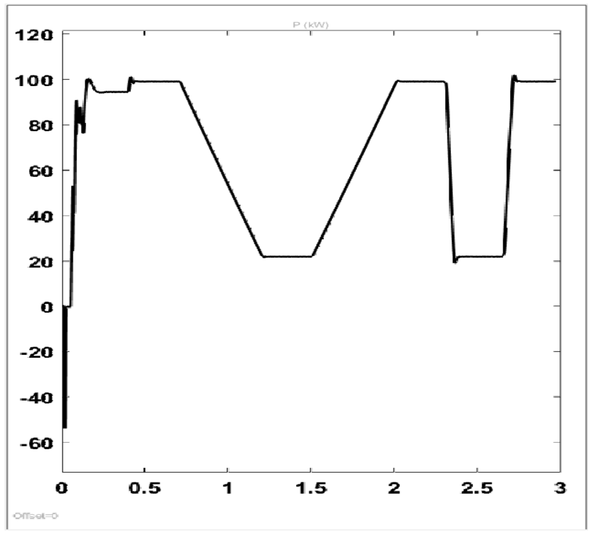

Fig.10 Power delivered by PV array to the Grid

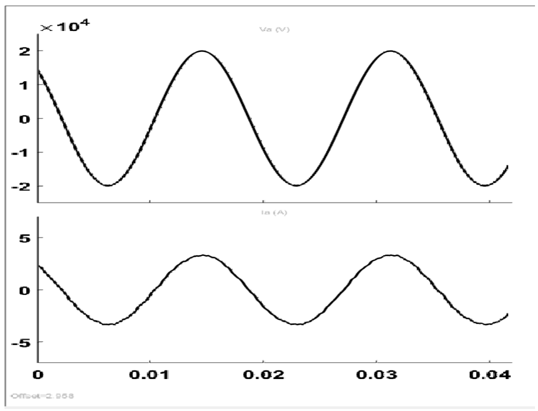

fig.11Line Voltage and currents at the input to grid

VI. CONCLUSION

InThis paper we discuss the completecircuit-based grid connected PV system simulation model. The output power is varying linearly with solar irradiance of PV array.

With the help of MPPT the maximum power is extracted from the given solar irradiance. Output characteristics of the inverter shows good agreement with the grid characteristics.This paper helpsfor the further research of PV station’s grid-connecting.in this paper PV array model is developed in MATLAB/SimulinkEnvironment.

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