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Abstract- Solar energy has become a very potential new energy; Connected directly with grid-connected photovoltaic (PV) systems does not require bulk and lossy battery. Distributed generation and on-site supply of PV system reduces losses of transmission and distribution, and mitigates environment pollution. This paper establishes a Dynamic model of grid-connected PV system by Matlab/Simulink with d-and q-axis as coordinates which is synchronously rotating with the grid voltage to reflect the characteristics of the system accurately. Based on the accurate modeling system, optimum control and fault analysis are studied. The simulation and analysis verify the effectiveness of the proposed algorithm, and demonstrate that the proposed control system has good static performance.

Keywords- *grid-connected photovoltaic system; simulation; Matlab; control*

I. INTRODUTION

Solar energy has become a very potential new energy. Connected directly with the grid, grid-connected photovoltaic (PV) system does not require bulk and lossy battery. Distributed generation and on-site supply of PV system reduce losses of transmission and distribution, and mitigate environment pollution.
Moreover, photovoltaic systems are a clean and noise-free source of electricity; Distributed PV generation would have far reaching consequences not only on the distribution network but also on the transmission grid and the rest of the generators. The effect of a large penetration of PV generation on the stability and security of the power system must therefore be considered carefully. In particular, the response of PV generators to disturbances could aggravate these incidents.

There are two types of the solar energy system; stand-alone power system and grid-connected power system. Both systems have several similarities, but are different in terms of control functions. The stand-alone system is used in off-grid application with battery storage. Its control algorithm must have an ability of bidirectional operation, which is battery charging and inverting. The grid-connected system, on the other hand, inverts dc to ac and transfers electrical energy directly to power grid. Its control function must follow the voltage and frequency of the utility-generated power presented on the distribution line. However, this thesis only scopes on the grid-connected power system. Several inverter topologies can be applied to the system; they all have the same objectives but are different in the principles A model of PV generators capable of simulating their response to changes in irradiance and grid ac voltage is the first step in this study and its development, the maximum power point tracking (MPPT) controller used to maximize the efficiency of the PV cell dictates the dynamic behavior of the PV generator. This paper Establishes a Dynamic model of grid-connected PV system by Matlab/Simulink with d-and q-axis as coordinates which is synchronously rotating with the grid voltage to reflect the characteristics of the system accurately.

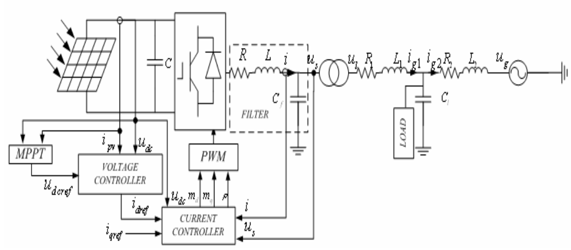

Fig 1: Grid-connected photovoltaic system

II. DYNAMIC MODEL FOR GRID CONNECTED PV SYSTEM

A typical single-stage grid-connected PV system is shown in Fig.1.1 A PV array is connected to a distribution network with a voltage source converter (VSC).

A photovoltaic model
The model of solar cell can be categorized as p-n semiconductor junction; when exposed to light, the DC current is generated. The typical equivalent circuit of PV cell is shown below

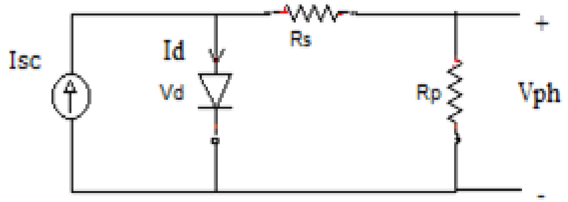

Fig 2: Typical Circuit for Typical Solar Cell

PV arrays consist of series connected cells which are actually diodes, thus the equivalent circuit is represented by a current source parallel to an ideal diode. The mathematical modeling of PV arrays is given:

$$i_{pv} = n_p\ I_{ph} - n_p I_{rs}\left[exp\frac{qv_{dc}}{AkT}\left(v_{dc} + \frac{n_s R_s i_{pv}}{n_p}\right) - 1\right] - I_{rsh} \qquad (1)$$

$$I_{ph} = [I_{scr} + K_v(v - v_r)\frac{S}{100} \qquad (2)$$

Where v_r is the cell reference temperature, is the short-circuit current of one PV cell at the reference temperature and irradiation level, and K_v is a temperature coefficient. v_{dc} is PV arrays voltage, n_p and n_s are the number of PV cells connected in parallel and in series respectively, I_{ph} is the photocurrent of a single solar module which is proportional to both illumination and surface area, I_{rs} is the saturation current of diode which is related to temperature, k is Boltzmann constant (1.38e-23, in Joules per Kelvin), q is electric charge (1.6e-19, in Coulombs), T is operating temperature, A is P-N junction ideal factor. R s is series resistance of the single solar module, and I_{rsh} is the current flowing through the shunt resistance. Ignoring the power absorbed by the inductance and the resistance of the VSC interface, the dynamic equations of the PV system are:

Based on above equation, the power delivered by the PV array
(i.e.,$P_{pv} = v_{dc}i_{pc}$) is expressed as:

$$P_{pv} = f(v_{dc}, S, v) \qquad (3)$$

$$= n_p I_{ph} - n_p I_{rs} v_{dc}\left[\exp\left(\frac{q}{kvA}\frac{v_{dc}}{n_s}\right) - 1\right] \qquad (4)$$

For a given irradiation level, P_{pv} is zero at $v_{dc} = 0$, but increases as v_{dc} is increased. However, this trend continues only up to certain voltage at which P_{pv} reaches a peak value; beyond this voltage, P_{pv} decreases with the increase of v_{dc} . The aforementioned behavior suggests that P_{pv} can be controlled/maximized by the control of. This is referred to as the "maximum- power-point tracking" (MPPT).

B Distrubution Network Model

Distribution network is referred as the composition of distribution line, transformer Tr1 and the shunt capacitor C_f and C_l. Distrubution network network is supplied by a utility substation which is represented by voltage source U_g.

If v_s , v_l , i_{g1} , i_{g2} and are chosen as the state variables, the following state-space model can be derived for the distribution network:

$$C_f\frac{dv_s}{dt} = i - Ni_{g1} \qquad (5)$$

$$C_l\frac{dv_t}{dt} = i_{g1} - i_{g2} - i_l \qquad (6)$$

$$L_1\frac{di_{g1}}{dx} = -R_1 i_{g1} + Nv_s - v_t \qquad (7)$$

$$L_2\frac{di_{g2}}{dx} = -R_2 i_{g2} + v_l - v_g e^{j\omega_0 t} \qquad (8)$$

Where the PV system ac-side current' i' and the load current i_l act as exogenous inputs to the distribution network subsystem. It is assumed that $v_{gabc}(t)$ is a balanced three-phase voltage whose amplitude and phase angle are v_g and ω_0 , respectively.

Using the above equations can be represented in decoupled form as shown below:

From Fig.1.1, we can get the reference model of the distribution network as follows:

$$\frac{di_{g1d}}{dt} = -\frac{R_1}{L_1}i_{g1d} + \omega i_{g1q} + \frac{N}{L_1}u_{sd} - \frac{1}{L_1}u_{ld} \quad (9)$$

$$\frac{di_{g1q}}{dt} = -\frac{R_1}{L_1}i_{g1q} - \omega i_{g1d} + \frac{N}{L_1}u_{sq} - \frac{1}{L_1}u_{lq} \quad (10)$$

$$\frac{di_{g2d}}{dt} = -\frac{R_2}{L_2}i_{g2d} + \omega i_{g2q} + \frac{N}{L_2}u_{sd} - \frac{1}{L_2}u_{ld} \quad (11)$$

$$\frac{di_{g2q}}{dt} = -\frac{R_2}{L_2}i_{g2q} - \omega i_{g2d} + \frac{N}{L_2}u_{sq} - \frac{1}{L_2}u_{lq} \quad (12)$$

$$\frac{du_{sd}}{dt} = \omega u_{sq} + \frac{1}{c_f}i_d - \frac{N}{c_f}i_{gld} \qquad (13)$$

$$\frac{du_{sq}}{dt} = -\omega u_{sd} + \frac{1}{c_f}i_q - \frac{N}{c_f}i_{glq} \qquad (14)$$

$$\frac{du_{ld}}{dt} = -\frac{1}{c_l}i_{gld} - \frac{1}{c_l}i_{g2d} + \omega u_{lq} \qquad (15)$$

$$\frac{du_{lq}}{dt} = \frac{1}{c_l}i_{glq} - \frac{1}{c_l}i_{g2q} - \omega u_{ld} - u_{lq} \qquad (16)$$

Where i_{g1d} and i_{g1q} are d- and q-axis components of the current between the VSC interface and the load, i_{2gd} and i_{g2q} are d- and q-axis components of the current between the load and the grid, R_1 and L_1 are resistance and inductance between the VSC interface and the load, R_2 and L_2 are resistance and inductance between the load and the grid, u_{ld} and u_{lq} are d and q-axis components of load voltage, N is the transformer turns ratio, C_f is filter capacitance, C_l is power-factor correction capacitance, and ω is the dq-system angular speed.

C Load Model

Three types of three-phase, balanced loads an asynchronous machine, a series circuit, and a thyristor-bridge rectifier. Let us pick the inductor (load) current as the state variable. Thus the load model considered is a series R-L circuit, it is shown as follows:

$$L_l\frac{di_l}{dt} = -R_l i_l + v_l \qquad (17)$$

Using the above equations can be represented in decoupled form as shown below:

$$\frac{di_{ld}}{dt} = \omega i_{ld} - \frac{R_l}{L_l} i_{ld} + \frac{1}{L_l} u_{ld} \qquad (18)$$

$$\frac{di_{lq}}{dt} = -\omega i_{lq} - \frac{R_l}{L_l} i_{lq} + \frac{1}{L_l} u_{lq} \qquad (19)$$

Where R_l and L_l are resistance and inductance of the load, i_{ld} and i_{lq} are d- and q-axis components of the load current.

III. CONTROL STRATEGY

The main objective of this control strategy is to regulate the dc link voltage to control/maximize the power extracted from PV array. VSC, SVPWM inverter and control (current control) are synchronized to the network voltage through a phase locked loop (PLL). Control Strategy of Grid connected PV system is separated as different strategies as current control & voltage controls. In order to control the grid current efficiently, it is necessary to transform the three-phase ac signals into proper dq-frame counterparts. It is achieved as follows: at first, u(s) is decomposed into d- and q-axis component, and then sq u passes through a compensation device to get ω, which is the differential coefficient of ρ. ρ is the reference angle of dq-axis

$$\Omega(s) = G_p(s)U_{sq}(s) = \left[\frac{s+1}{s^2+s}\right] U_{sq}(s) \qquad (20)$$

Where Ω(s) and Usq(s) correspond to the Laplace transform of ω and sq u, respectively. In a steady state, Usq(s) is forced to 0.

$$G_i(s) = \frac{I_d(s)}{I_{qref}(s)} = \frac{1}{\tau_i s + 1} \qquad (21)$$

Control of the q-axis current at 0 will enable the inverter output current exactly to be the same phase with the grid voltage, and power factor is 1.i_d and i_q are coupled due factor Lω .The dynamics of i_d and i_q are coupled and non linear. Introduce i_{dref} and i_{qref} ,which are two new control inputs. Regulating i_d and i_q to track their corresponding reference value i_{dref} and i_{qref} fast, the current control is completed. And then active and reactive outputs of PV system are expressed as:

$$P_s = \frac{3}{2} U_{sd} i_d \qquad (22)$$

$$Q_s = -\frac{3}{2} U_{sd} i_q \qquad (23)$$

The purpose of voltage control is to make dc-link voltage track the voltage which corresponds to the maximum power point. In this case, i_q = 0, dc link voltage is adjusted by regulating the d-axis component of i

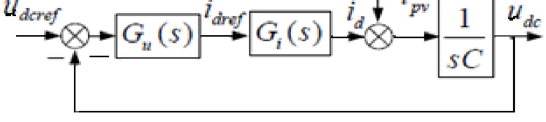

Fig 3: Block Diagram of dc-link voltage control

$$G_i(s) = \frac{I_d(s)}{I_{qref}(s)} = \frac{1}{\tau_i s + 1} \qquad (24)$$

$$G_u(s) = K_p + \frac{K_I}{s} \qquad (25)$$

Normally, the time constant τ_i takes 0.5ms. G_u(s) is a proportional-integral compensator. It is processed by an error signal between reference voltage and the actual PV array voltage to gain i_{dref} .The reference voltage is provided by maximum power point tracking scheme.

It is a technique that solar inverters use to get the maximum possible power from the PV array. It is the purpose of the MPPT system to sample the output of the cells and apply a resistance (load) to obtain maximum power for any given environmental conditions.

MPPT can effectively improve the solar energy conversion efficiency of PV systems. Perturb-and-observe (P&O) method is used to achieve this function. P&O method first measures the current output power of the array, and then adds a small perturbation to the original output voltage, after that, compares the current power with the original one.

IV. SIMULATION RESULTS

Here we have totally three phase voltages which are 120 degrees phase shift with each other having equal magnitude, the pulses generated by this SVPWM inverter are given to the six MOSFETS presented in VSC. The need to go for SVPWM is to increase the duty cycle range and the pulses generated by this SVPWM inverter are mentioned in the results clearly. PV array consists of 6 PV modules connected in series altogether generating 140v dc voltage, This model is well suited for the case when modules are connected in series and share the same current.

Inputs to PV module	• PV current IPV [A] • Insolation [W/m2]
Outputs:	• PV voltage VPV [V] • PV output power Ppv [W]

Table 1: current input PV module

A user defined embedded matlab code block is taken to insert the code for the P&O algorithm, and the algorithm is explained.

Here in this paper Current input PV array is made up of 6 similar PV modules. Each module details is as shown below these are the standard PV module data-sheet parameters

open-circuit voltage *Voc*	22.2
short-circuit current *Isc*	5.45
rated current *IR at maximum power point (MPP)*	17.2
rated voltage *VR at MPP*	4.92
Pn-junction reverses saturation current (Io)	2.615e-01
Irradiation to short circuit current gain (G)	0.00545
Cell Parallel Resistance (Rp)	2.742
Cell Series Resistnce (Rs)	0.01309
Default no. of cells in Series (Ns)	36

Table 2 Tabular column for PV module parameters

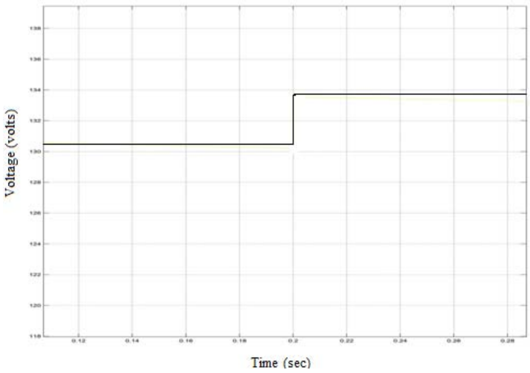

Fig 4: change in array voltage due to sudden increase in Irradiation

Initially, the entire system is in a steady state. u_{dcref} and i_{qref} are set to 600V(peak) and 0A, respectively. At t = 0.2s, as a result of disturbance, the reference value u_{dcref} provided by MPPT scheme is suddenly increased to 600V. We can see this process shows the responses of dc voltage. When there is a disturbance, u_{dc} tracks its reference value smoothly, and reaches 600V in less than 0.01 second. After the required voltage achieved u_{dc} can remain stable. The simulation results show that the control method achieve the design requirements.

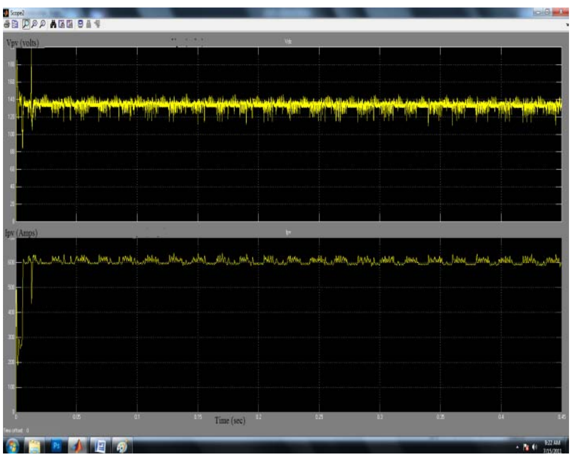

Fig 5 Voltage & Current waveform DC side -VSC

It is observed that the input voltage obtained from PV module is 140V ,this is fed to Voltage source converter and convert it into 3 phase ac voltage and fed to distributed grid of 440V rms,by make use of a transformer 200/440,here the output of VSC is approximately 200V rms. SVPWM inverter is used to generate pulses to VSC; space vector technique makes duty cycle range to be improved. The Inverter side voltage and Current waveforms of a Grid connected PV system are shown above,Voltage magnitude is 600 V peaks, i.e 440 V rms, connected to distributed grid. Current magnitude is 15A peak which is the line current. due to system internal inductance current waveforms settles at 0.025 sec.

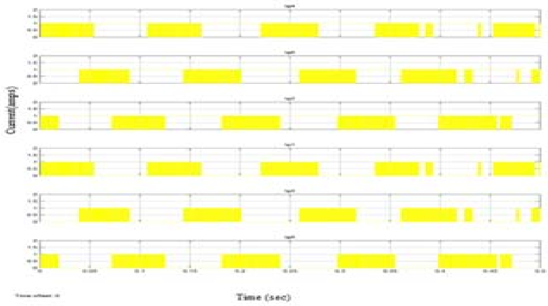

Fig 6 output pulses of SVPWM as Input toVSC

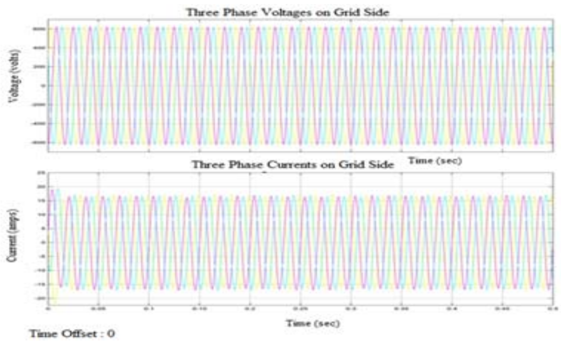

Fig 7 Output waveforms of Vabc and Iabc on Grid side without fault

Fault is initiated at 0.04 sec and it is cleared at 0.1 sec. As the system is connected to Infinite bus(grid) ,usually voltage at grid is always maintains at 1 pu,so that there is no considerable change in grid voltage wave forms for th fault near to pv system.

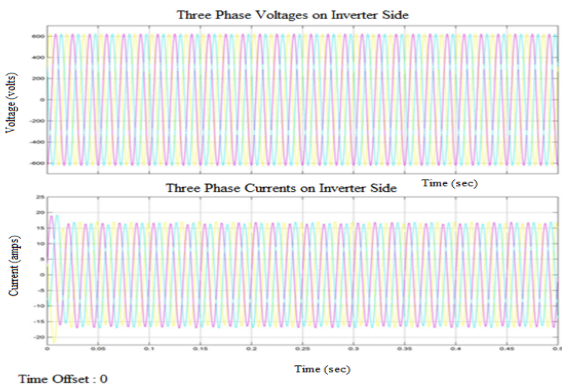

Fig 8 Output waveforms of Vabc and Iabc on Inverter side without fault

When a 3 phase fault occurs on grid side the corresponding change in voltage and current waveforms are shown below, Fault is initiated at 0.01 sec and it is cleared at 0.08 sec, breaker re connect PV system to grid at 0.17 sec, the fault current magnitude is 3.5×10^5 A. From Voltage waveforms, Inverter side 3 phase voltage Vabc is negligible when a 3 phase fault occurs on grid side.

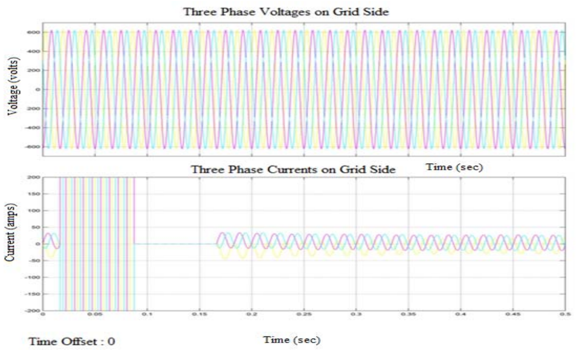

Fig9 : Output waveforms of Vabc and Iabc on Grid side for a 3 phase fault

When the fault happens in a inverter connected energy system, the output current of the inverter becomes asymmetrical.

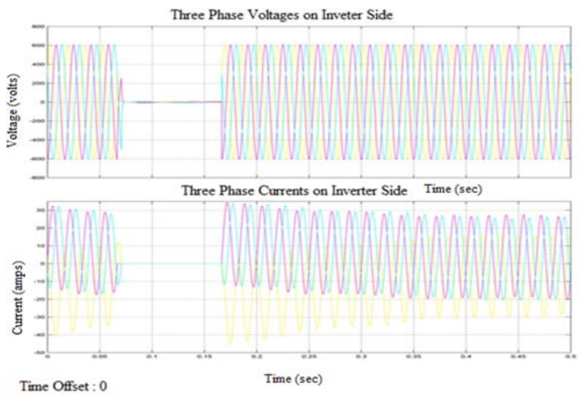

Fig 10 Output waveforms of Vabc and Iabc on Inverter side for a 3 phase fault

When this happens, a DC current is superimposed on top of the AC current causing asymmetry. The PV energy system works as a load; it consumes energy from the utility grid. So it is significant to make sure the PV energy system absorb as much energy as possible from sun irradiation to ensure the sufficient high voltage level of the battery so as to get a stable AC output power. Meanwhile, it is necessary to cut it off from the main grid when PV energy system doesn't produce sufficient energy and the battery voltage level is lower than the threshold.

A 3 phase circuit breaker is connected at grid side and a 3 phase fault simulink block is configured for a 3 phase to ground fault and connected on grid side. In emergency condition, when PV system must be shutdown the breaker isolates the PV system from the distribution network.

V. CONCLUSION

In this paper, a grid-connected PV system based on MATLAB has been proposed. Optimum control and fault analysis were studied based on it. The control consists of a voltage control loop and a current control loop. Current control can achieve the dc voltage regulation and power factor control. Voltage control can achieve the maximum power point tracking. The dc-side voltage is controlled through the ac-side d-axis current component which is associated with the real power flow, based on the power balance approach between the ac- and dc-side. Control of i_d enables control of p_s and p_{pv} and a saturation block limits i_{dref} to protect the VSC against over load and external faults. Simulation and analysis results show that the model can correctly reflect the system characteristics and the methods can meet the actual needs.

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