Active Power Filter in a Transformerless Grid Connected Photovoltaic System

B. Boukezata, A.Chaoui, J P. Gaubert, and M. Hachemi

***Abstract*—This paper presents a transformerless grid-connected photovoltaic (PV) with active power filter functions. It compensates for the reactive and injects active power demanded by nonlinear loads simultaneously; the developed PV array model may be directly connected to dc-side of the voltage source inverter with Direct Power Control Algorithm used for grid PV interaction. The system presents increased efficiency when compared to the conventional systems. Simulation results are provided to demonstrate the effectiveness of the proposed system.**

***Index Terms*—Direct Power Control, Active Power Filter, PV, P&O**

I. Introduction

THE global energy consumption is increasing by leaps and bounds to improve the living standards of mankind's worldwide. However, the conventional fossil fuels which are the primary sources of electric power so far are on the verge of extinction. Also, the extensive use of fossil fuels and nuclear resources causes the serious environment pollution and safety problems. Due to above mentioned facts, world is turning towards environmentally clean and safe renewable energy sources such as PV, wind, fuel cells, etc. [1].

Photovoltaic (PV) energy has great potential to supply energy with minimum impact on the environment, since it is clean and pollution free [2], and it is a suitable choice for a variety of applications mainly due to its capability to be directly converted to electrical energy using solar cells. This useful energy is supplied in the form of DC power from photovoltaic arrays (PV) bathed in sunlight and converted into more convenient AC power through an inverter system [3].

The grid-connected PV system supplies the active power from the PV array to the grid via an inverter. Today, non-linear loads are widely used in residential and office buildings. If the grid-connected PV system is applied to non-linear loads, the power quality is relatively poorer, because of the active power supply by the PV array.

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To solve this problem, the grid-connected PV system should not only supply active power to the system via MPPT, but also improve the power quality (low THD and unity power factor) [4].

In this paper, a transformerless grid-connected photovoltaic (PV) system with a direct power (active and reactive) control algorithm is proposed. This system increases the conversion efficiency (Single stage PV system) and operating as power supply as well as harmonic and reactive power compensator when the sun is available. At low irradiation, the system operates only as harmonic and reactive power compensator (Active Power Filter). The aim is that the system can operate as an inverter of distributed generation or/and as a shunt APF independently or simultaneously .In order to verify the proposed system. The PV system is simulated using Simpower of MATLAB/Simulink.

II. System Configuration

The system that has been simulated consists of a photovoltaic array connected through a DC bus to a three-phase inverter that is connected to a grid through a simple filter and nonlinear load, as shown in Fig. 1.The MPP tracker is integrated in the inverter control (Fig.3), as there is a one stage Grid connected PV system. The inverter is used to transfer the power from PV module, it also assure the compensation of the harmonic currents, reactive power and unbalanced current. The load is represented by three phase of rectifier with R L load.

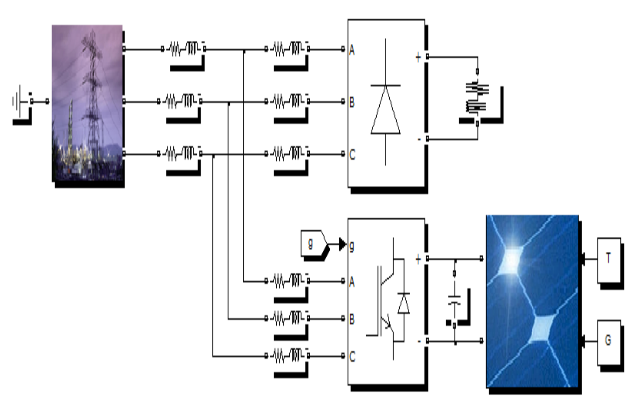


Fig. 1.Three-phase grid connected to the PV module

III. PV ARRAY MODEL

The PV array used in the proposed system is MSX60 and it is simulated using a model based on [5]. In this model, a PV cell is represented by a current source in parallel with a diode and a series resistance as shown in Fig. 2(a). The basic current equation is given in the following equation:

$$I = I_{pv,cell} - I_{o,cell}\left[\exp\left(\frac{qv}{akT}\right) - 1\right] \quad (1)$$

where I_(pv,cell) is the current generated by the incident light (directly proportional to sun irradiation), I_(o,cell) the leakage current of the diode, q the electron charge 1.60217646e10_19 C, k the Boltzmann constant, T the temperature of the PN junction, and a is the diode ideality constant. But practically the PV array comprised with many PV cells connected in series and parallel connection. This makes some additional parameters to be added with the basic Eq. (1). The modified equation is shown in the following equations:

$$I = I_{pv} - I_o\left[\exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \frac{V + R_s I}{R_p} \quad (2)$$

$$I_{pv} = \left(I_{pv,n} + K_I \Delta_T\right)\frac{G}{G_n} \quad (3)$$

A practical PV array consists of several connected PV modules formed by Ns solar cells connected in series and parallel. Therefore, (1) which presents a single PV cell should be amended into (4) to represent a PV array [6].

$$I = N_{pp} I_{pv} - N_{pp} I_o\left[\exp\left(\frac{V + IR_s\left(N_{ss}/N_{pp}\right)}{V_t a N_{ss}}\right) - 1\right] - \frac{V + IR_s\left(N_{ss}/N_{pp}\right)}{R_p\left(N_{ss}/N_{pp}\right)} \quad (4)$$

Where:

N_{pp} is the number of PV modules connected in parallel;

N_{ss} is the number of PV modules connected in series.

The PV model is simulated using Solarex MSX60, 60W PV module. The simulated I-V and P-V characteristics of the Solarex PV module at constant temperature and varying insolation are shown in Fig. 2(b) and Fig. 2(c) respectively.

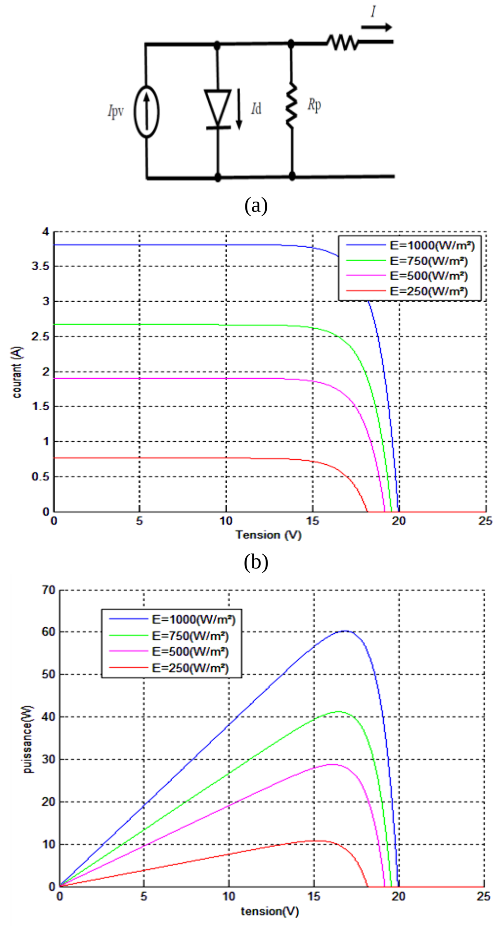


Fig. 2 (a) Equivalent circuit of a PV cell, (b) I-V characteristics, (c) P-V characteristics

IV. MPPT CONTROLLER

Most of the MPPT implementations for photovoltaic inverters output either a dc-link voltage reference to the inverter, or a duty cycle reference to a DC/DC converter depending on the system topology.P&O method is one of the popular methods to track the maximum-power point and probably the most frequently used in practice, mainly due to its easy implementation. [7,8]. The working principle of P&O is depicted by the flow chart in Fig. 3.

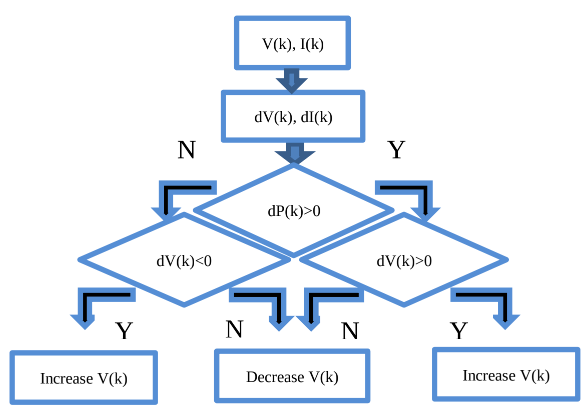


Fig. 3 P&O Flow Chart

V. ACTIVE POWER FILTER

Active power filters (APF) are basically power electronic devices that are used to compensate the current or voltage harmonics and the reactive power flowing in the power grid. The APF may be used as a controlled current source and it has to supply a current wave as close as possible to current reference. [10].

The basic compensation principle of APF is explained in Fig. 4.

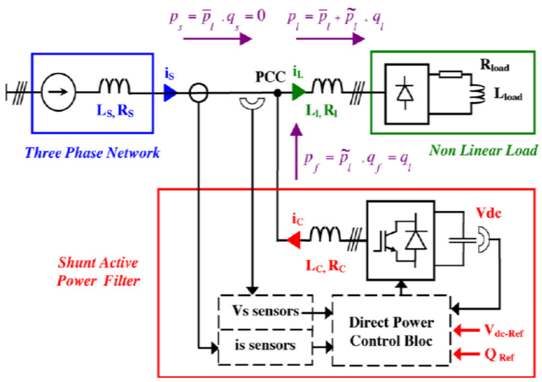


Fig. 4 Shunt active power filter configuration

A. Direct Power Control

The bloc scheme in Fig. 5 gives the configuration of direct power control where the commands of reactive power (set to zero for unity power factor) and active power pref (delivered from the outer integral-proportional (IP) DC voltage controller) are compared with the calculated ps and qs values given by (5), in reactive and active power hysteresis controllers, respectively.

$$s_s = ps + jqs$$

$$ps = vsa \cdot isa + vsb \cdot isb + vsc \cdot isc$$

$$qs = \frac{1}{\sqrt{3}}\left[(vsa - vsc)\, isa + (vsc - vsa)\, isb + (vsa - vsb)\, isc \right] \quad (7)$$

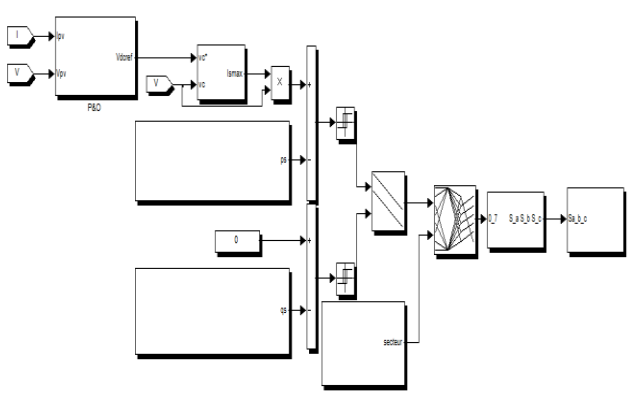


Fig. 5 bloc scheme of DPC with source voltage sensors

The digitized variables d p ,d q and the line voltage vector position θ p = tan-1 (V s β / V s α) form a digital word, which by accessing the address of lookup table selects the appropriate voltage vector according to the switching table. For this purpose, the stationary coordinates are divided into 12 sectors, as shown in Fig. 6, and the sectors can be numerically expressed as:

$$(n-2)\frac{\pi}{6} \le \theta_n \le (n-1)\frac{\pi}{6}\; n = 1, 2, ..., 12. \quad (8)$$

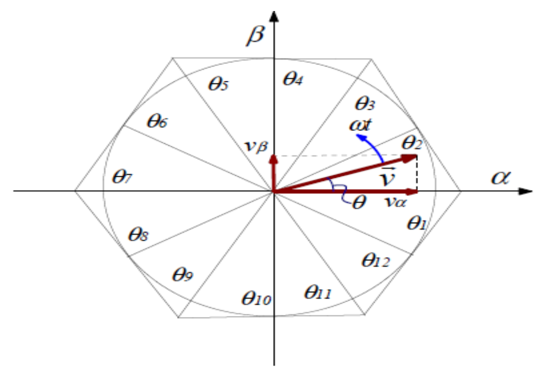


Fig. 6 Sectors on stationary coordinates

The digitized error signals d p, d q and digitized voltage phase θ n are input to the switching table in which every switching state S a ,S b and S c of the converter is stored, as shown in Table 1. By using this switching table, the optimum switching state of the converter can be selected uniquely in every specific moment according to the combination of the digitized input signals. The selection of the optimum switching state is performed so that the power errors can be restricted within the hysteresis bands [9].

TABLE I
SWITCHING TABLE

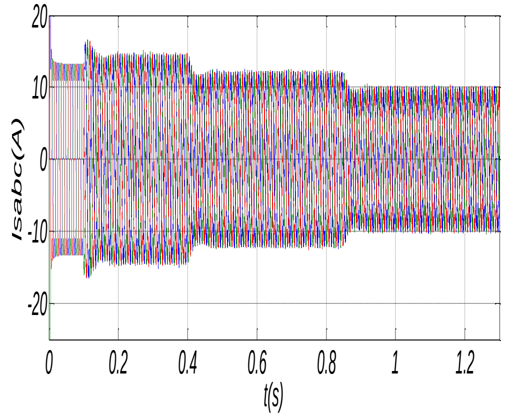
dp	dq	θ1	θ2	θ3	θ4	θ5	θ6	θ7	θ8	θ9	θ10	θ11	θ12
1	0	101	111	100	000	110	111	010	000	011	111	001	000
1	0	111	000	111	000	111	000	111	000	111	000	111	000
0	0	101	100	100	110	110	010	010	011	011	001	001	101
0	1	100	110	110	010	010	011	011	001	011	101	101	100

VI. RESULTS AND DISCUSSION

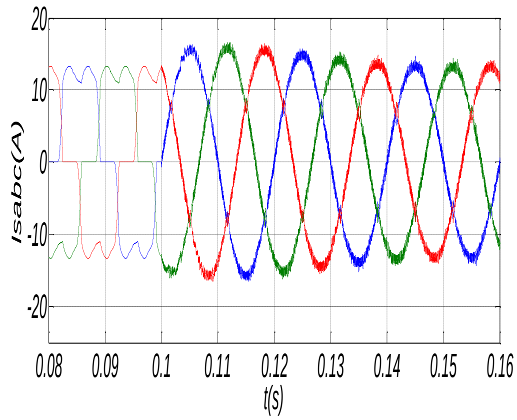
In Matlab/SIMULINK environment; a SimPower Systems based model has been developed to simulate the behavior of the controlled APF.

Figures 7 a, b, c and d show the dynamic response of the system with the PV system under different variations of the irradiation.

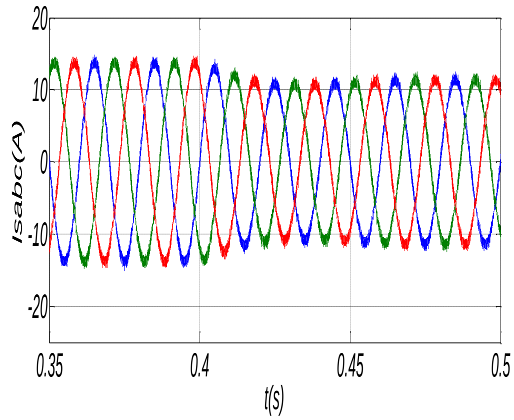
Fig. 8 shows that the dc bus voltage across the grid interfacing inverter is maintained at constant level in order to keep good functionality of the inverter and to facilitate the active power flow.



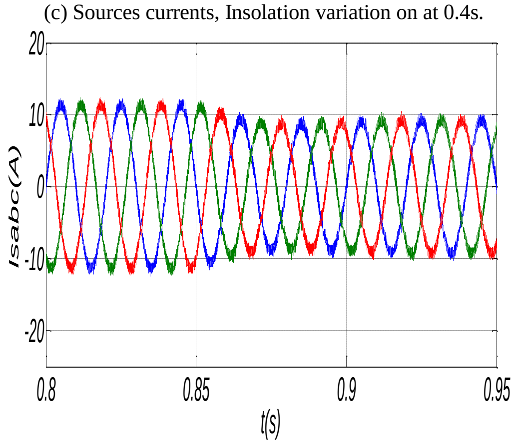
(a) Sources currents.



(b) Sources currents, Filter switched on at 0.1s.



(c) Sources currents, Insolation variation on at 0.4s.



(d) Sources currents, Insolation variation on at 0.85s

Fig. 7 Dynamic response of the system under different variations of the irradiation (a, b, c and d)

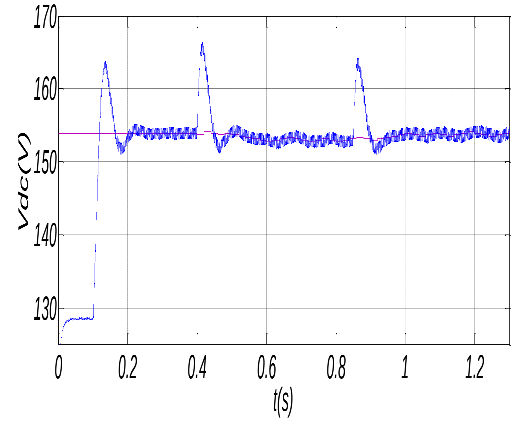


Fig. 8 DC Bus Voltage

In Fig. 9 we can see that the active power followed its nominal value and decreased when the PV system supplies the active power to the load. The reactive power becomes null when the active filter is activated at 0.1s as well as when the insolation is changed (0.4 and 0.85 s).

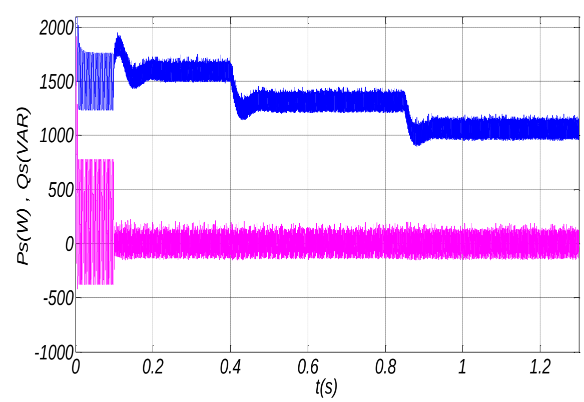
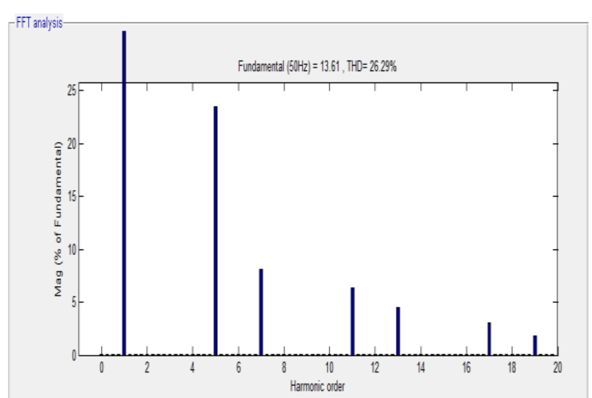
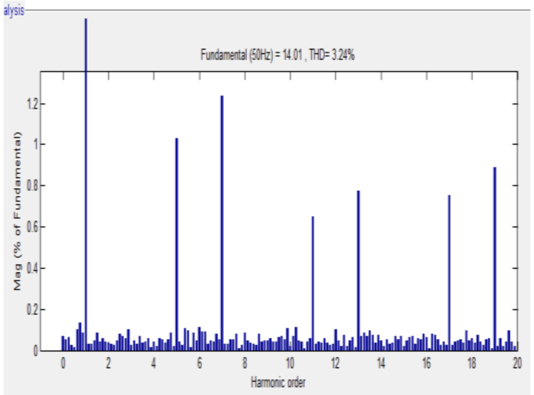


Fig. 9 Active and reactive powers source

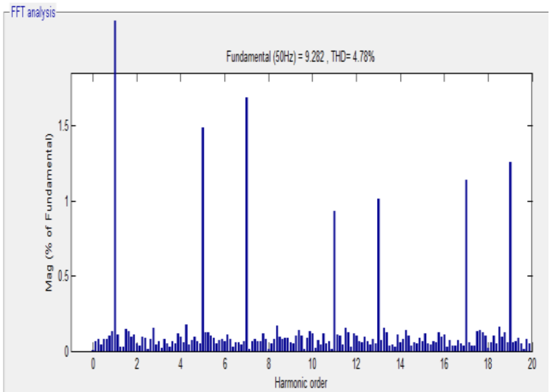
Fig. 10 illustrates the FFT result of the grid current after the switch of APF (26.29%).and before (3.24 %), and when the PV supplies the power, the total harmonic distortion (THD) of the grid current is 4.78%.



(a)



(b)



(c)

Fig. 10 a, b, c A grid current THD at steady-state

VII. Conclusion

This paper presents a behavioral model and control of a Grid-PV system with active power filter functioning suitable for changing atmospheric conditions. The Solarex MSX60, 60W PV module is used for simulation that has 36 series connected polycrystalline cells. The PV system is developed using one string having 9 series connected PV modules. A DPC for APF has been presented. One can see that the control algorithm is simple, it has a good dynamics, and it offers sinusoidal line currents (low THD). Simulation results verify the performance of the combined PV–APF and the P&O MPPT method.

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