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PV Power Injection Associated with a Reactive Power Compensator

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***Abstract*— Non-linear loads such as diode or thyristor rectifier consume reactive power and inject harmonic currents into the grid causing a low power factor and important harmonic distortion (THD). To work around the harmful effects of harmonics, an approach offers a reduced harmonic distortion of the current source, more used to compensate the reactive power via the use of a parallel active filter. The active filter is a three-phase voltage inverter controlled by a hysteresis control, a PI regulator (proportional / integral) is synthesized to reduce the DC bus voltage fluctuations and compensate the losses of the system, the second purpose of this work is to inject through the filter the power delivered by the photovoltaic system, which comprises a photovoltaic generator (GPV) and a (DC/DC) boost converter controlled by a P&O algorithm to extract at any moment the maximum power available at the GPV boundaries.**

***Keywords*—Non-linear loads, THD, Active filter, Photovoltaic generator, P&O algorithm, Boost.**

I. Introduction

Over the recent years, power quality has been given attention due to the intensively use of power electronic controlled applications in all branches of industry, such as controlling or converting AC power to feed electrical loads. As a result, harmonics were generated from the power converters or non-linear loads that caused the power system operate with low power factor, low efficiency, voltage and current distortions, and increased losses in transmission and distribution lines [1].

To overcome these disturbances, active filtering has proven effective as an alternative to solutions based on passive filters, active filter concept uses power electronics to produce harmonic current components with 180 phase shift to the harmonic current components generated from nonlinear loads.[2].

The purpose of our study is to evaluate the contribution of a parallel hysteresis compensator feded by a photovoltaic energy system. Simulation algorithms are developed on MATLAB Simulink.

The proposed system consists of a parallel active filter constructed by a three-phase full-bridge voltage source inverter (VSI) connected to a DC-bus capacitor; and PV arrays in parallel with the DC-bus capacitor. Fig. 1 presents the power circuit of the proposed system with a PV system in parallel with a nonlinear load that is supplied by a source voltage from the point of common coupling (PCC). In the proposed scheme, the system has two main functions: In the day-time with intensive sunlight, the PV interactive shunt active power filter system brings all its functions into operation. At night and during no sunlight periods, the power required by the load is received from the distribution system while the inverter system only provides reactive power compensation and filter harmonic currents [3].

The principle scheme of a parallel active filter is illustrated in Fig .1.

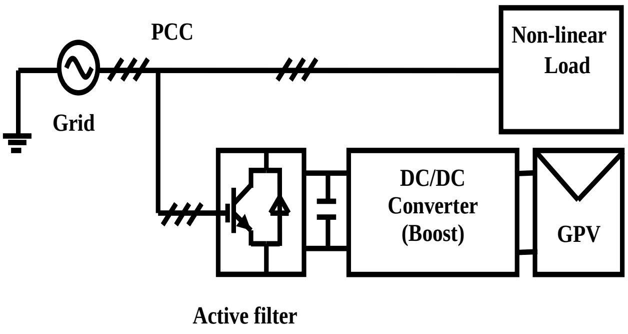

Fig.1 Principle scheme of a parallel active filter

II. CARACTERIZATION OF DISTURBANCES

Harmonic disturbance is characterized by harmonic distortion (THD) defined on voltage or current. It allows us to characterize the deformation introduced by the harmonics with respect to a sine wave.

To involve the participation of harmonics in the apparent power, we define the deforming power D [4]:

$$D = 3 * V_1 \sqrt{\sum_{h=1}^{\infty} I_h^2} \tag{1}$$

Thus, the apparent power is given by:

$$S = \sqrt{(P^2 + Q^2 + D^2)} \tag{2}$$

And the power factor by:

$$F = \frac{P}{\sqrt{(P^2 + Q^2 + D^2)}} \quad (3)$$

From (3) it is clear that the power factor is degraded in presence of harmonics.

III. PROPOSED CONTROL

A. Photovoltaic system

1) Photovoltaic generator: The building block of the PV arrays is the solar cell, which is basically a p-n semiconductor junction, shown its equivalent model in fig.2, The V-I characteristic of a solar cell is given by the equation. (4) [5].

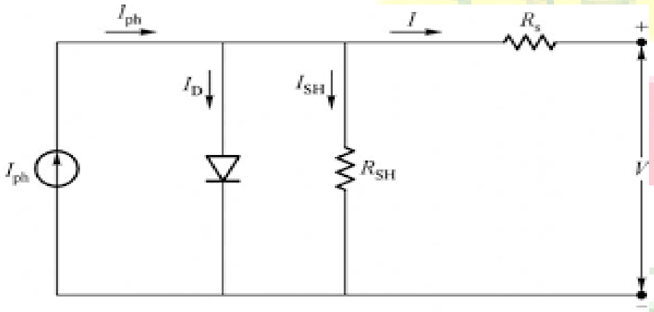

Fig.2 Equivalent model of a PV cell

The Kirchhoff's law gives:

$$I = I_{ph} - I_o\left(\exp\left[\frac{q(V+R_s I)}{nkT_k}\right] - 1\right) - \frac{V+R_s I}{R_{SH}} \quad (4)$$

Where V and I represent the output voltage and current of the PV cell, respectively; R_s and R_{SH} are the series and shunt resistance of the cell; q is the electronic charge; I_{ph} is the light-generated current; I_o is the reverse saturation current; n is a dimensionless factor; k is the Boltzmann constant, and T_k is the temperature in Kelvin.

The PV cells will be arranged in series or parallel to produce a PV modules or arrays, the fig.3 shows the (P-V) characteristics of a PV module (36 cell in series) :

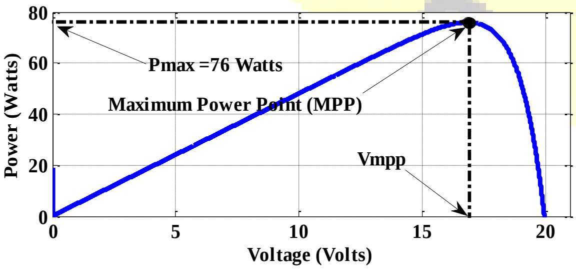

Fig.3 Characteristic power-voltage (P-V) of GPV module

It is clear that the feature (P-V) of the GPV is a nonlinear function with a maximum power point MPP, in direct connection mode between the load and the GPV, we can find a large gap between the power delivered by the GPV and the actually transferred to the load, to extract at every moment the maximum power available at the terminals of the GPV and transfer it to the load, a boost converter controlled by a P&O algorithm is used; whose role is to vary the duty cycle of the converter such that the power supplied by the GPV is the Pmax available at its terminals.

2) P&O MPPT algorithm: The P&O algorithms operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage or current and comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases (dP/dV>0), the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way [6].

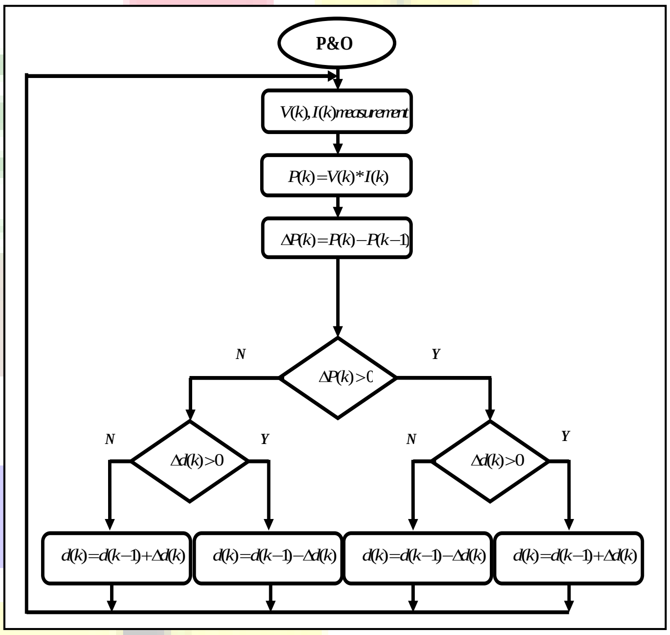

Fig.4 Flowchart of the P&O algorithm

B. Active filter control

1) Hysteresis direct current control: The basic operation of this method is shown in Fig 5. The estimation of the reference currents from the measured dc bus voltage is the basic idea behind the PI controller based an operation of the active power filter. The capacitor voltage *Vdc* is compared with its reference value *Vdcref* in order to maintain a constant stored energy in the capacitors. The PI controller is applied to regulate the error between the capacitor voltage and its reference. The output of PI controller gives the magnitude *Ismax* of the three source reference currents, and then this value is multiplied by a unit sinusoidal signals in order to obtain the instantaneous supply reference currents *Isaref*, *Isbref*, *Iscref* [7].Conventional hysteresis control then is used, the method is based on the comparison of the difference between the reference currents and the grid measured currents with a fixed band. Each violation of this band gives a switching command to the switches.

The principle scheme of this control is shown in the fig.5 [8]:

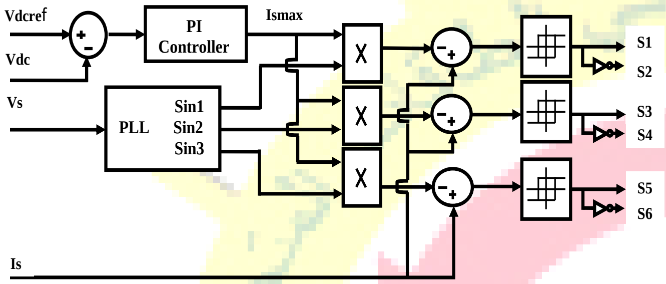

Fig.5. Principle scheme of the hysteresis current control

2)Dc bus control: In order to regulate the DC bus voltage and obtain a fixed value required to fed the power circuit, a PI controller will be used. First, the *Vdc* is measured by a voltage sensor then compared to a reference value (400 volts), the resulting error is corrected by the PI controller, the output of this control loop provides the reference peak current value of the source *Ismax*, this current will be multiplied by three unit sine (*sin (ωt)*, *sin (ωt+2π/3)*, *sin (ωt+4π/3)*) which are obtained from a phase locked loop (PLL).

The controller will be synthesized by the following method:

The power absorbed by a capacitor is given by:

$$P_f = \frac{d}{dt}\left(\frac{1}{2}.C.V_{dc}^2\right) \qquad (5)$$

After the Laplace transform:

$$V_{dc} = P_f \cdot \frac{1}{V_{dc}^*.C.p} \qquad (6)$$

The PI controller transfer function is given by:

$$K_p + \frac{K_i}{T_i} = \frac{1+\tau.p}{T_i.p} \qquad (7)$$

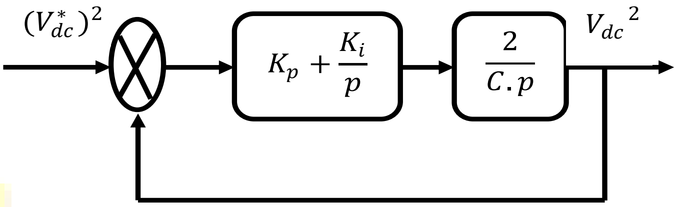

Fig.6 Functional control diagram of the DC bus voltage.

The transfer function in a closed loop F (p) is given by:

$$F(p) = \frac{w_0^2.(\tau.p+1)}{p^2 + 2\zeta w_0.p + w_0^2} \qquad (8)$$

So:

$$w_0 = \sqrt{\frac{2}{C.T_i}}, \zeta = \frac{\tau}{\sqrt{C.T_i}} \qquad (9)$$

IV. SIMULATION RESULTS

In direct connection between the grid and the non-linear load and before compensation, the figures (Fig.7 and Fig.8) although showing the deformation of the grid current and their high harmonic content (THDi = 25.21%).

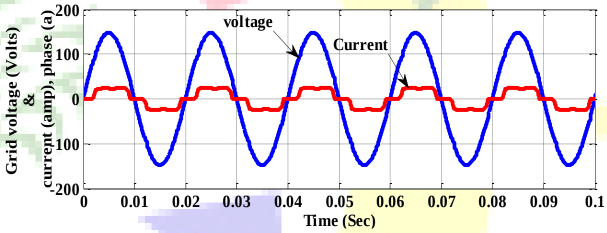

Fig.7 Source voltage and current waveforms (Vsa & Isa) before compensation

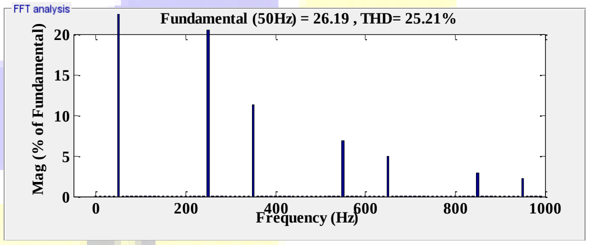

Fig.8 Spectral analysis of the source current

Before the insertion of the active filter, the load consumes an active power reaches to (Ps ≈ 6kW) as shown in Fig .9

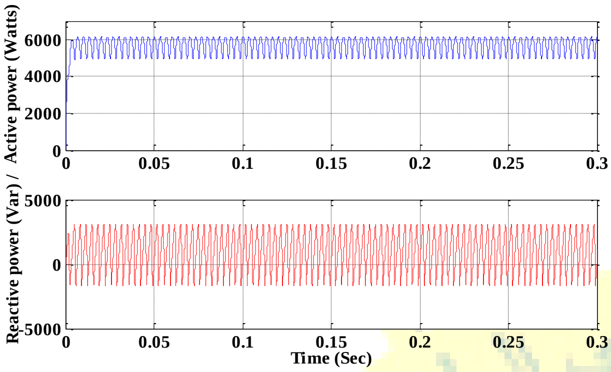

Fig.9 Active and reactive power consumed by a non-linear load before compensation.

After the insertion of the active filter:

The DC bus voltage tends to its chosen reference value (400 volts) as shown in fig.10.

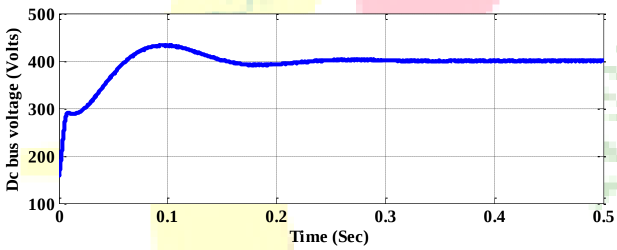

Fig.10 DC bus voltage

The fig.11 shows that the waveform of the grid current has been improved and synchronized with the grid voltage, this explains that the reactive power consumption is almost zero, so the power factor is unity.

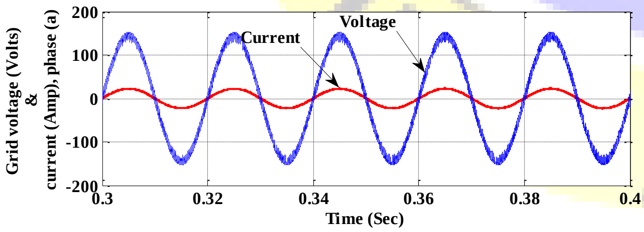

Fig.11 Grid voltage and current waveforms (phase a) after compensation

The spectral analysis of the grid current (phase a) shows that there is a clear reduction in harmonic distortion (THDi = 2.05%), (Fig.12).

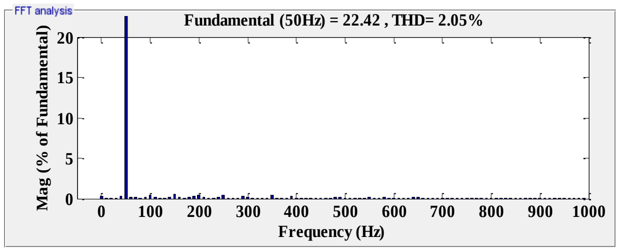

Fig. 12 Spectral analysis of the current source after compensation

The fig.13 shows the compensating current produced by our active filter to correct the imbalance in the system.

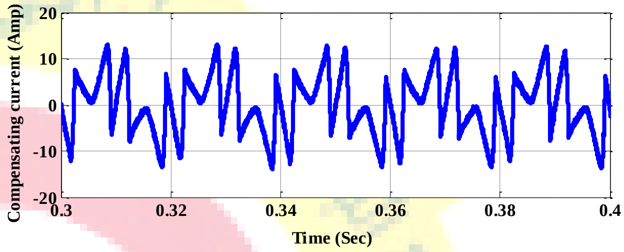

Fig.13 Compensation current injected by the filter (phase a)

The GPV consists of 13 modules (36 cells each) connected in series. The Fig.14 shows the maximum power extracted by the P&O controller from the GPV and injected to the grid:

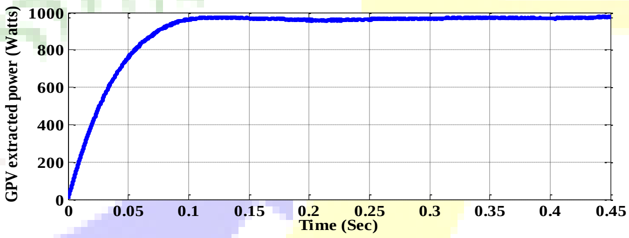

Fig.14 look of active power injected by the GPV

From the Fig.15, we see an active power injection to the grid by the photovoltaic system. This is characterized by an active power reduction provided by the three-phase network (Ps ≈ 5Kw) (source current decrease) so there is a P≅1Kw power produced by the GPV injected to the grid to meet the energy requirement of the non-linear load. More the imbalance in the reactive power produced by the non-linear load has been corrected, this is significate that the two purposes of this work have been accomplished.

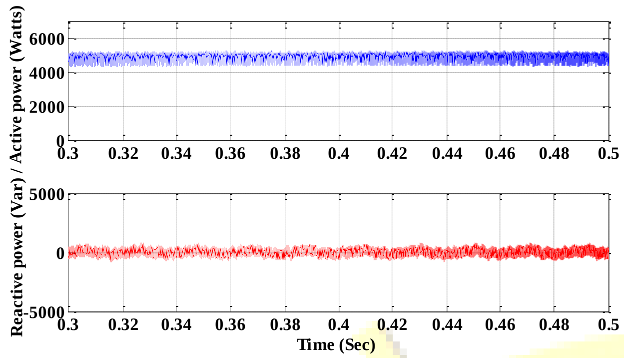

Fig.15 Active & reactive power after compensation

V.CONCLUSION

In the present work we have treated the problem of harmonic pollution of power systems, its source and adverse effects on the power grid, to remedy this problem: improve the quality of the grid currents; reducing its THDi and increase the power factor of the system, we introduced a modern solution based on a shunt active filter powered by a renewable energy source (solar generator). The purpose of this work is to design an active filter system with two main functions: provide the solar power (active power injection), both to compensate the reactive power imbalance, it is important to note that the power factor is still high, the source currents have low harmonic distortion and the consumption of reactive power is almost zero.

REFERENCES

[1] K. H. Yiauw and M. S. Khanniche, " A Novel Three-Phase Active Power Filter". Rev. Energ. Ren. : Power Engineering (2001) 77-84.

[2] R. Belaidi, A. Haddouche, M. Hatti, and M. M. Larafi."Shunt active power filter connected to a photovoltaic array for compensating harmonics and reactive power simultaneously". 4th International Conference on Power Engineering, Energy and Electrical Drives, Istanbul, Turkey, 13-17 May 2013.

[3] S. Mohamed, A. Dahidah, N. Mari.un, S. Mahmod and N. Khan." Single Phase Active Power Filter for Hannonic Mitigation in Distribution Power Lines," National Power and Ene rgy Conference (PECon) 2003 Proceedings, Bangi, Malaysia.

[4] A. Aboubou and S. E. Zousou, "Contribution à la compensation de la pollution harmonique en utilisant un filtre actif parallèle commandé par logique floue," Courrier du Savoir – N°03, Janvier 2003, pp. 59-63.

[5] J. A. Jiang, T. L. Huang, Y. T. Hsiao and C. H. Chen, "Maximum Power Tracking for Photovoltaic Power Systems,". Tamkang Journal of Science and Engineering, Vol. 8, No 2, pp. 147_153 (2005).

[6] R. Faranda and S. Leva, "Energy comparison of MPPT techniques for PV Systems," WSEAS TRANSACTIONS on POWER SYSTEMS, ISSN: 1790-5060, Issue 6, Volume 3, June 2008.

[7] N. Belhaouchet, S. Begag, and L. Rahmani " A Digital Hysteresis current controller for three phase shunt active power filter,". 4th International Conference on Computer Integrated Manufacturing CIP'2007, 03-04 November 2007.

[8] B. Boukezata, A. Chaoui, J. P. Gaubert, M. Hachemi,"Système solaire photovoltaïque connecté au réseau électrique et associé à un filtre actif parallèle,". Symposium de G_enie _Electrique 2014, Jul 2014, Cachan, France. <hal-01065188>.