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Control of a Shunt Active Power Filter by the Synchronous Referential Method Connected with a Photovoltaic Solar Energy

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Abstract: This paper presents a depollution technique for low voltage electrical networks. This technique is based on the control of the shunt active power filter (SAPF) at two levels by the instantaneous power method (Sychronous Reference Frame - SRF) which has allowed us to obtain reference currents by eliminating the harmonic currents generated by the non-linear load (three-phase rectifier). We have thus proposed a DC voltage source from the SAPF by a photovoltaic solar generator while ensuring energy maximization by the MPPT controller. The simulation results under the MATLAB/Simulink environment obtained for the shunt active filtering system clearly indicate the efficiency of the chosen control (SRF) and follow the international standard recommendations IEEE519-92 which require that the Total Harmonic Distortion of the source current be less than 5 %.

Keywords: *maximum power point tracking (MPPT), photovoltaic generator (PVG), perturb and observe (PandO), synchronous reference frame (SRF), total harmonic distortion (THD).*

Mathematics Subject Classification (2010): 93C42, 03B52, 93E11, 93Cxx.

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1 Introduction

The increase in pollution of power supply networks is caused by the appearance of devices based on power electronics components as a non-linear load. For this, the best solution to improve the quality of electrical energy is the Active Power Filter [1–3]. In this paper, the shunt active power filter is the main responsible for eliminating the harmonics in the power supply lines caused by the non-linear load (Three-phase rectifier). For the shunt Active Filter to work within the standards and give good results of Total Harmonic Distortion of the supply currents, it suffices to choose its best control in terms of precision and speed [4]. The authors of [5,6] propose a resonant control scheme in the SRF method to reduce the calculation rate. This proposal is essential for non-linear loads such as DC-DC converters where there are electric currents composed by the fundamentals and harmonics of order $6h \pm 1$, $h = 1, 2, ...$ [7].

2 Principle of the Shunt Active Power Filtering System

The global diagram of the proposed shunt active power filtering system is shown in Figure 1. It consists of a non-linear load (three-phase rectifier) which is the source of the harmonics injected into the supply network which becomes polluted [8].

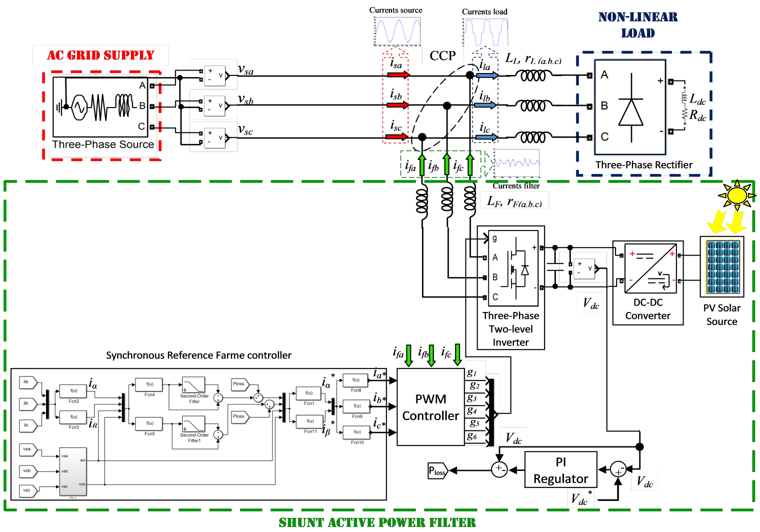

Figure 1: Structure of the SAPF controlled by the SRF method and powered by the PV system.

3 Synchronous Reference Frame (SRF) Method

Figure 2 shows the block diagram of the SRF method [1, 9]. This method is based on the transformation of three-phase load currents (i_{la}, i_{lb}, i_{lc}) into a two-phase stationary

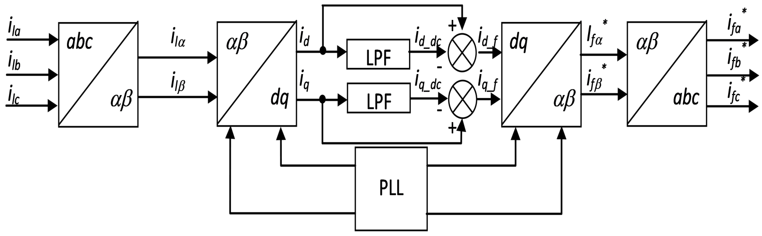

Figure 2: Block diagram of the SRF method.

frame $(\alpha - \beta)$ as shown in equation (1):

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}. \tag{1}$$

The two-phase currents $i_{l\alpha}$ and $i_{l\beta}$ of stationary $(\alpha - \beta)$ axes are transformed in i_d and i_q into a two-phase synchronous frame (d-q axes) employing equation (2), where $cos\theta$ and $sin\theta$ represent the synchronous unit vectors which can be generated using the Phase Locked Loop system (PLL):

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}. \tag{2}$$

So, we see the alternative components $i_{dq\text{-}f}$ can be obtained by subtracting the i_{dq_dc} part from the total d-axis current (i_d and i_q), which leaves behind the harmonic component present in the load current. The inverse Park transformation allowed us to obtain the reference currents of the two-phase stationary frame $i^*_{f,\alpha\beta}$ from the currents of the two-phase stationary frame i_{dq_dc} as shown in equation (3):

$$\begin{bmatrix} i^*_{f\alpha} \\ i^*_{f\beta} \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_{d\_dc} \\ i_{q\_dc} \end{bmatrix}. \tag{3}$$

Finally, the currents of the two-phase stationary frame $i^*_{f,\alpha\beta}$ are transformed back into a three-phase stationary frame and the reference filter currents i^*_{fa}, i^*_{fb} and i^*_{fc} are obtained according to equation (4):

$$\begin{bmatrix} i^*_{fa} \\ i^*_{fb} \\ i^*_{fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*_{f\alpha} \\ i^*_{f\beta} \end{bmatrix}. \tag{4}$$

4 The Photovoltaic Solar Source Description and Modeling

In PV systems, they achieve great performance, fast responses and less fluctuations in steady state for rapid irradiance and/or temperature variation improving the amount of energy effectively extracted from the PV generator [10]. The datasheet of the monocrystalline photovoltaic module of BP SOLAR MSX120 type is given in Table 1.

Technical characteristics	Values
Maximum power : P_{max}	120 W
Open-circuit voltage : V_{OC}	42.1 V
Short-circuit current : I_{SC}	3.87 A
Maximum power voltage : V_{max}	33.7 V
Maximum power current : I_{max}	3.56 A
Number of cells	72
Température coefficient of I_{SC} : k_i	(0.065 ± 0.015) %/°C
Température coefficient of V_{OC} : k_v	-(80 ± 10) $mV/°C$

Table 1: Technical characteristics of the PV module of BP SOLAR MSX120 type.

The model used to simulate the performance of the PV module (group of cells in series) is deduced from the model of the characteristic of a solar cell by the following equation, with z photovoltaic cells connected in series [11, 12]:

$$I_{pv} = I_{ph} - I_0 \left[e^{\frac{q(V_{pv}+z.R_s.I_{pv})}{z.a.k.T_{ck}}} - 1 \right] - \frac{V_{pv} + z.R_s.I_{pv}}{z.R_{sh}}. \tag{5}$$

Figure 3 shows the block diagram of the PV system containing the boost chopper with its MPPT controller by the Perturb and Observe algorithm (PandO).

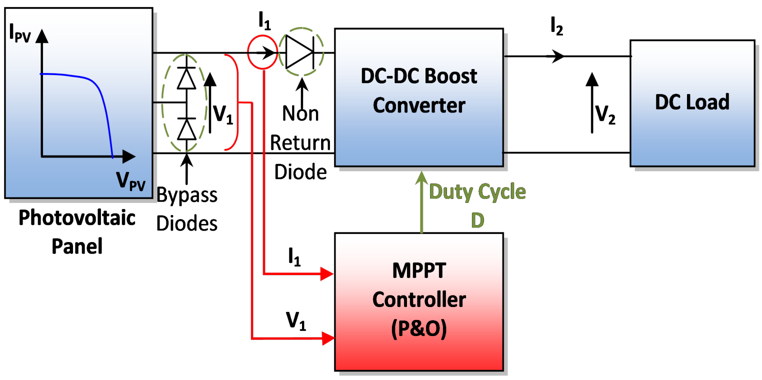

Figure 3: Block diagram of the PV system used.

5 Simulation Results and Discussion

Table 2 shows the parameters of the two-level shunt active filtering system controlled by the Synchronous Reference Frame (SRF) method.

Figure 4 illustrates the two forms of line currents. The first, the load current i_{la} (before filtering up to 0.05 s), and the second, the source current i_{sa} (after filtering up to 0.1 s). We observe in the first part that the non-linear load influences the supply line and distorts the i_{la} wave, which indicates that this line is full of harmonics. We also note in the second part that the electric current began to take its sinusoidal curve i_{sa} after

Parameters	**Values**
Supply voltage $v_S(rms)$ and frequency f	$220V$, 50 Hz
Line's inductance L_s and resistance r_s	19.4 μH, $0.25m\Omega$
DC link's inductance L_{dc}, and resistance r_{dc}	15 mH, 4 Ω
Load inductance L_l and resistance r_l	0.3 mH, 0.3 Ω
DC link voltage V_{dc}	$620V$
Coupling inductance L_{fa} and resistance r_{fa}	1.22 mH, 0.2 Ω

Table 2: Parameters of the shunt active filtering system controlled by the Synchronous Reference Frame (SRF) method.

it had passed the transient phase in the time of 0.07 seconds. This indicates that the SAPF has almost completely eliminated impurities.

The THD of the load current i_{la} shown in Figure 5 is high (23.56 %) and would be rejected by the energy supplier. It also affects the non-linear load (devices malfunction). We also see that the harmonics of order $(6h \pm 1)$ appeared because of the use of the non-linear load (the rectifier).

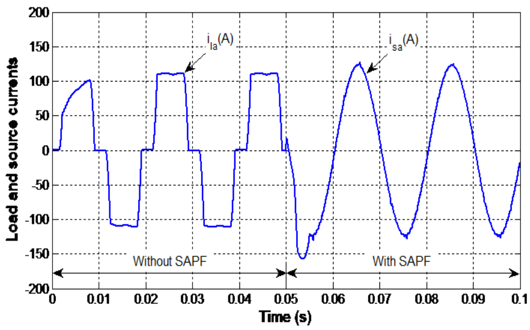

Figure 4: Load and source currents of the SAPF system supplied by a PV source.

In Figure 6, we can clearly see the harmonics decrease by the THD ratio of the source current i_{sa} equal to 1.16 %, which is very acceptable.

Figure 7 shows the three currents of the shunt active filtering system. Before the insertion of the SAPF, the line current is deformed, it is the load current i_{la} only. After closing the breaker at the time of 0.05 s, the filter current intervenes and compensates for the line current and becomes almost sinusoidal source current i_{sa}.

The two stages of the filter current i_{fa} and its reference i^*_{fa} are shown in Figure 8. At the breaker closing time (at 0.05 s), the filter current follows the trajectory of its reference produced by the SRF block, especially in the permanent state. This means that the error is almost zero.

The DC link voltage V_{dc} which supplies the inverter is shown in Figure 9. Its value increases from 351.2 V without the SAPF to 620 V with the SAPF. Note that the value stabilizes just after the transient regime in each part.

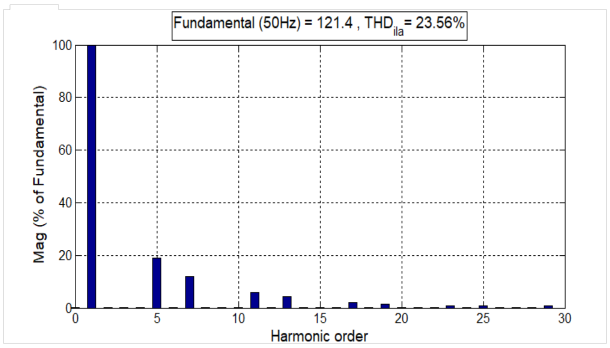

Figure 5: Total Harmonic Distortion of the load current before applying the SAPF.

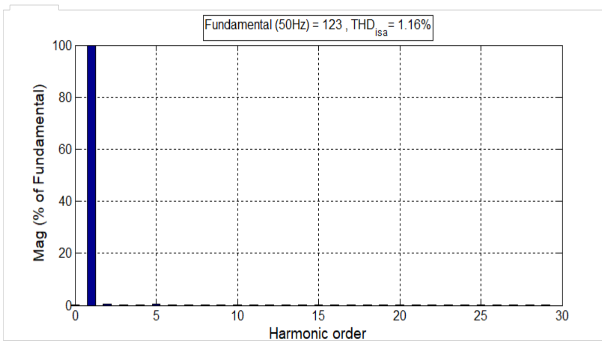

Figure 6: Total Harmonic Distortion of the source current after applying the SAPF.

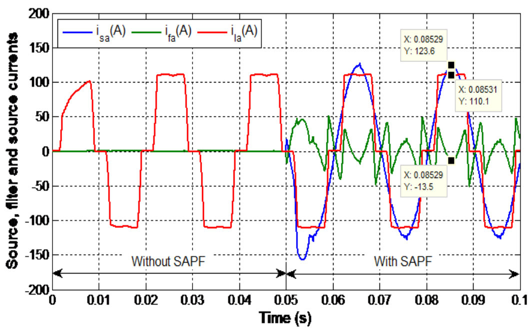

Figure 7: Different currents before and after the insertion of the SAPF.

6 Conclusion

In this paper, we studied the identification by the Synchronous Referential Frame method (SRF) on the one hand and the optimization of the energy which feeds the inverter by

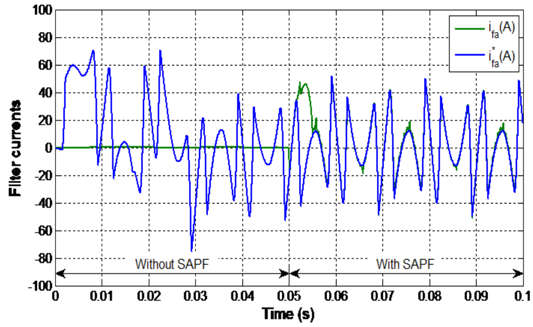

Figure 8: Filter current and its reference before and after the insertion of the SAPF.

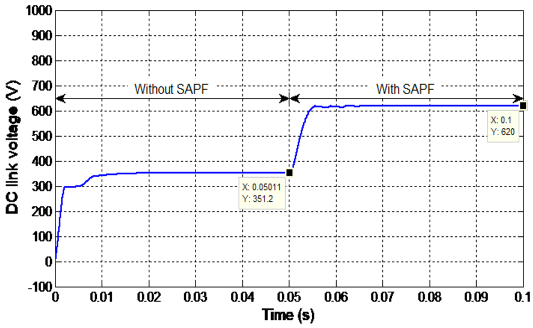

Figure 9: DC link voltage before and after the insertion of the SAPF.

the MPPT controller on the other hand, we can say that the quality of the compensation of current harmonics depends on the performance of the chosen identification method. The simulation results have shown the efficiency of the SAPF powered by a photovoltaic generator and controlled by the SRF technique and offering good results from the THD of the current on the source side, so the power factor is close to unity. This implies that the conditions of the international recommendation IEEE519-92 are well verified.

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