

Dynamic Control of Grid Connected Solar Energy Source System

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Abstract— In the last years a crazy advance in renewable energy sources topic researches is observed. However, the connecting of this devices with the grid systems still a major area of research. In this paper the performance of a solar renewable energy source connected with a grid system with a control strategy is evaluated through a simulation test by using MatLab/Simulink. The control strategy which was investigated is the decoupling proportional integral. The proposed control strategy is a simple control method is applied to the proposed configuration to simultaneously achieve three desired goals: to extract maximum power from the system component; to guarantee DC bus voltage regulation at the input of the DC/AC converter and to transfer the total produced power to the grid. The obtained simulation results indicate the fast dynamic response, validity and effectiveness of the presented control system.

Keywords — Solar Energy, MPPT, Grid, PI controller, PLL.

I. INTRODUCTION

The solar energy sources (SES) have the advantages of simplicity, efficiency and low cost when compared to other renewable energy sources [1]. So, this energy is often used for the commercial energy sources. Consequently, the research and manufacture of SES become more popular and competitive. However, except for the most important specification recital, there are some realistic terms considered in the commercial energy, such as cost, complexities of functions, and generality of used components. In the last years the researches in renewable energy sources domain orientes to connect these sources with the grid systems and solar energy source is the most one [2]. However, the output voltage of solar energy source is continuous and the voltage in the grid is

alternative. So, in order to connect this energy source with a grid system is necessary to use a DC/AC converter [3]. Generally, this structure enables DC voltage control and independent active and reactive power control. However, the control of the active and reactive power in grid connected systems requires precise detection of the grid phase and also the frequency to synchronize the voltage of the inverter with its counterpart of the grid side, therefore the use of phase locked loop (PLL) becomes necessary [4].

This paper presents a detailed model of grid connected solar energy source system and the analysis of its performances under realistic conditions. The transient model of grid connected solar energy source and a preferment control strategy namely PI is presented. The control system is capable of controlling active and reactive power and extracts maximum power from the system component after a transient condition. Also, by adding a supplementary control system to the DC/DC converter with maximum power point tracking (MPPT) control system, it is possible to regulate the DC-bus voltage [5, 6]. The simulation results show the performance and effectiveness of the presented control strategy.

The present paper is organized as follows: The basic concepts of the proposed grid connected solar energy source system and sums up the performance equations which were implemented in the simulated model are presented in section II. In section III, the mathematical formulation to realize an independent control of active power (P) and reactive power (Q) in grid is developed. Section IV, simulation results are given and discussed. Finally, in section V the concluding remarks are given and some nots indicates the behaviour of the proposed control strategy for grid connected solar energy sources in order to independently grid powers control.

II. SYSTEM DESCRIPTION

The detailed description is given as follows:

A. Photovoltaic energy conversion system (DC-DC part)

The configuration of the solar energy source system considered in this part consists of PV array, DC/DC boost converter where the generated DC power charges the DC link capacitor [7, 8].

The PV array can be mathematically modeled as [9]:

$$P_{pv} = V_{pv} I_{pv} = N_p I_{ph} \left[\left(\frac{q}{K \cdot A \cdot T_o} \cdot \frac{V_{pv}}{N_s} \right) - 1 \right] \quad (1)$$

$$\text{With, } I_{ph} = \left[I_{sc} + K_{sc} (T_o - T_s) \right] \cdot \frac{G_o}{G_s}$$

Where,

- N_s Number of serial connected PV modules;
- N_p Number of parallel connected PV modules;
- q Charge of an electron ($q = 1.602 \cdot 10^{-19} C$);
- A Ideality factor;
- K Boltzmann constant;
- I_{ph} Photo current of the PV cell;
- I_{sc} Cell's short-circuit current at standard conditions;
- K_{sc} Cell's short circuit current temperature coefficient;
- T_s, T_o Cell's standard temperature, operating temperature;
- G_s, G_o Cell's standard radiation, operating radiation;

Eq. (1) is used to obtain the output characteristics of the PV system at different irradiance conditions. This equation shows that the output characteristics of a PV system are non-linear and are crucially influenced by the solar radiation, temperature and load condition. The PV system is basically a standard PV array incorporating a DC/DC converter with MPPT controller (Fig.1) [10, 11]. The PV panel is connected to a DC/DC boost converter that provides a stepped-up voltage to the DC-bus link. The PV voltage is adjusted by appropriate switching of the boost converter to maximize the average power output of the array. At a given irradiation condition, the working voltage of the PV array is varied and therefore, the power flow from the PV varies. The goal of the PV MPPT controller is to force the boost converter to track the PV maximum power as quickly as possible, irrespective of solar irradiation or other variances.

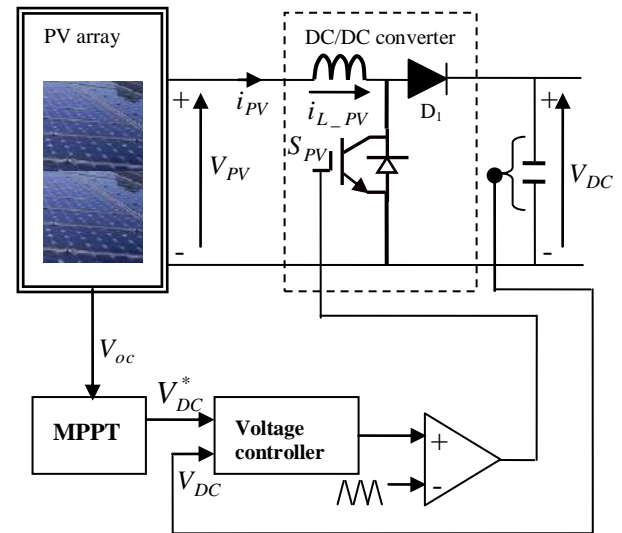


Fig. 1 PV array connected to DC-bus line through DC/DC converter

B. Grid system (DC-AC part)

The structure of the grid with the DC/AC converter under consideration is shown in Fig. 2. The balanced three phase voltage source is supplying the nonlinear load. The three phase electrical grid voltage (v) and current (i) are defined by the following relations:

$$\begin{cases} v_a = V_m \cos(\omega t) \\ v_b = V_m \cos(\omega t - 2\pi/3) \\ v_c = V_m \cos(\omega t - 4\pi/3) \end{cases} \quad (2)$$

$$\begin{cases} i_a = I_m \cos(\omega t) \\ i_b = I_m \cos(\omega t - 2\pi/3) \\ i_c = I_m \cos(\omega t - 4\pi/3) \end{cases} \quad (3)$$

Where a, b, c are the indexes of each phase, m index is the maximum values of the electrical parameters and ω is the angular frequency of the grid.

In the a, b, c frame of references, the amplitude and the direction of the instantaneous space vectors v_i and i_i are varying in time. The transformation of the coordinates between a, b, c and d, q frame references, displaced for the angle θ , is defined by the following Park transformation matrix (P) [12]:

$$P = \sqrt{2/3} \cdot \begin{bmatrix} \cos \theta & \sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} 1 & -1/2 & 1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \quad (4)$$

Where the angle θ is defined as:

$$\theta = \int \omega dt \quad (5)$$

The solar energy source is connected with grid by a DC/AC converter and in order to connect this source with the grid it's necessary to define the converter control and elaborate the control input signal of the DC/AC converter, the next section detailed the elaboration of the PWM control converter based on the decoupling PI control strategy.

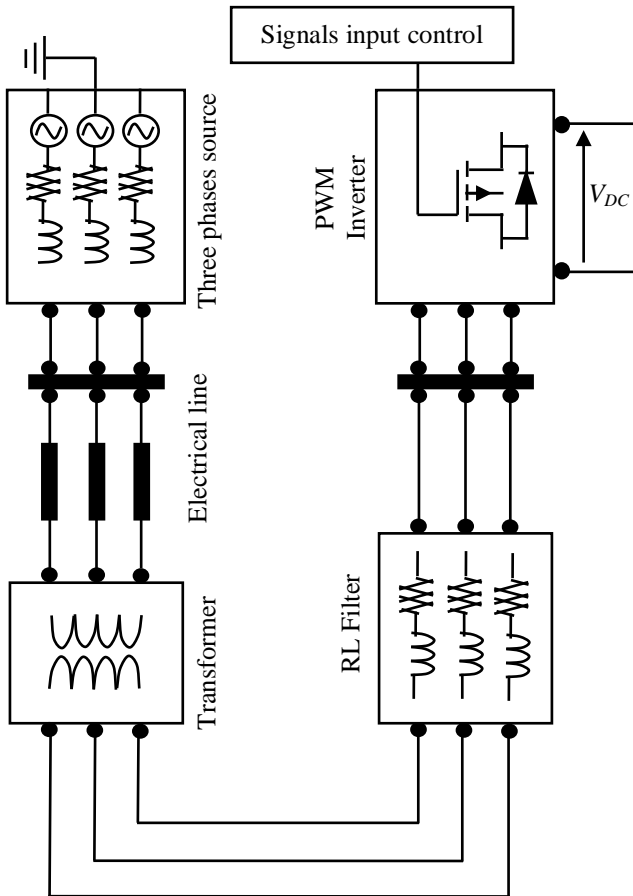


Fig. 2 Grid and DC/AC converter scheme

III. CONTROL SYSTEM

One of the desired goals of this study is to transfer the total produced power to the grid. So the reactive power is quasi-removed. The aim of the proposed control is to realize an independent control of active and reactive power in grid. Thus, tow Park coordinates currents are defined, were the direct coordinate controlled the active power and the quadratic controlled the reactive power. In order to remove the reactive power it's necessary to fix the quadratic coordinate of currant at zero [13]. To do this a proposed command is evaluated as decoupling-proportional integral is shown in Fig. 3.

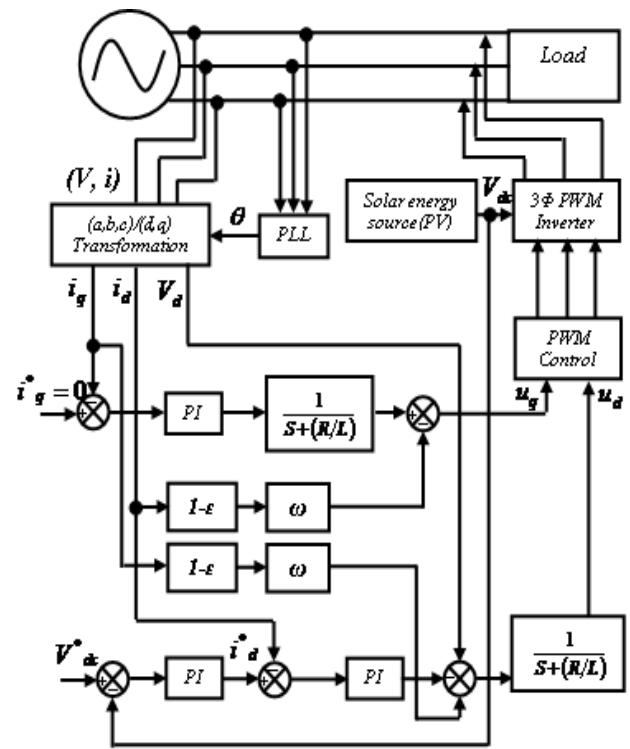


Fig. 3 Diagram of the PI-D control system

The active and reactive power (P and Q) are given by the following system equations:

$$\begin{cases} P = \frac{3}{2}(V_d i_d + V_q i_q) \\ Q = \frac{3}{2}(V_d i_q - V_q i_d) \end{cases} \quad (6)$$

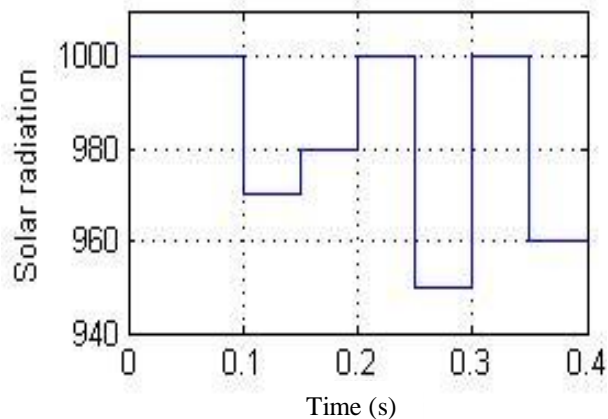
For the control application, the direct and the quadratic references currants are injected (used as input to the control system) to obtain the desired u_d and u_q to realize the PWM control of the DC/AC converter. The reference currents can be calculated as follows:

$$\begin{cases} \frac{di_d}{dt} = \omega(1-\varepsilon)i_q - \frac{R}{L}i_d + \frac{1}{L}(V_d - u_d) \\ \frac{di_q}{dt} = \omega(1-\varepsilon)i_d - \frac{R}{L}i_q - \frac{1}{L}(u_q) \end{cases} \quad (7)$$

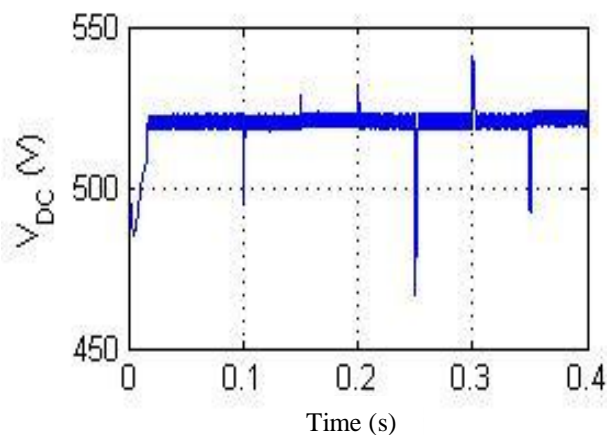
Where: R and L are the resistance and the inductance of the electrical line. ε is the decoupling parameter when at what time $\varepsilon = 1$, we obtain a perfect decoupling. In practice, ε is greater than 1, which means that the decoupling parameter is greater than the coupling parameter and the system is overcompensated. In this case, the system performance decreases because the return which causes a slow response time of the system.

IV. SIMULATION RESULTS

Grid connected solar energy source with control scheme are simulated by MatLab/Simulink for different solar radiation (Fig. 4.a). Fig. 4.b depicts the output voltage V_{DC} of the DC/DC part system which is the input of the DC/AC converter. We show that the V_{DC} is constant and contains some picks at the instants of solar radiation changing but there are compensated instantaneously caused by the addition of the control system to the DC/DC control system. Fig. 5.a represents the output voltage inverter become filtering and Fig. 6.b the d, q currents flows their references. However in Fig. 5.c, the output voltage inverter after filtering and i_a are shown superposed. We note the best synchronized of the both variables. The active and reactive powers are illustrates in Fig .6.a, we not that the active power is controlled by the direct current i_d and the reactive power by the quadratic current i_q , correspondently at the Fig .5.b. with good depiction, we have present in Fig .6. (b and c) the zoom of grid powers we note that the oscillations of powers signals caused by the by the designing of the conventional PI controllers.

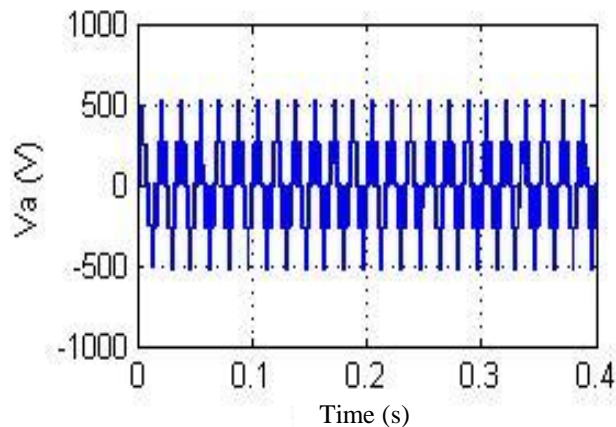


a. Solar radiation

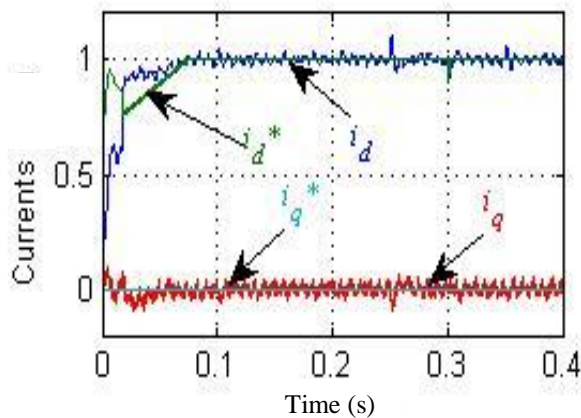


b. DC Voltage

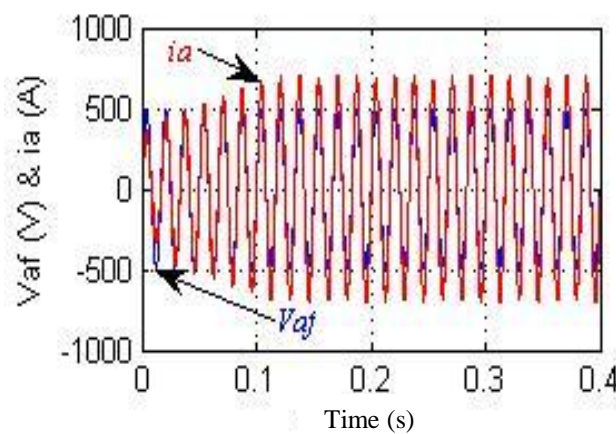
Fig. 4. PV signals.



a. Voltage inverter before filtering

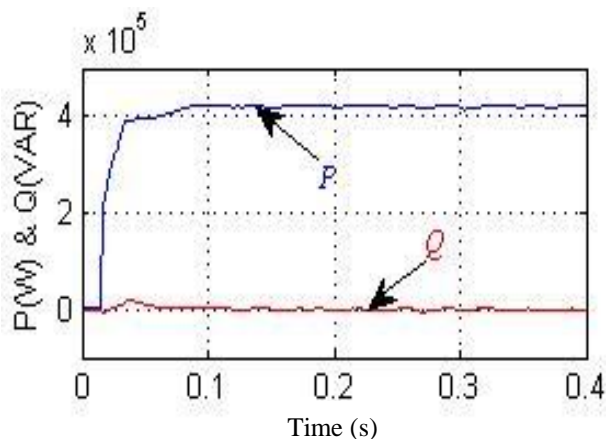


b. Park currents

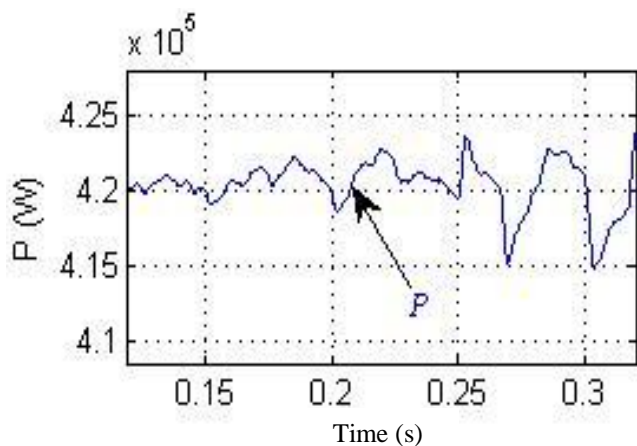


c. Voltage and current of line

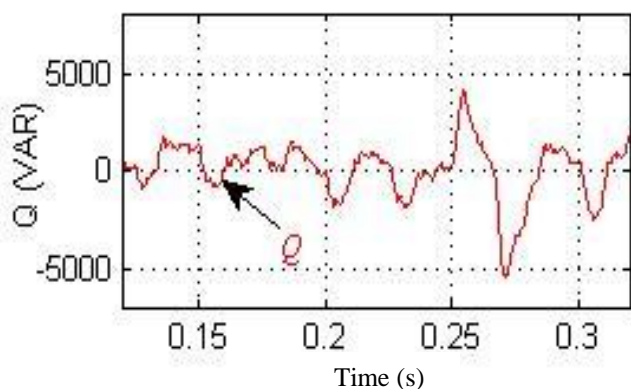
Fig. 5. Grid voltages and currents signals.



a. Active and reactive powers.



b. Zoom view active power.



c. Zoom view reactive power.

Fig. 6. Power signals.

V. CONCLUSIONS

This paper presents the transient model and control system of a grid connected solar energy source. The presented control system can regulate line active and reactive power and the DC-bus voltage. The simulation results indicate the fast dynamic response, validity and effectiveness of the presented control scheme. In this paper the power circuit and control system of grid connected solar energy source are simulated by using Matlab/Simulink.

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