PQ Theory of SAP Filter in Photovoltaic System Connected to Three-Phase Grid and Controlled Nonlinear

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Abstract. Currently, we are trying to improve electrical energy in the world. In practice, the use of switching devices is increased in the various applications. Non-linearity of loads has adverse effects on energy efficiency, power factor, etc. This increases the reactive power and oversizes the devices of the electrical installation. Several solutions are therefore proposed. Unlike passive filter, active filters work due to their small size. In this paper, work is done on the Parallel Active Power Filter (SAPF) using nonlinear control based on Lyapunov theory and PQ theory for attenuation of harmonics and reduction of imaginary power in operation of a photovoltaic system. The simulation of the circuits is implemented in MATLAB / SIMULINK. The measurements have been presented with or without SAPF filter. We start the article by modeling the different devices used, then an analysis of the PQ theory is carried out, carrying out simulations, results and interpretations. Finally, we end with a conclusion where we can say that the THD value of the source current reached is less than 5% imposed by the required standards.

Keywords: SAPF, PV, MPPT, PQ theory, THD, Nonlinear load, MATLAB/SIMULINK.

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1 Introduction

The increase in energy demand often exceeds the production of electricity available in any developing country. Therefore, renewable and clean energy production systems like the wind and photovoltaic power systems are used to fill the energy gap produced on fuels and biomass. Due in particular to the non-linearity of the load, static converters consume non-sinusoidal currents. They then behave as sources of polluting currents, which can distort the network voltage via the short-circuit impedance. In addition, most static converters consume reactive power, resulting in low utilization rate of equipment constituting the network such as generators, transformers, lines, etc. Ordinary LC filters cannot effectively compensate for polluting currents due to non-linear loads in a network connected to the photovoltaic (PV) system [1]. Thus, active power filters (SAPF) are introduced due to their performance, for harmonic compensation of non-linear loads in this type of systems. The minimization of harmonic rates and the reduction of reactive power can be achieved simultaneously by the use of a voltage inverter connected in parallel with the system and which acts as a SAPF filter. This SPAF filter produces a compensation current of the same amplitude as the polluting current and in phase opposition with it, this current is injected into the network. The APF is used in series, bypass or in hybrid with conventional filters. In the literature, different topologies of SPAF filters have shown their efficiency in several applications, such as instantaneous control of active and reactive power [2] and direct power control [3] - [4], itself based on that introduced by Noguchi et al [5]. In [6], a simulation model of the three-phase SPFA had been implemented on the basis of the mathematical modeling of the system where one can observe the considerable improvement of the source current in the standards of total harmonic distortion (THD). Power quality complications can be improved by using an active power filter system in series.

This article discusses the nonlinear control based on the PQ theory of the active power shunt filter (APF) in a photovoltaic (PV) system connected to the three-phase source. Among the control objectives, we can cite: (i) the

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simplicity of implementation of the command; (ii) improvement of the source current shape in the total harmonic distortion (THD) standards of the system (the increase in cos (fi) (PFC)) and (iii) the pursuit of power and currents at the irradiation variation profile. It is also shown by a theoretical study that the controller really achieves its objectives, which is justified by the simulation results.
The article includes: a presentation of the system with its modeling, the design of the controller (control laws, generation of reference currents based on the PQ theory and the MPPT) and finally the monitoring performance of the controller are illustrated by the results of the digital simulation presented.

2 System presentation and modeling

2.1. System presentation

The system presented in this article is illustrated in **Fig. 1.** It consists of a photovoltaic SAPF filter connected to the power source through a common point (PCC) using the Lf coil. The filter is used to reduce the distortion currents produced by the nonlinear load.

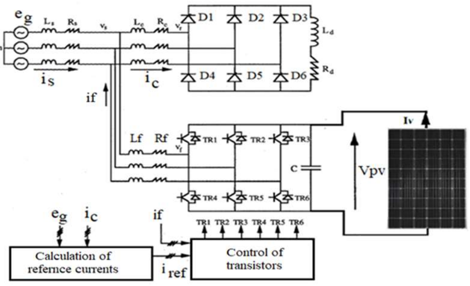

Fig. 1. Energy system with photovoltaic system and active filter

2.2. PV Generator modeling

The equivalent assembly to a diode [7] is adopted for the photovoltaic cell. According to the content of the article [7], we can write:

$$I_{pvc} = I_{phc} - I_{dc} - I_{pc} \quad (1)$$

$$I_{pvc} = I_{phc} - I_{0c}\left[\exp\left(q\frac{V_{pvc}+R_S.I_{pvc}}{nKT}\right)-1\right]+\frac{V_{pvc}+R_S I_{pvc}}{R_p} \quad (2)$$

The solar module used is the SHARP NU-183E1, the studied photovoltaic panel comprises 28 chains in series and 14 solar modules connected in parallel.

2.3. Three phase Inverter modeling:

A photovoltaic system connected to the three-phase network makes it possible to control the injected active and reactive power while monitoring the MPPT point imposed by the photovoltaic source. In this work, we use the spatial vector method which is an algorithm used to achieve the pulse width modulation because this method allows to obtain a good compromise between the reduction of the harmonic content of the voltage produced and the reduction of losses. of commutation. 8]. In addition, the voltage of the photovoltaic source is chosen higher than the peak voltage of the network [9] in order to be able to control the active and reactive power without the need for a DC-DC voltage step-up stage (see Fig. 1), The equations representing the state model of the system studied in the αβ frame of reference are summarized by (3) - (5) taking into account the average of the model over a switching period [10], we then obtain:

$$\frac{di_\alpha}{dt} = -\frac{r}{L}i_\alpha + \frac{Vpv}{L}\mu_\alpha - \frac{1}{L}eg_\alpha \quad (3)$$

$$\frac{di_\beta}{dt} = -\frac{r}{L}i_\beta + \frac{Vpv}{L}\mu_\beta - \frac{1}{L}eg_\beta \quad (4)$$

$$\frac{dVpv}{dt} = -\frac{1}{C}\left(\mu_\alpha i_\alpha + \mu_\beta i_\beta\right) + \frac{1}{C}i_{pv} \quad (5)$$

Where the values μ_α and μ_β denote the averaged values of U_α and U_β.

3 Controller Design

3.1. Control laws

In order to make the reactive power consumed by the network zero, we write:

$$i\alpha r = K.eg_\alpha \quad \text{and} \quad i\beta r = K.eg_\beta$$

Where: K output of the MPPT system.

Then we define the errors z1 and z2 such that:

$$z_1 = i_\alpha - i_\alpha^* \quad (6)$$

and $$z_2 = i_\beta - i_\beta^* \quad (7)$$

Where: $i_\alpha^* = i_{\alpha ref} + i_{\alpha r}$ and $i_\beta^* = i_{\beta ref} + i_{\beta r}$, $i_{\alpha ref}$, $i_{\beta ref}$, $i_{\alpha r}$ and $i_{\beta r}$ are current reference signals to be determined in the next Subsection.
based on the model (3) - (5), on the objective of canceling the z_1 and z_2 errors, on the currents and ensuring system stability using Lyapunov theory as explained in the article [11], the following control laws were obtained:

$$u_\alpha = -\frac{L}{Vpv}\left(-c_1.(i_\alpha - i_\alpha^*) + \frac{r}{L}i_\alpha + \frac{eg_\alpha}{L} + \frac{d(i_\alpha^*)}{dt}\right) \quad (8)$$

$$u_\beta = -\frac{L}{V_{pv}}\left(-c_2.(i_\beta - i_\beta^*) + \frac{r}{L}i_\beta + \frac{eg_\beta}{L} + \frac{d(i_\beta^*)}{dt}\right) \quad (9)$$

Where c_1 and c_2 are positive design parameter, $i_{\alpha ref}$ and $i_{\beta ref}$ are current reference signals to be determined in the next Subsection.

3.2 Current reference signal generation using PQ theory

The Concordia transformation defined by equation (10-a)-(10-b) makes it possible to obtain the orthogonal components for the voltages and the currents: v_α, v_β, i_α and i_β.

$$\begin{bmatrix} v\alpha \\ v\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} va \\ vb \\ vc \end{bmatrix} \quad \text{(10-a)}$$

and

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} \mathrm{ia} \\ \mathrm{ib} \\ \mathrm{ic} \end{bmatrix} \quad \text{(10-b)}$$

Finally, the reference currents in the abc and αβ frame respectively are:

$$\begin{bmatrix} i_{\alpha ref} \\ i_{\beta ref} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} \tilde{p} \\ \bar{q} + \tilde{q} \end{bmatrix} \quad (11)$$

$$\begin{bmatrix} i_{a ref} \\ i_{bref} \\ i_{cref} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_{\alpha ref} \\ i_{\beta ref} \end{bmatrix} \quad (12)$$

By summarizing these different stages developed, the diagram allowing the obtaining of the reference currents using the instantaneous active and reactive power method, is illustrated (see Fig. 2).

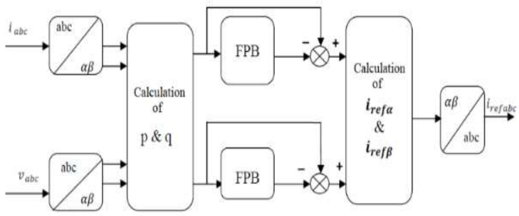

Fig. 2. Assembly for the identification of reference currents.

3.3. MPPT System

The maximum power point tracking, often called the MPPT, is an electronic device that looks for the voltage VM and the current IM corresponding to the maximum power PM during the operation of a photovoltaic module, and this in changing environmental conditions. The principle of the algorithm used is to generate a disturbance on the voltage of the PV panel by acting on the duty cycle. In fact, following this disturbance, the power supplied by the PV panel at time t is calculated, then it is compared with that calculated at time (t-1). The implementation of this algorithm in MATLAB / Simulink is given in Fig. 3.

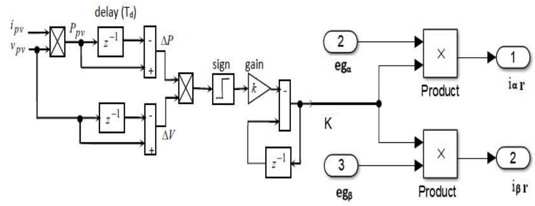

Fig. 3. Implementation of the P&O algorithm in Matlab/Simulink software

4 Simulation results

In this study, we will present a numerical simulation analysis under the MATLAB/Simulink environment of the proposed energy system in the presence and absence of the active power filter. The non-linear load is of the three-phase bridge rectifier type with all diodes supplying an R-L load. The results are taken with the data of the components of the table (see Table 1.). The simulation bench is illustrated in Fig. 4.

4.1. Results discussion

Before the operation of the SAPF filter, the THD of the current in grid is 30.73%, this shows that the load is a source of pollution, (see Fig. 5 and Fig. 6).
The Fig. 7 to Fig. 10 show that implementation of the parallel active power filter makes it possible to have a THD of 2.75%, this shows the efficiency of this real and imaginary power method which is based on the SAPF technique.
The shape of the currents in the electrical network is almost sinusoidal, it is clear that the polluting power is almost zero. The reference currents produced by the PQ theory therefore compensate for the currents caused by the nonlinear load.
The THD value of the source current reached is less than 5% imposed by the required standards.

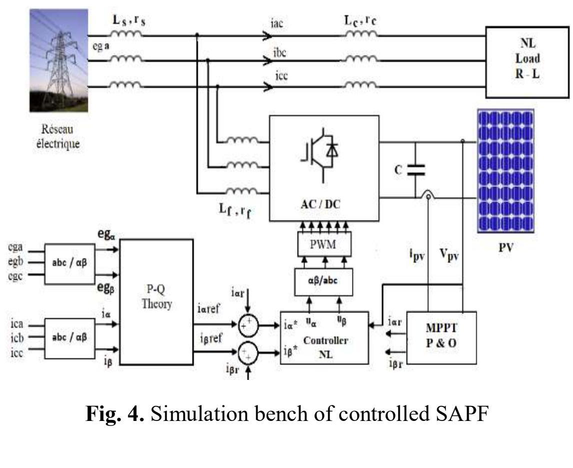

Fig. 4. Simulation bench of controlled SAPF

Table 1. Characteristic of the three-phase controlled system

Settings	Symbols	Values
PV panel	Power PV	71.75 kW
DC Capacitor	C	3300 µF
Filter inductor	L , r	3 mH , 0.2 Ω
PWM	Modulation frequency	10 kHz
Electrical network	Phase-neutral rms value	220 V – 50Hz
Non-Linear LOAD	Bridge rectifier Lc , rc	30mH , 10 Ω
P & O algorithm	Td - Step	10^{-4} s – 0.3s

we observe that the electrical signals i and v of the source have zero phase shift, the current is almost sinusoidal (very low THD), we can say that the source only supplies the active power requested by the circuit (see Fig. 7 and Fig. 10). The SAPF active filter injects a harmonic current of amplitude equal to the harmonic current demanded by the load, but having a phase shift of 180 to compensate for current pollution in the circuit, which makes source current sinusoidal. Power and currents follow the irradiation profile, this shows that the controller used is robust (see Fig. 9 and Fig. 10).

4.2. Electric grid characteristics when the SAPF is omitted

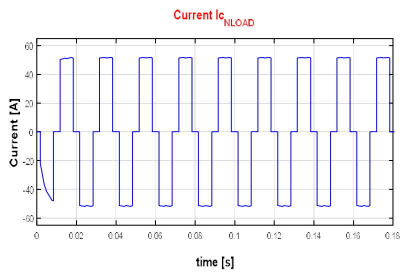

Fig. 5. Current in the load

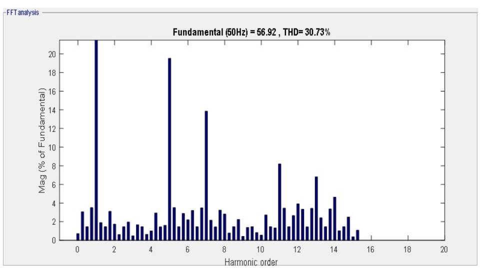

Fig. 6. Current THD in the network

4.3. Electric grid characteristics in the presence of the controlled SAPF

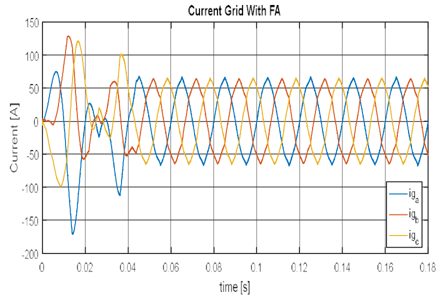

Fig. 7. Current Grid with SAPF

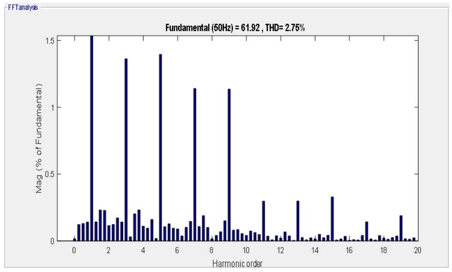

Fig. 8. Total harmonic distortion for current in grid side

4.4. SAPF behavior in the presence of solar irradiance changes

For an irradiation profile starting at 1001 W/m^2, then 801 W/m^2 from 0.1s and finally 1200 W/m^2 from 0.16s, the results are:

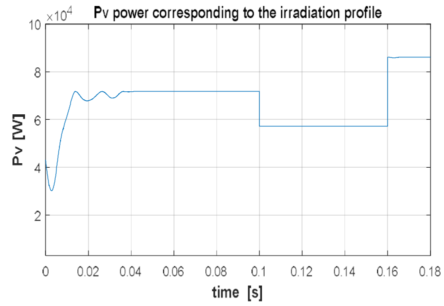

Fig. 9. Power PV corresponding to the irradiation profile

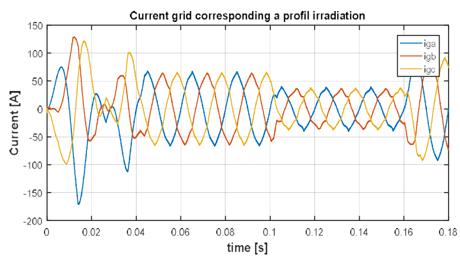

Fig. 10. Curent grid corresponding to the irradiation profile

5 Conclusion

Non-linear loads disturb electrical networks because they inject harmonic currents and mainly consume reactive power. Conventional solutions, in particular passive filtering and reactive power compensation by capacitor banks, are no longer sufficient for pollution control. In this study, we have presented the method of real and imaginary instantaneous powers for the identification and design of suitable currents similar to harmonic currents in the installation. This method is effective especially when the three-phase voltage supplied by the network is healthy (sinusoidal and balanced). the injection of the reference currents with an opposite phase makes it possible to reduce the polluting currents. Our contribution also has the major advantage, that of using renewable and clean energies preserving the environment by the cancellation of CO2 gas and does not generate radioactive waste and their resource would be renewable thanks to the sun.

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