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Three Phase Grid Connected Photovoltaic System with MPPT Technique Based on Voltage Oriented Control Using Average Current Mode Controller

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ABSTRACT: This paper presents a Matlab/Simulink model of grid connected photovoltaic (PV) system, including a PV array, a maximum power point tracking boost converter and a grid interactive, a control system. A space vector pulse width modulation (SVPWM) has been widely applied in the current control of three-phase voltage source inverters (VSI). The proposed system consists of two main controllers: a boost converter and a grid interactive voltage source inverter. The boost converter is used to regulate the PV voltage and track the MPP of PV array. A perturbation and observation (P&O) is used as MPPT method and it determines the system operation point according of rapidly changing atmospheric conditions. A cascaded control structure with an outer dc link voltage control loop and an inner current control loop is used. The currents are controlled in a synchronous orthogonal d, q frame using a decoupled feedback control. The reference current of proportional–integral (PI) d-axis controller is extracted from the dc-side voltage regulator by applying the energy balancing control. Furthermore, in order to achieve a unity power factor, the q-axis reference is set to zero.the average current mode control of a grid connected inverter is investigated. Two control loops are used: the outer one controls the power flow from the source generator to the grid and the inner one controls the grid currents. This control method is applied to two system configurations with di erent filter cells, L- and LCL-filter. The comparison shows the e ectiveness of the last configuration in terms of harmonics rejection. Simulations of the proposed method show performances in both transient and steady state.

KEYWORDS: grid-connected photovoltaic system, Maximum Power Point Tracking (MPPT), average current mode controller(ACMC), Boost converter, Proportional-Integral (PI) control, voltage oriented control VOC.

I.INTRODUCTION

The characteristic voltage and power of a photovoltaic (PV) array is nonlinear and time varying because of the changes caused by the atmospheric conditions, a maximum power point tracking algorithm is adopted to maximize the output power. In recent years, the grid connected PV systems have become more popular because they do not need battery backups to ensure MPPT [13]. The two typical configurations of a grid-connected PV system are single or two stages. In two stages, the first is used the conversion of this power into high-quality ac voltage, the second to boost the solar array voltage and track the maximum power. The presence of DC/DC converter allows to maintain the fixed DC link voltage enough high to make the inverter operate. Although there is much information in the literature [1], development of dynamic models of grid-connected PV systems are including a PV array, a control system using PI, a distribution network and a load, a PWM technique. Reference [12], a sliding mode controller for the threephase grid-connected photovoltaic system the proposed system consists of maximum power point tracker (MPPT) and sliding mode current controller with PWM control inverter, the experimental results verify the validity of the proposed controller. In [3], a technique for improving P&O MPPT performances of double-stage grid-connected photovoltaic systems and experimental measurements confirm the effectiveness of the proposed approach.

The typical configuration of a three-phase grid-connected photovoltaic system is shown in Fig. 1. It is consists of solar array, a three-phase inverter, the filter inductor L, and a three grid voltage. The three-phase inverter with filter inductor converts a DC input voltage into an AC sinusoidal voltage by means of appropriate switch signals to make the output current in phase with the utility voltage and obtain a unity power factor. The configuration consists of two main

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controllers; the DC-side controller for the boost DC/DC converter, and AC-side controller for the inverter. The DC/DC converter is controlled to maintain the fixed DC link voltage enough high to make the inverter operate, to achieve the maximum power from the PV array. Many algorithms have been developed for the MPPT of a PV array [1,5,15]. A perturbation and observation (P&O) method is applied for the maximum power point tracking (MPPT) controller, the MPPT techniques is most popular because of the simplicity of its control structure. ACMC is a current control technique that has an almost constant frequency and produces a user-defined current waveform. It has a fast response time and is capable of supporting a wide range of power circuit topologies. ACMC is based on a compensator circuit which compensate the poles of an integrating filter transfer function. It uses this integrating filter to produce an average current error signal that is compared to a triangular waveform to produce the required pulse width modulation signal [2].

II. SOLAR CELL AND PV ARRAY MODEL

The equivalent-circuit model of PV is shown in Fig. 2(a). In this model, it consists of a light-generated source, a diode, series and parallel resistances [2]. The terminal equation voltage-current characteristic equation of a solar cell is given by:

$$I_{ph} - I_s q \exp q(V + R_s I) / AKT \ldots\ldots\ldots\ldots (1)$$

Where I and V are the cell output current and voltage, Iph: is photocurrent, Is: is the reverse saturation current, n is the diode factor, q is the electron charge (q=1.6 10-19C), K: the Boltzmann's constant (K=1.38 10-23), and T is the solar array panel temperature, Rs: is the intrinsic series resistance of the solar cell, Rsh: is the equivalent shunt resistance. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The equivalent circuit for the solar module arranged in Np parallel and NSseries is shown in Fig. 2(b) and the terminal equation for the current and voltage of the array becomes as follows:

$$I = N_p I_{ph} - N_p I_s \exp q(V / N_s + R_s I / N_p) / KTA) - 1 - (N_p V / N_s + R_s I) / R_{sh} \ldots\ldots\ldots\ldots (2)$$

Where Np represents the parallel number of module. Note that each module is composed of Ns series number of cells of a PV array

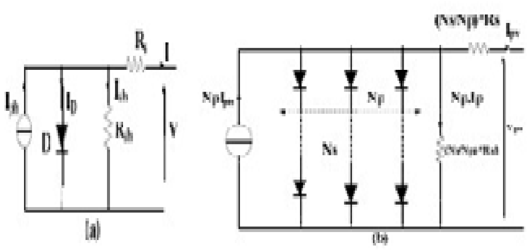

Fig. 1. Equivalent circuit model of solar cell (a)/array (b).

The PV model is simulated using Solaris E20, 333W PV module. The characteristic P-V, I-V is plotted in Fig. 3 under different irradiance levels, and P-V, I-V characteristic under different temperature is plotted in Fig.4.

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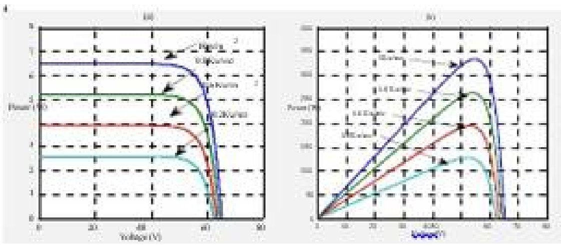

Fig. 2. (a) I-V characteristics and (b) P-V characteristics of the PV module at constant temperature T=25°C under different irradiance levels G=250,500,750,1000W/m2.

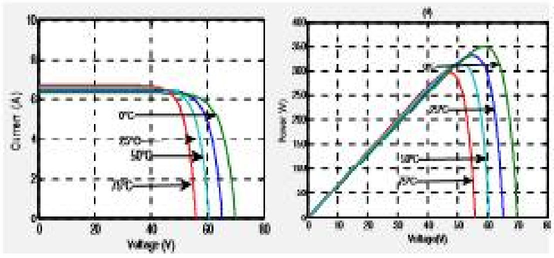

Fig. 3. (a) I-V characteristics and (b) P-V characteristics of the PV module at constant insolation G=1000W/m2 and different temperature T= 0°C,25°C,50°C,75°C

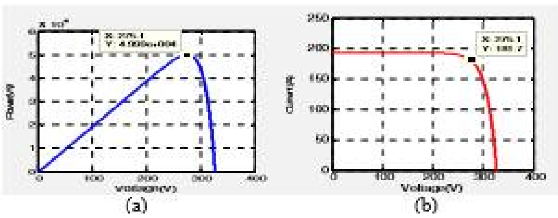

Fig. 4(a) P-V characteristics and (b) I-V characteristics of the PV array at STC (T=25°C, G=1000W/m2)

III. PROPORTIONAL-INTEGRALE CONTROL

A. voltage control

The block diagram of dc-link voltage control is shown in Fig. 7, where Ru(s) is a proportional-integral compensator. It is the processed by an error signal between reference voltage and the actual DC voltage output boost converter.

*R*U(S)=Kup+Kuits

Where, kup and kui are the proportion coefficient and integral coefficient, respectively

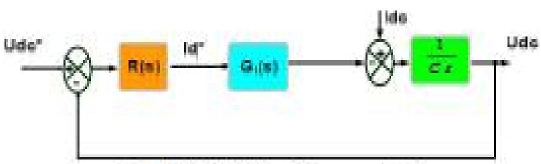

Fig. 5 DC- link voltage regulation.

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The closed-loop transfer of DC link voltage regulation, obtained from Fig. 7, has the following form

$$\frac{V_{dc}}{V^*_{dc}} = \frac{K_{up}\frac{K_{ui}}{K_{up}}+s}{c\,S^2+\frac{K_{ups}}{c}+\frac{K_{ui}}{c}} \text{..................................(3)}$$

B. Current Control

The diagram of the current regulator is shown in Fig. 8. The current controller is designed with two control loops for active and reactive power controls [8]. The PI current controller Ri (s) in the d-q reference frame is defined as:
The voltage regulator parameters can be given as follows

$$R_{i(s)=K_{ip}+K_{II}/_S} \text{..................................(4)}$$

Where, kip and kii are the proportion coefficient and integral coefficient, respectively

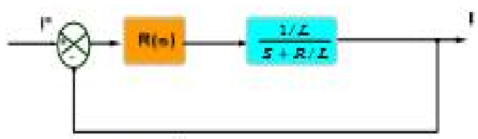

fig 6 DC link current regulation

The closed-loop transfer of the d-q current loops, obtai0ned from Fig. 8, has the following form:

$$\frac{I_{(qs)}}{I_{q^*(s)}} = \frac{I_{a(s)}}{I_{a^*(s)}} = \frac{K_{ip}}{l} = \frac{\frac{K_{ii}}{k_{ip}}+s}{S^2+\left(\frac{K_{ip}+R}{L}\right)S+\frac{K_{ii}}{l}} \text{................(5)}$$

Fig. 9 is shows the block diagram of the proposed current controller. The PI controller is used to regulate dc side voltage, and to generate reference value of d-axis current. To obtain unity power factor condition, reference value of q-axis current is set to zero. When the location information of grid voltage vector is obtained from PLL block, the three voltage vectors can be determined from switching table block

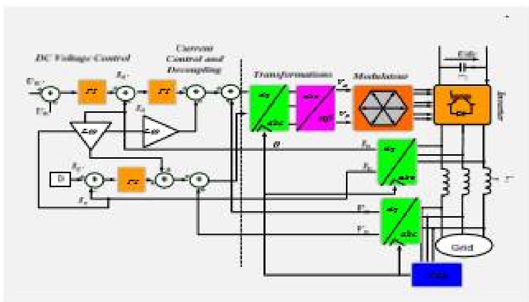

fig 7 PI control of three phase grid connected photovoltaic system

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IV. AVERAGE CURRENT MODE CONTROL

A wide range of power conversion applications use the current control technique. This technique controls the peak inductor current to regulate the converter output.

The most drawbacks of current control are a poor noise immunity and instability at duty ratios exceeding 0.5. The Average Current Mode Control (ACMC) is a control technique that overcomes problems listed above. ACMCis a two-loop technique that uses an integrator in the inner loop to average the sensed current. ACMC description and its standard design are presented in [2]. A circuit scheme that could be used to implement ACMC is shown in Fig. 8. The current to be controlled is sensed through RS and averaged. The voltage reference Vref is delivered by the outer loop. The integrator output is compared to a triangular waveform, the switch control is then generated. The transfer function of the integrator circuit [4] is described by equation

$$V_O = V_{ref} + (V_{ref} - v_i)\frac{S_{rf}C_{FZ}+1}{SR_i(S_{rf}.C_{fp}.F_Z+C_{fp}+C_{fz})}\text{..........................}(6)$$

Where $v_i = R_s I_c$

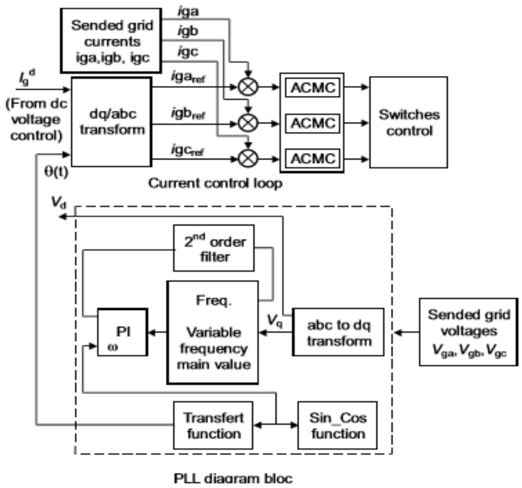

Fig 8 average current mode control

V. SIMULATION RESULT

The rated power, AC voltage level, filters parameters and frequencies switching used in this simulation arelisted below.

Rated power: 1 KW
Voltage (RMS): 220 V

L-filter:
Inductance (L, r): 10 mH, 1Ω
Frequency switching: 10 KHz

LCL-filter:
Converter side inductance (L1, r1): 2 mH, 0.2Ω
Grid side inductance (L2, r2): 1 mH, 0.1Ω
Capacitor (C, rd): 5μF, 5Ω
Frequency switching: 2.5 KHz

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A. DC-link Voltage regulation

Figure 8 shows the DC-link voltage result. It is regulated and reaches closely the voltage reference after a small rise time compared to the grid period. Furthermore, in actual case, the DC-link capacitor should be charged before starting the system.

B. VSI and Grid currents

The grid current is generated using two filter cells mentioned earlier (L and LCL ones), Figs. 9 and 10(b). It can be seen that the result are enhanced using an LCLfilter.

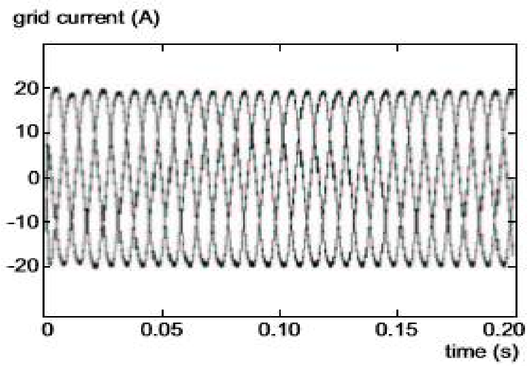


Fig. 9. Grid currents: L-filter case.

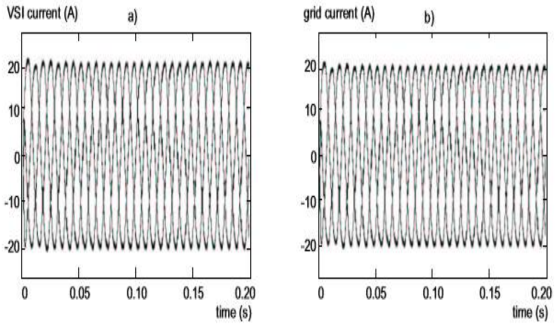
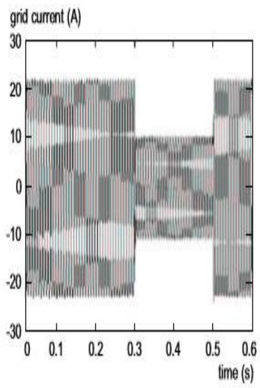


Fig. 10. Generated current: a):before and b):after filtering with LCL-filter case.



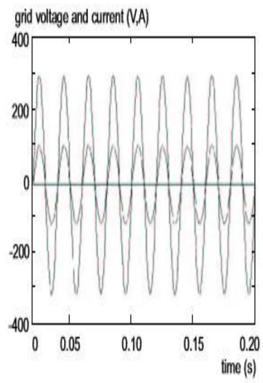


Fig. 11. Transient response: effect in step change (lower and upper) Fig. 12. Phase displacement between grid voltage and current

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VI.CONCLUSION

In this paper,averagecurrent mode control for three phase grid connected DC/AC converters offers an excellent steady-state response featured by precise control with zero steadystate error, very fast dynamic response, highly sinusoidal waveform., voltage, although the grid voltage has a low-order harmonic distortion. As well as the convenient active and reactive power decoupled controls. The sliding mode control has excellent robustness with nominal inductance varied from 33% of the actual value.

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