Study of a Photovoltaic System Connected to the Distribution Network

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***Abstract*— Rural areas located far from the electrical distribution grid are in increasingly demand to receive electricity from renewable energy sources. Among the renewable energy sources, solar energy is the most interesting for the isolated areas in Algeria. Especially since the Sahara has a large amount of solar energy and the houses are still far away.**

Nowadays, the connection to the network of renewable energy sources applications, and particularly the photovoltaic ones have become more important and competitive compared to autonomous systems. However, a dc/dc boost converter adopted by a maximum power point tracking control strategy is used to achieve the maximum generated power regardless of climatic conditions, mainly temperature and irradiation. In terms of contribution to the development program and installation of grid-connected photovoltaic systems in isolated sites.

In this work, the connection to the distribution network of a photovoltaic system is treated by integrating an MPPT algorithm for the maximum power monitoring. The studied case is validated by simulation using MatLab/Simulink software and the results are presented and discussed.

***Keywords* — Photovoltaic, Control, MPPT stategy, Network.**

I. INTRODUCTION

The wide use of the conventional methods of electric power production such as hydro-electric, fossil fuels, and nuclear energy played an important role in exacerbating the problem of global warming resulting primarily from their emissions contaminated, this confusion has resulted a new policy in energy production which was adopted by the Tokyo Protocol aims to reduce these emissions by relying on non-polluting renewable sources [1]. The research in the field of renewable energies, the solar energy is one of the most prominent areas of engineering and this is due to the great attention enjoys by the party of industry and government [2]. Electric power generated by photovoltaic systems and due to their low price is able to provide a lot of energy requirements, especially in remote areas. This decrease in prices has encouraged the development of grid-connected photovoltaic systems technology using several methods [3]. Almost, grid connected photovoltaic systems are tied to electrical network without disturbing this last. However photovoltaic systems produce continuous variable voltage and in the other side the grid provides an alternative constant voltage. So, the adaption necessitates two conversion stages, the first is a DC/DC converter which is able to step up the output voltage and eliminate the resulted variation, while the second is a DC/AC converter which converts its input voltage proven by the DC/DC converter into an alternative voltage [4].

In this paper a three phase grid-tied photovoltaic system is presented. The proposed strategy focuses the control of grid reactive power through the control of grid current components. Otherwise, a DC/DC boost chopper adopted by Incremental Conductance (INC) maximum power point tracking algorithm (MPPT) have been employed in this work in order to control the output DC voltage under various climatic condition effects (intensity of solar irradiation and temperature). To join the photovoltaic system with grid a three phase inverter has been intervened to ensure similarity between grid original power quality and the injected photovoltaic power. Furthermore, the synchronization in grid side between current and voltage requires the use of a phase locked loop which was integrated indirectly in the global control system. The global control structure is programmed and tested by numerical simulation under MatLab/Simulink software to confirm the ability and effectiveness of the presented control technique in grid-connected photovoltaic systems.

II. SYSTEM DESCRIPTION

A. Modeling of photovoltaic generation system

The photovoltaic conversion system is based on the connection in series and parallel of numerous photovoltaic cells to form a panel and so on until obtaining of a module with high voltage degree [5]. Many cell's circuits have been dealt in literature to show the logic agreement on the electrical

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proposed cell's model [6-8]. The electrical equivalent circuit of the photovoltaic cell is depicted in the fig. 1.

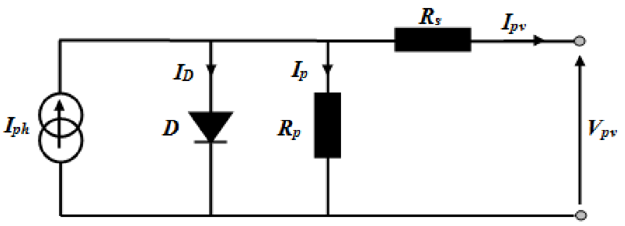

Fig. 1 Electrical circuit of photovoltaic cell

Normally, it's composed of a current source representing the light generated current, a diode for cell polarization function and series (R_s) and parallel resistance (R_p) indicating losses happened during the conversion. Hence, the *I-V* characteristics of the cell circuit can be given by the following equations [9] [10]:

$$I_{pv} = I_{ph} - (I_D + I_p) \tag{1}$$

Where,

I_{ph} is the light generated cell current which heavily depends on operating environmental conditions according to the following expression [11]:

$$I_{ph} = [\, I_{sc} + K_{sc}(T_o - T_s)\,] * \frac{\lambda_o}{\lambda_s} \tag{2}$$

And, I_D is the diode reverse current given by the given exponential relation [12]:

$$I_D = I_0 \left\{ \exp\left[q \frac{(V_{pv} + I_{pv}R_s)}{AKT_o} \right] - 1 \right\} \tag{3}$$

And, I_P is the current across parallel resistance, according to Kirchhoff's law it is expressed as follow:

$$I_p = \frac{V_{pv} + I_{pv}R_s}{R_p} \tag{4}$$

Knowing that,

I_{sc} and K_{sc} are respectively the short circuit current and its temperature coefficient;

T_o and T_s are respectively the operating and standard temperature;

λ_o and λ_s are respectively the operating and standard irradiance;

I_0 is the diode saturated current;

q is the elementary charge ($1.602 .10^{-19}$ Colomb);

A is the diode's ideality factor;

K is Boltzmann constant ($1.38 .10^{-23}$ j/K).

So, after serial and parallel connections of numerous cell's and panels, the output generated current of the photovoltaic generator is given by the following equation.

$$I_{pv} = N_p * \frac{\lambda_o}{\lambda_s}[\, I_{sc} + K_{sc}(T_o - T_s)\,] - N_p * I_0 \left\{ e^{q\frac{(V_{pv}+I_{pv}R_s)}{N_s \cdot AKT_o}} - 1 \right\} \tag{5}$$

Hence, the output generated power is given by [13]:

$$P_{pv} = I_{pv} * V_{pv} \tag{6}$$

B. DC/DC boost conversion stage

Since the generated power of a photovoltaic system is not sufficient and depends on climate data variations, the transfer into grid of the maximum obtained power became a necessary task. Wherefore, the use of a boost converter is recommended as a step up electronic interface to enhance the photovoltaic voltage level and consequently upgrade the generated power. Otherwise, to achieve maximum energy exploitation under any conditions, maximum power point tracker (MPPT) is an essential part to increase the efficiency of the system. [4] [14]. Fig. 2 presents the equivalent electric circuit of the DC/DC boost converter adopted by an MPPT based Incremental Conductance algorithm.

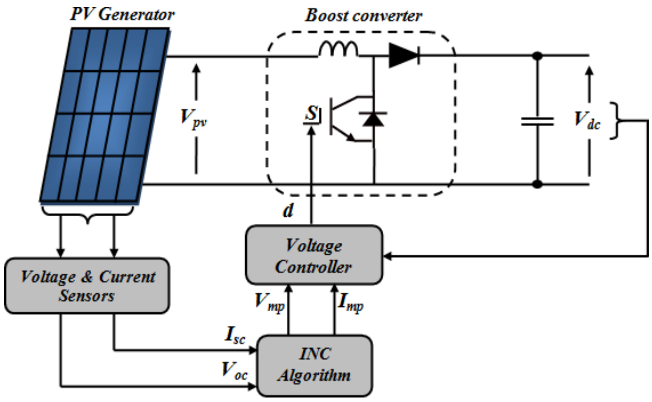

Fig. 2 DC/DC boost conversion diagram

In the Incremental Conductance strategy, the adjustment of the boost output voltage depends on the maximum available power which can be provided by the photovoltaic generator. The Incremental Conductance technique is based on the variation of the conductance (G) of the photovoltaic generator and its influence on the position of the operating point [15]. So, the conductance and the elementary variation of the conductance (ΔG) (increment) of the photovoltaic generator are respectively defined by the expressions (7) and (8):

$$G = \frac{I_{pv}}{V_{pv}} \tag{7}$$

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$$\Delta G = \frac{dI_{pv}}{dV_{pv}} \quad (8)$$

As the boost converter amplifies the output voltage of the photovoltaic system while the power flow is controlled by varying the duty cycle (d) of the switching (S). Hence, the boosted voltage is given by the subsequent equation [16]:

$$V_{dc} = \frac{V_{pv}}{1-d} \quad (9)$$

III. CONTROL SYSTEM CONFIGURATION

In grid connected photovoltaic systems, the main objective of the DC/AC conversion stage is to transform the DC generated power into an AC power which has a sinusoidal voltage with same frequency as the utility grid. Fig. 3 shows the circuit scheme of three phase grid connected photovoltaic inverter.

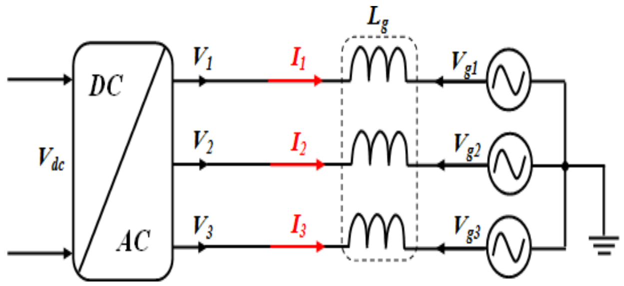

Fig. 3 Grid connected three phase photovoltaic inverter

According to Fig. 3 , the three phase grid-injected currents (I_1, I_2 and I_3) can be described by the following dynamic expression system [17]:

$$\begin{cases} \frac{dI_1}{dt} = \frac{V_1}{L_g} - \frac{V_{g1}}{L_g} \\ \frac{dI_2}{dt} = \frac{V_2}{L_g} - \frac{V_{g2}}{L_g} \\ \frac{dI_3}{dt} = \frac{V_3}{L_g} - \frac{V_{g3}}{L_g} \end{cases} \quad (10)$$

Where, V_1, V_2, V_3 are the inverter simple voltages, L_g is grid inductance and V_{g1}, V_{g2} and V_{g3} present grid line voltages.

The main purpose for photovoltaic grid-connected systems is to control the power transfer from photovoltaic generator into utility grid [18]. The control topology used in this work is illustrated in Fig. 4 and it is based on double loop control strategy applied on the inverter leg gates. To ensure high system performances of the general system during control steps, the system model presented in equation (10) is reformulated through Park transformation to be applied in the *dq* rotating reference frame. Hence, the mathematical model of the three phase grid connected system can be developed by the following equation system:

$$\begin{cases} \frac{dI_d}{dt} = \left(\frac{V_d}{L_g} - \frac{V_{gd}}{L_g}\right) + \omega.I_q \\ \frac{dI_q}{dt} = \left(\frac{V_q}{L_g} - \frac{V_{gq}}{L_g}\right) - \omega.I_d \end{cases} \quad (11)$$

With, ω is grid pulsation and detected instantaneously as grid angle (Θ) using a three phase locked loop.

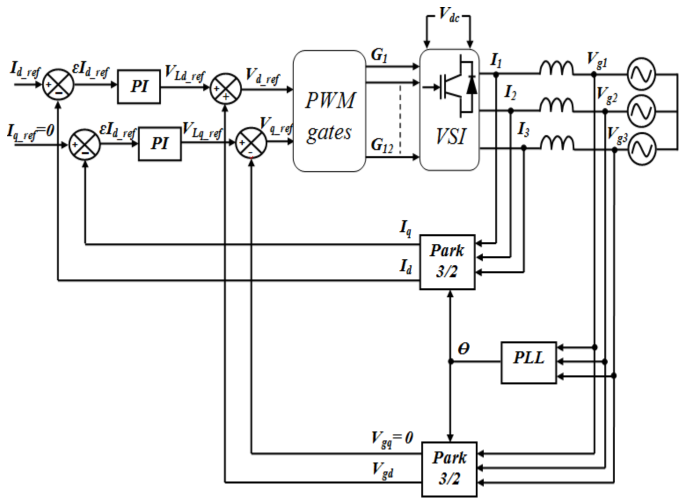

Fig. 4 Power control scheme

The control scheme depicts the inverter current and voltage control technique. The components $I_{d\text{-}ref}$ and $I_{q\text{-}ref}$ are the referential currents imposed by the boost converter, To turn the system operating in interconnected mode and close to unit power factor the quadratic component must be zero-forced ($I_{q\text{-}ref} = 0$). εI_d and εI_q represent the currents errors removed by two PI controllers. So, at the output we obtain the reference voltages of the filter $V_{Ld\text{-}ref}$ and $V_{Lq\text{-}ref}$ which are added to their counterparts in network V_{gd} and V_{gq} to get reference voltages ($V_{d\text{-}ref}$, $V_{q\text{-}ref}$) which are used to generate the twelve semiconductor pulses of the inverter gates.

In *dq* reference frame the grid active and reactive powers exhibit a strong dependency according to the following expressions [19]:

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$$\begin{cases} P_g = \frac{3}{2}(V_{gd}.I_d + V_{gq}.I_q) \\ Q_g = \frac{3}{2}(V_{gd}.I_q + V_{gq}.I_d) \end{cases} \quad (12)$$

Added to the role of phase and frequency detector, the phase locked loop has as main purpose is to guarantee grid synchronization between voltage and current of each phase. Shown by Fig. 5, the operational philosophy accomplishes upon two steps: transforming into the dq frame of the phase voltages then forcing in zero the quadratic component (V_{gq} = 0) to ensure a separated power control. Hence, power expressions are modified as below:

$$\begin{cases} P_g = \frac{3}{2}(V_{gd}.I_d) \\ Q_g = \frac{3}{2}(V_{gd}.I_q) \end{cases} \quad (13)$$

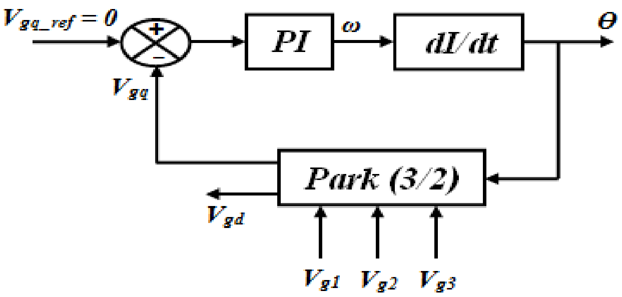

Fig. 5 Phase locked loop operating philosophy

IV. Simulation Results and Discussion

The simulation results when the solar source is connected to the utility grid are shown in this section. The intensity of the solar irradiation has been considered inconstant as shown in Fig. 6. Under this variation, the dc bus output voltage V_{dc} did not influenced, it is kept constant as illustrated by Fig. 7. Noted that it correctly follows its reference voltage V_{dc}* = 520*V*. It is also noted that the direct and quadratic current components (I_d and I_q) presented by Fig. 8 and Fig. 10 control the grid active and reactive powers (Fig. 9 and Fig. 11) where the reactive power is removed since quadratic component is zero forced (I_q = 0). Also the zero forcing of the grid quadratic component voltage (V_{gq}) juststifies the principle of the separate control of powers which we have adopted in this work.

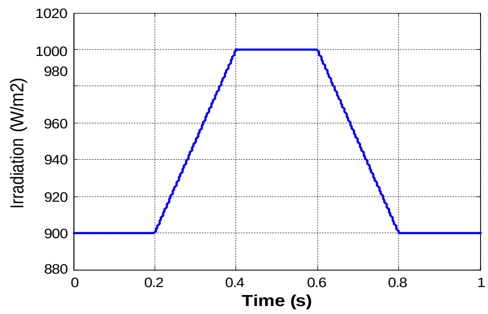

Fig. 6 Intensity of solar irradiation

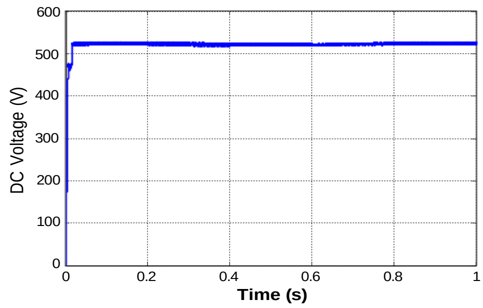

Fig. 7 DC output voltage

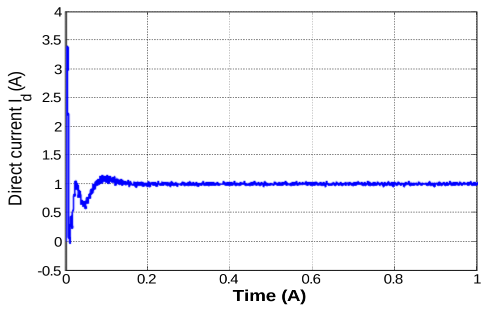

Fig. 8 Direct current

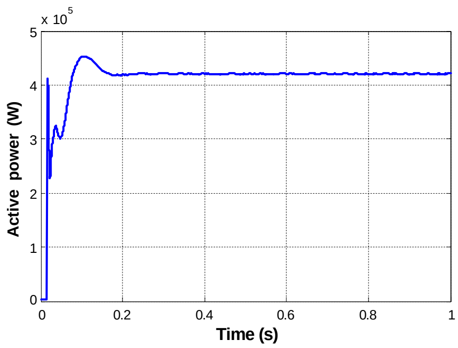

Fig. 9 Active power of grid side

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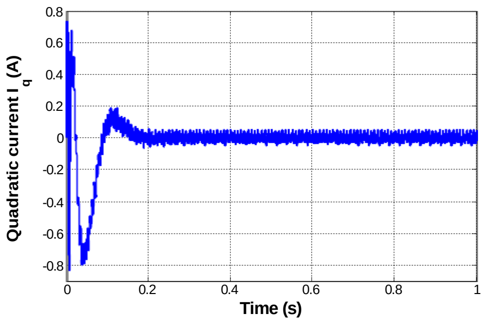

Fig. 10 Quadratic current

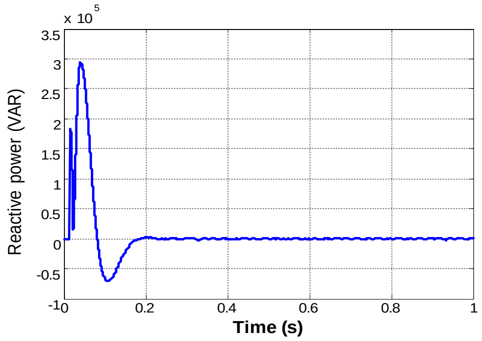

Fig. 11 Reactive power in grid side

V. CONCLUSIONS

The interest of the connection of the electrical production chains based on solar energy is focused during this work. Indeed, ensuring continuity of service and making accessibility of electricity for isolated areas is a paramount importance. At the end of this work, we conclude that the considered control structure fit for a grid connected systems with high power quality.

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