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CONFERENCE PAPER

MODELLING AND SIMULATION OF A GRID-CONNECTED PHOTOVOLTAIC SYSTEM USING P&O MPPT AND SVPWM-CONTROLLED VOLTAGE SOURCE INVERTER

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Abstract

This paper presents detailed model of PV cell connected to the three phase utility grid connected voltage source inverter. Here perturb and observe (P&O) algorithm is implemented to track the maximum power point, even in cases of rapidly changing atmospheric conditions like varying temperature and solar irradiation. Space vector pulse width modulation technique is used to generate the switching sequence of the inverter. It is easy to implement, smooth inverter operation and provides low harmonics at the inverter output. The theoretical analysis of the system has been verified by the MATLAB computer simulation in terms of the inverter voltage, grid voltage, grid current, dc link voltage, active power delivered to load and total harmonic distortion of load current waveforms.

Introduction:-

The rapid growth of population and industrialization has significantly increased global energy demand, while fossil fuel depletion and environmental concerns have accelerated the adoption of renewable sources such as photovoltaic (PV), wind, and battery systems. Efficient solar energy utilization requires accurate PV modeling and operation at the maximum power point (MPP), achieved using MPPT techniques implemented through DC–DC converters [1–4].With increasing grid integration of PV systems, power quality and reliability have become critical challenges. Grid-connected PV systems are now a major application area, requiring advanced control strategies [5–6]. Three-phase voltage source inverters (VSI) are widely used for grid interfacing, where Space Vector PWM (SVPWM) offers reduced switching losses and improved waveform quality [7].To meet IEEE 519-1992 standards, effective current control is essential [8]. This paper presents an SVPWM-based PI current control technique, providing fast dynamic response, low current ripple, and improved sinusoidal output for grid-connected PV systems [9].

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Working of a PV Cell:
A photovoltaic generator is the whole assembly of solar cells, connections, protective parts, supports etc. In the present modelling, the focus is only on cell/module/array [3]. Solar cells consist of a p-n junction fabricated in a thin wafer or layer of semiconductor (usually silicon). Fig.1 shows the equivalent circuit of the ideal single diode model of the PV cell. Thus the solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell (photocurrent Iph).

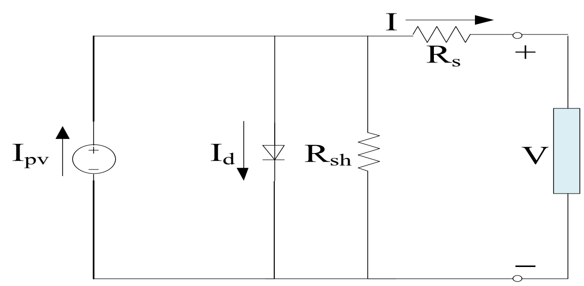

Fig 1.Block diagram of a single solar cell

The basic equation that mathematically describes the I-V characteristic of the ideal photovoltaic cell is:

$$I = I_{pv} - I_d \tag{1}$$

Where $I_d = I_0\left[\exp\left(\frac{V}{aV_t}\right) - 1\right]$

The thermal voltage can be calculated in the following equation:

$$V_t = \frac{kT}{q} \tag{2}$$

$$I = I_{pv} - I_0\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \tag{3}$$

The practical PV device has a series resistance R_s whose influence is stronger when the device operates in the voltage source region, and a parallel resistance R_{sh} with stronger influence in the current source region of operation.When a series resistance (R_s) is included, the equivalent circuit is the four parameter model, as shown in Fig.1 (b)[3].

$$I = I_{pv} - I_0\left[\exp\left(\frac{q(V + IR_s)}{akT}\right) - 1\right] \tag{4}$$

A modification to four parameter equivalent circuit is achieved by adding a shunt resistor (R_{sh}) in parallel with the diode resulting in the five parameter model, as shown in Fig.1(c).

The voltage-current characteristic equation of a solar cell is given as:

$$I = I_{pv} - I_0\left[\exp\left(\frac{q(V + IR_s)}{akT}\right) - 1\right] - \frac{V + IR_s}{R_{sh}} \tag{5}$$

The photocurrent (I_{pv}) in eq. (1) depends on irradiance intensity and cell temperature, which is described

$$I_{pv} = \left(I_{pvref} + K_1\Delta T\right)\frac{G}{G_{ref}} \tag{6}$$

Where I_{pvref} is the light generated current at the reference condition, T=25˚C, G_{ref} =1000W/m^2

ΔT =T-T_{ref}

The assumption Isc ≈Ipv is generally used in the modelling of PV devices because in practical devices the series resistance is low and the parallel resistance is high. The diode saturation current is given by

$$I_0 = I_{0ref}\left(\frac{T}{T_{ref}}\right)^3 \exp\left[\frac{qEg}{ak}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \tag{7}$$

$$I_{0ref} = \frac{I_{scref}}{\exp\left(\frac{V_{ocref}}{aV_t}\right) - 1} \tag{8}$$

Control Strategy of Grid Connected Inverter:-

This paper presents a three-phase grid-connected PV system using a two-level inverter modelled in the synchronously rotating (d–q) reference frame. Vector control is employed to regulate grid currents by transforming them into DC quantities in the d–q frame. Decoupling is achieved using Clarke (α–β) and Park (d–q) transformations, converting three-phase (abc) variables into two-phase stationary and rotating frames. The control strategy employs two loops: an outer DC-link voltage control loop generating the active current component, while the reactive current reference is set to zero to ensure unity power factor. The system configuration used for modeling and implementation is shown in Fig. 2.

The state-space representation in the three-phase (abc) reference frame is given by (9) .

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{1}{L}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} - \frac{1}{L}\begin{bmatrix} v_{ga} \\ v_{gb} \\ v_{gc} \end{bmatrix} \tag{9}$$

Where

$\begin{bmatrix} i_a & i_b & i_c \end{bmatrix}^T$ is the inverter output current vector

$\begin{bmatrix} v_a & v_b & v_c \end{bmatrix}^T$ is the output phase voltage vector

$\begin{bmatrix} v_{ga} & v_{gb} & v_{gc} \end{bmatrix}^T$ is the grid phase voltage vector

L and C is the inductance and Capacitance of the filter in each phase and the equivalent series resistance between the grid and inverter is neglected. To improve the current controller performance, a pulse width modulated controller is developed in the d-q reference frame.

The state space equation of the three phase grid connected VSI is

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} 0 & \omega \\ -\omega & 0 \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L}\begin{bmatrix} v_d \\ v_q \end{bmatrix} - \frac{1}{L}\begin{bmatrix} v_{gd} \\ v_{gq} \end{bmatrix} \tag{10}$$

Where i_d and i_q are output currents in d-axis and q-axis

v_d and v_q are output voltages in d-axis and q-axis

v_{gd} and v_{gq} are grid voltages in d-axis and q-axis

ω is grid angular frequency.

Overview of the PV System:-

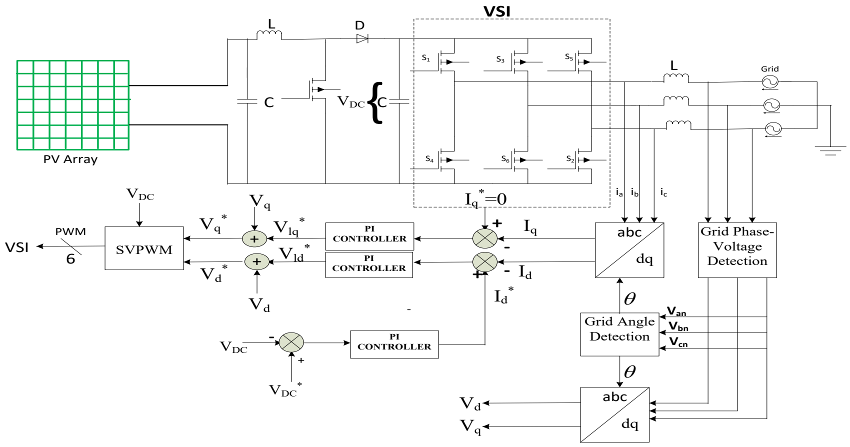

Fig 2.Block diagram of the SVPWM- based current control system for two level VSI

The system is designed, modelled, and simulated in the MATLAB/Simulink environment using Simscape. Fig. 2 illustrates the current control block diagram. To enhance control performance, an SVPWM-based PI current controller is implemented in the synchronous d–q reference frame, where AC variables are converted to DC quantities. Based on Park transformation [9], the voltage equations of the three-phase grid-connected VSI in the d–q frame are given in (10).The outputs of PI controllers are inductor filter voltage references $v_{ld}^{\ *}$ and $v_{lq}^{\ *}$ that are superimposed by v_{gd} and v_{gq} to generate the inverter output voltage references $v_d^{\ *}$ and v_q^* for SVPWM.The current references i_d^* is provided by the DC link voltage Controller whereas the i_q^* is set to zero for unity power factor operation.In the synchronous d-q reference frame, the voltage equation, the active and reactive power delivered to the utility grid is given in the equations belown

$$v_d = L\frac{di_d}{dt} - \omega L i_q + v_{gd} \tag{10}$$

$$v_q = L\frac{di_q}{dt} + \omega L i_d + v_{gq} \tag{11}$$

$$P = \frac{3}{2} v_{gd} \cdot i_d \ (12)$$

$$Q = \frac{3}{2} v_{gd} \cdot i_q \tag{13}$$

$$v_{ld} = L\frac{di_d}{dt} - \omega L i_q \tag{14}$$

$$v_{lq} = L\frac{di_q}{dt} + \omega L i_d \tag{15}$$

From eq.(10),(11),(12),(13),(14)and(15) it is seen that in order to compensate for the grid harmonics, $v_{Ld,q}$ should be directly controlled in real time instead of $v_{d,q}$ which can be controlled indirectly by superimposing $v_{Ld,q}$ to $v_{gd,q}$.

Space Vector Pulse Width Modulation (SVPWM):-

Space vector pulse width modulation is employed to generate the desired output voltage vector V* in d-q reference frame [8]. For a three-phase VSI, there are totally eight possible switching patterns and each of them determines a voltage space vector. As shown in Fig.3, eight voltage space vectors divide the entire vector space into six sectors, namely 1- 6. Except two zero vectors, V_0 and V_7, all other active space vectors have the same magnitude of $(2/3)V_{DC}$[9]. According to the phase angle of the reference voltage vector in the d-q coordinates and the grid angle indicating the relative position of the d-axis to the A-axis, the sector in which the reference voltage vector is located can be easily found out. In SVPWM, the reference voltage vector should be synthesized by the adjacent vectors of the located sector in order to minimize the switching times and to minimize the current harmonics.

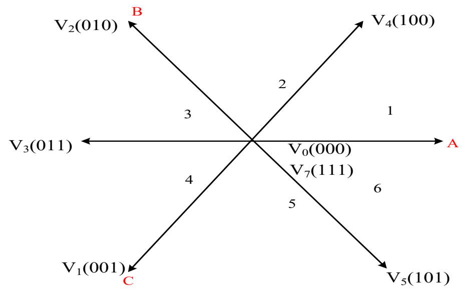

Fig 3.Voltage space vectors of three phase VSI

Results and Discussion:-

The control strategy of photo voltaic cell connected to the grid-connected voltage source inverter is verified by the simulation study by Matlab 8.1, the elements such as PV cell, Boost converter, PWM inverter,inductors and capacitors are from Simpower Systems of Simscape, and the algorithm is realized by Simulink.

Table 1 Parameters of the KC200GT PV array at 25 ◦C, AM1.5, 1000 W/m2.

I_{mp}	7.61A
V_{mp}	26.3V
P_{max}	200.143
I_{sc}	8.21A
V_{oc}	32.9V
K_V	−0.1230V/K
K_I	0.0032A/K
N_s	54

Simulation Results of PV cell with P&O MPPT:-

The equivalent circuit of the photovoltaic model is shown in Fig. 1 and used to simulate the PV array. The KC200GT module is selected for accurate modeling, with parameters evaluated using the equations from the previous section. The output current is computed based on module parameters (I_{SC},V_{OC}) and variables such as voltage, irradiation (G), and temperature (T).Fig. 4(a) and (b) show the I–V and P–V characteristics of a single cell, indicating I_{SC}=8.5 A, V_{OC}=32.9 V, and a maximum power of 200 W. Fig. 4(c) and (d) illustrate the variation of I–V and P–V characteristics with temperature at constant irradiance.4(c) and (d); open circuit voltage, V_{OC} drops and short circuit current, I_{SC} rises slightly when the temperature increases.

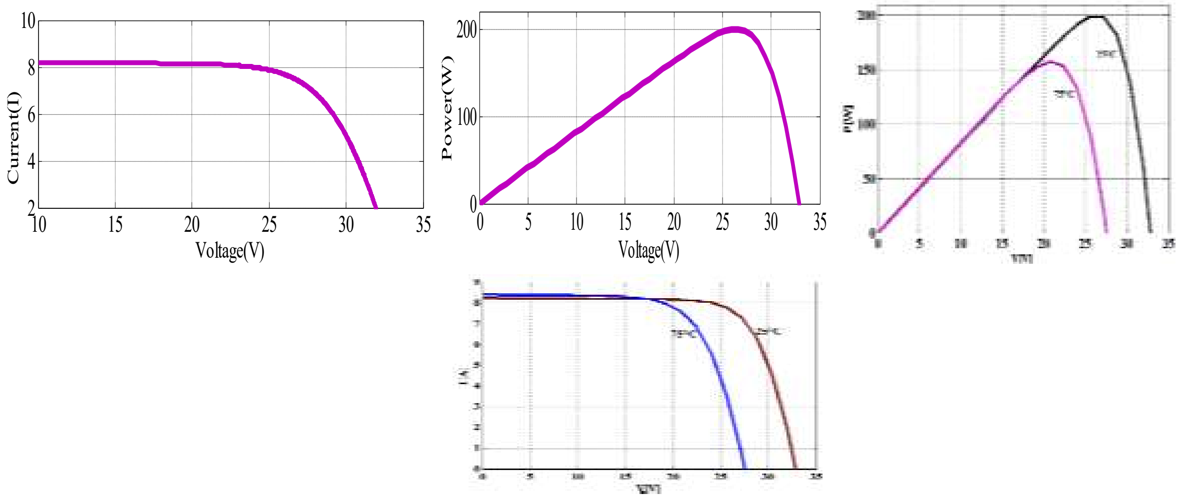

Fig.4. (a)I-V characteristics of single solar cell (b) P-V characteristics of single solar cell(c)I-Vcharacteristics of solar cell with variable Temp. & fixedRadiation (d) P-V characteristics of solar cell with variable Temp. & Fixed Radiation.

Simulations Results of PV Cell Connected to Grid:-

The simulation parameters are as follows:DC link reference voltage (Vdc*) = 210V, Reference Reactive Power (Q*) = 0 Var, Proportional gain (Kp) =0.05, Integral gain (Ki) =20.

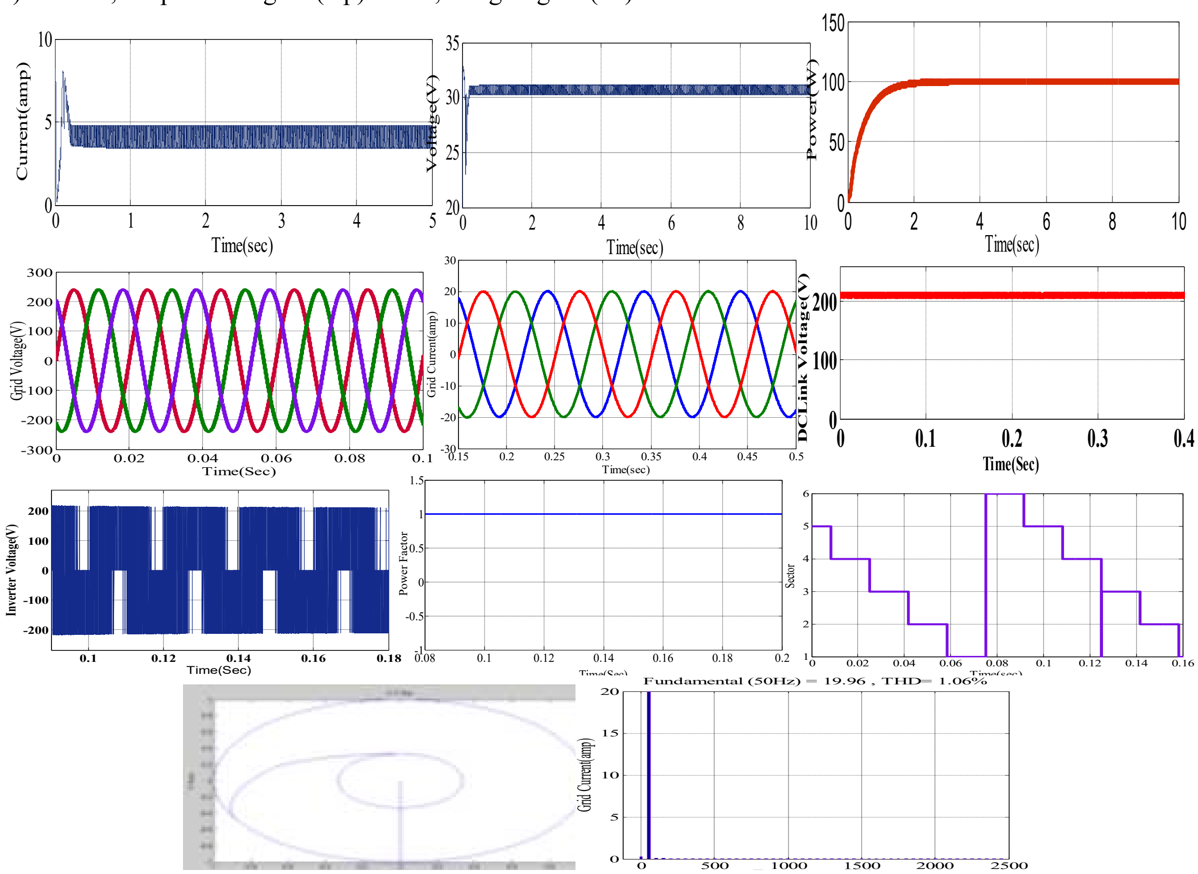

Fig.5.Simulation Results of SVPWM-PI controller (a)Current before boost converter (b)Voltage before boost converter (c)Power outputof the boost converter (d) Grid Voltage(e)Grid Current(f)DC link voltage(g)Inverter Voltage(h)Sectors(i)XY plot of Current at stationary reference frame (j)%THD of Grid Current

This section describes the simulation results of proposed control strategy ofPV connected grid-connected VSI system and the results are presented here. Fig.5shows the steady state performance concerning voltage of PV cell, current of PV cell, output power of boost converter, grid voltage, grid current, dc-link voltage, invertervoltage, active and reactive power for the space vector pulse width modulation technique. The magnitude of the grid current is 20 A. The high quality current at the utility end is the natural result of the controllers' ability to minimize distortions at the utility end and to maintain the power quality of the system

Conclusion:-

The paper presents the control strategy for PV Cell with grid-connected VSI systems based on SVPWM-PI controller in the inner feed-forward control loop. The study includes independent control of active and reactive power of the utility end, harmonic current reduction via current error minimization and lesser THD at the PCC. The result shows that the SVPWM-PI control offers significant improvement in terms of waveform quality and current harmonic distortion. The proposed controller offers an excellent steady-state response featured by accurate control with low current ripple and highly sinusoidal waveform.

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