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Study and Simulation of a Shunt Active Power Filter powered by a Photovoltaic Source Controlled by Sliding Mode

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Abstract

The development of energies from renewable sources and the increase in electricity consumption will require new solutions to maintain the levels of service, quality of voltage and availability of electricity networks. A tailor made role for power electronics.

The objective of this work on this paper is the remediation of the problem caused by the injection of harmonics discharged by the non-linear load (i.e. by the rectifier in our case). This remediation consists in reducing as much as possible the impurities diffused in the electrical network. For this we used a Shunt Active Power Filter (SAPF) as a perfect solution by eliminating all harmonics one by one. In this article, we have proposed a control technique on the voltage inverter, it is the technique "Synchronous Reference Frame -SRF" and an MPPT regulator on the photovoltaic generator which is used as a continuous source of the SAPF, it is the "Sliding Mode Control- SMC" technique. The simulation results obtained under MATLAB / Simulink clearly showed us that the system sizing choices, as well as the control techniques are efficient and according to the international standard recommendations IEEE519-92 (The total Harmonic Distortion is less than 5 percent).

Keywords: Photovoltaic Generator, Sliding Mode Control, Shunt Active Power Filter, Synchronous Reference Frame

1. Introduction

The increasing demographic populations with technological developments in this day are keen to induce sufficient energy and ensure its quality.

The electric charge, whatever its type of change (non-linear load or change in the parameters of the electrical network) is very important for the quality of electrical energy, especially with the implementation of renewable energies (solar, wind, hydraulic biomass, geothermal, etc.)
Because of these conditions, this load influences the power grid by injecting harmonics, reactive energy and malfunctioning electrical devices such as transformers, rectifiers, electric motors, etc [1-2].
One of the most important impacts regarding the quality of electrical power is the harmonics we have talked about. These harmonics do not have the same frequencies and the same amplitudes; in addition to that, they are mixed with the fundamental. There are two types of harmonics, voltage and current. The latter is the most important since it has negative effects on power supply lines [1-3].

2. Shunt Active Power Filter

The power supply of the shunt active power filter is provided by a direct voltage source or by an expensive capacitor [4].
In this article, we take advantage of the sun as a free, clean and inexhaustible source to produce photovoltaic solar energy by the solar sensor.
In order to keep constant DC voltage of solar PV panel and follow the reference value, we applying sliding mode regulator for maximum power point tracking (MPPT) to a static DC-DC converter. The three-phase two-level inverter is controlled by the PWM technique in series with the RSF method as shown in Figure 1.

3. Sliding Mode Control of the MPPT

For photovoltaic systems, the most important stage is the pursuit of the point of maximum power. For that, the convergence towards zero is made by the MPPT command of the DC-DC converter by the derivative of the power compared to the voltage [5]. The duty cycle injected into the converter is extracted directly by the sliding mode control as shown in Figure 2 [6].

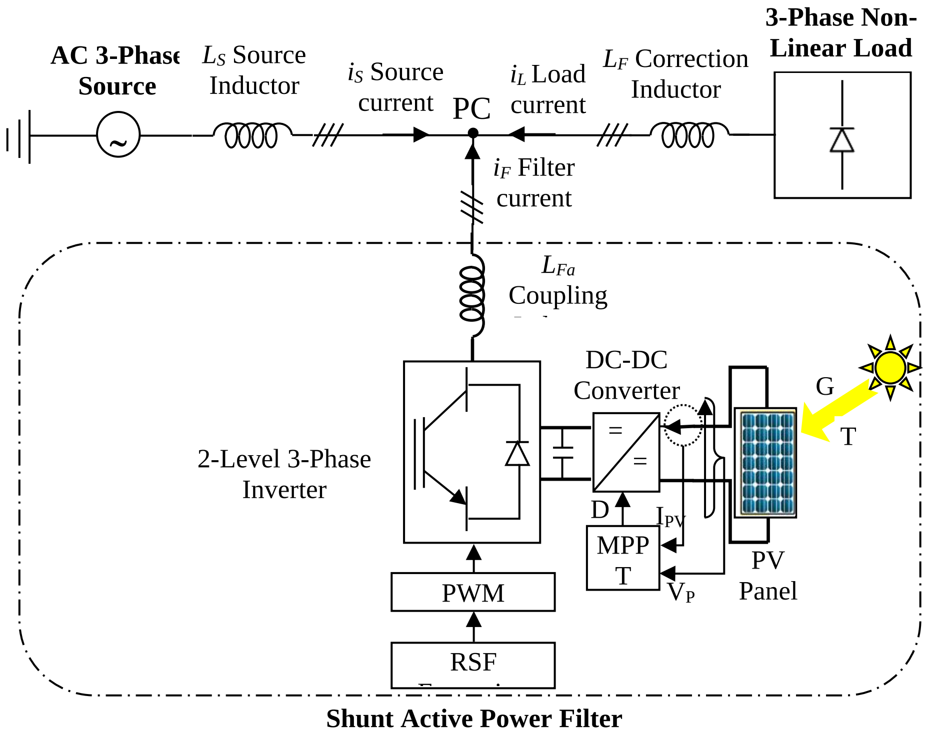

Fig 1. Shunt Active Power Filter structure

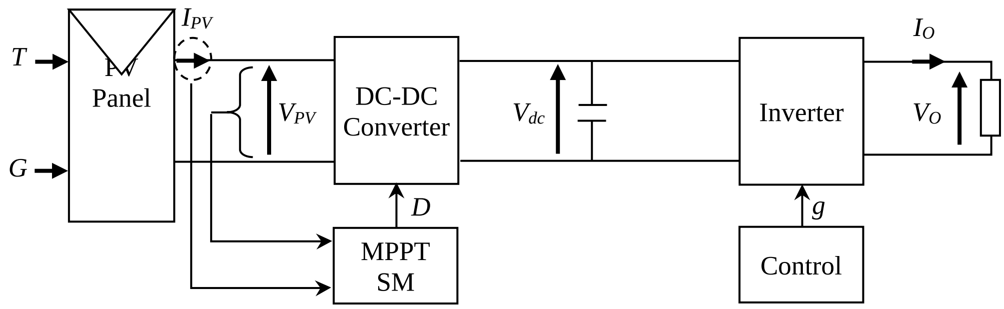

Fig 2. Block diagram of the Sliding Mode Control for a PV System

The diagram of a switching structure at the level of the control unit is given in Figure 3. This control structure is the most classic and the most used.

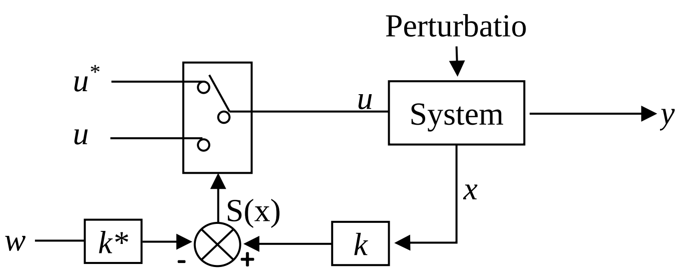

Fig 3. Regulation structure by switching at the level of the control unit

A possible choice of the structure of a sliding mode controller is:

$$U = U_{eq} + k \cdot \sin g(S) \tag{1}$$

with:

• U_{eq} : represents the equivalent command which expresses the movement of the state trajectory along the switching surface ;

• K : represents the maximum output of the regulator required to overcome the uncertainties and disturbances of the parameters (it is a constant value) ;

• S : represents the switching function (i.e. the control action switches its sign on both sides of the switching surface).

The expression of a sliding mode regulator is given by:

$$U = D(k+1), U_{eq} = D(k) \tag{2}$$

with $D(k)$ and $D(k+1)$ are the duty cycle a time (k) and ($k+1$) respectively [7,8].

S is defined as follows:

$$\frac{p_{pv}(k) - p_{pv}(k-1)}{I_L(k) - I_L(k-1)} = 0 \tag{3}$$

and:

$$\frac{p_{pv}(k) - P_{PV}(k-1)}{I_L(k) - I_L(k-1)} = \frac{I_L(k)^2 R_{pv}(k) - I_L(k)^2 R_{PV}(k-1)}{I_L(k) - I_L(k-1)}$$

$$= I_L(k)\left((2R_{PV}(k) + I_L(k)\frac{R_{PV}(k) - R_{PV}(k-1)}{I_L(k) - I_L(k-1)}\right) = 0$$

$$=> 2R_{PV}(k) + I_{PV}(k)\frac{R_{PV}(k) - R_{PV}(k-1)}{I_L(k) - I_L(k-1)} = 0 \tag{4}$$

To ensure the correct functioning of the system around the point, the sliding surface must be chosen equal to zero. The resistance at the terminals of the photovoltaic field that is given by:

$$R_{PV}(k) = \frac{V_{PV(k)}}{I_L(k)}, \tag{5}$$

In order to obtain an equivalent command (u_{eq}) proposed by (6).

$$s_u(\mathrm{k}) = 2R_{PV}(k) + I_L(k)\frac{R_{PV}(k) - R_{PV}(k-1)}{I_L(k) - I_L(k-1)} \tag{6}$$

The equivalent command is to terminate from the following condition:

$$u_{eq} = 1 - \frac{V_{pv(IL)}}{V_{out}} = \mathrm{D(k)} \tag{7}$$

As the interval of the duty cycle must be $0 \leq \mathrm{D(k)} \leq 1$.

The actual control signal is offered as:

$$\mathrm{D(k+1)} = \begin{cases} 1 \quad D(k) + k * sing(su) \geq 1 \\ D(k) + +k * sing(su) \ \text{ dans le reste} \\ 0 \quad D(k) + k * sing(su) \geq 1 \end{cases} \tag{8}$$

Thus, the algorithm which corresponds to this method is represented in Figure 4:

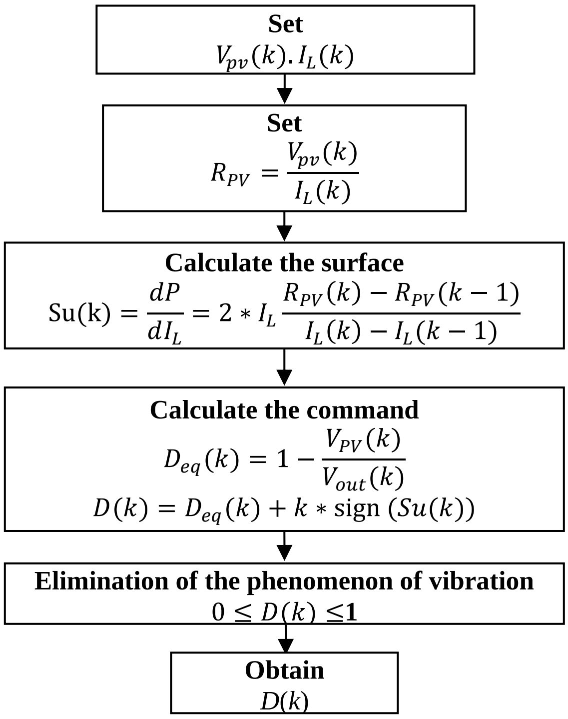

Fig 4. Sliding Mode Control of the MPPT

4. Conventional Synchronous Reference Frame

Among the techniques for extracting the reference harmonic currents, we find the SRF technique which is based on the time domain in which the three-phase load currents in a stationary frame (abc) transform into two-phase direct (d) and quadrature (q) via a low pass filter as shown in Figure 5 [9].

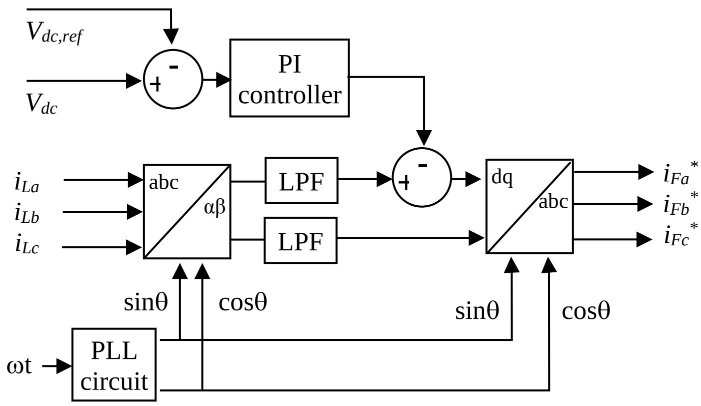

Fig 5. SRF method for reference current generation

The transformation process is summarized as [10]:

$$\begin{bmatrix} I_{Ld} \\ I_{Lq} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega t) & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos(\omega t) & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \times \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \tag{9}$$

With the angular position of the frame dq is represented by the transformation angle ωt. The harmonic currents injected by the nonlinear loads pollute the load currents in the dq frame (I_{Ld} and I_{Lq}) which are expressed by :

$$\begin{bmatrix} I_{Ld} \\ I_{Lq} \end{bmatrix} = \begin{bmatrix} I_{Ld(dc)} + I_{Ld(ac)} \\ I_{Lq(dc)} + I_{Lq(ac)} \end{bmatrix} \tag{10}$$

or,

$$\begin{bmatrix} I_{Ld(ac)} \\ I_{Lq(ac)} \end{bmatrix} = \begin{bmatrix} I_{Ld} - I_{Ld(dc)} \\ I_{Lq} - I_{Lq(dc)} \end{bmatrix} \tag{11}$$

The fundamental and harmonic currents of the load current in the *d* and *q* frames are represented by $I_{Ld(dc)}$ and $I_{Ld(ac)}$ respectively.

To obtain the reference currents, it is necessary to extract harmonic currents by alternating components in the two frames d and q. By using the conventional method, and by means of the indirect detection technique [11], the reference currents expressed in (12) are obtained. Using a digital low pass filter (LPF) with the suppression of the DC components detected from the real components I_{Ld} and I_{Lq}, the DC components of the respective reference currents are detected.

$$\begin{bmatrix} i_{Fa}^* \\ i_{Fb}^* \\ i_{Fc}^* \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & \cos(\omega t) \\ \sin(\omega t - \frac{2\pi}{3}) & \cos(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t + \frac{2\pi}{3} & \cos(\omega t + \frac{2\pi}{3} \end{bmatrix} \times \begin{bmatrix} I_{Ld(ac)} \\ I_{Lq(ac)} \end{bmatrix} \tag{12}$$

5. Results and discussions

The simulation results of the Shunt Active Power Filtering system proposed under MATLAB / Simulink are shown in Figures 6 to 15.

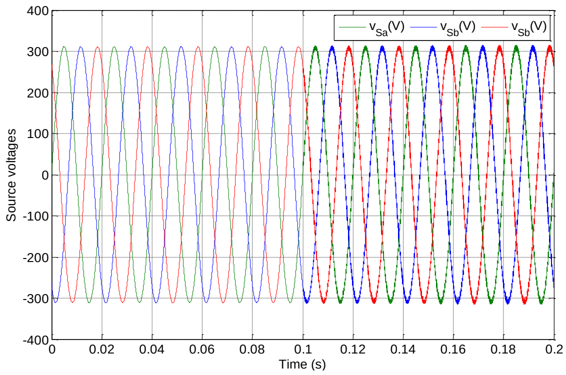

Fig 6. Source voltages without and with SAPF

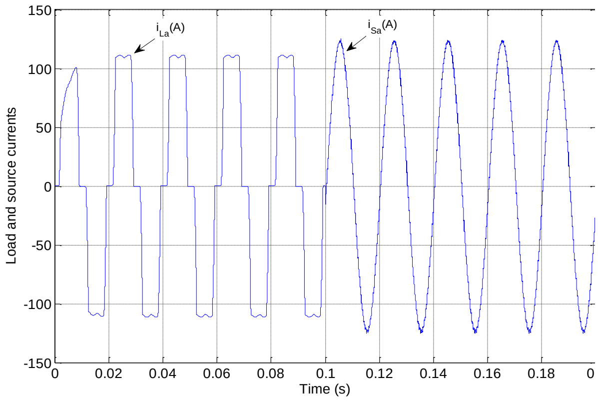

Fig 7. Load and source currents without and with SAPF

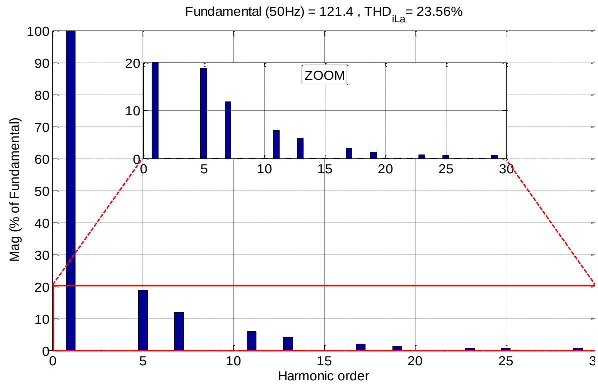

Fig 8. Spectral analysis of load current

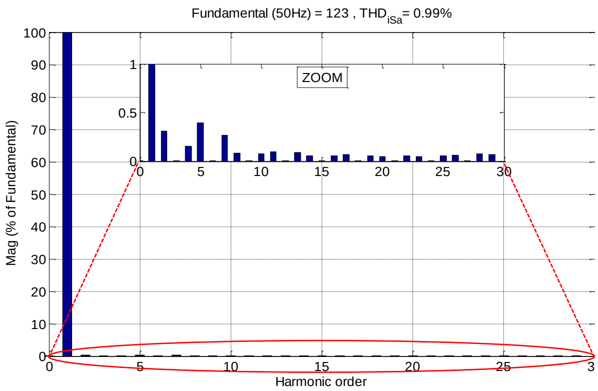

Fig 9. Spectral analysis of source current

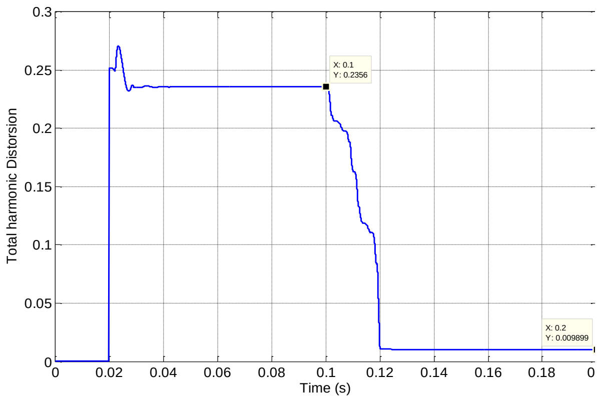

Fig 10. Temporal pattern of the THD without and with SAPF

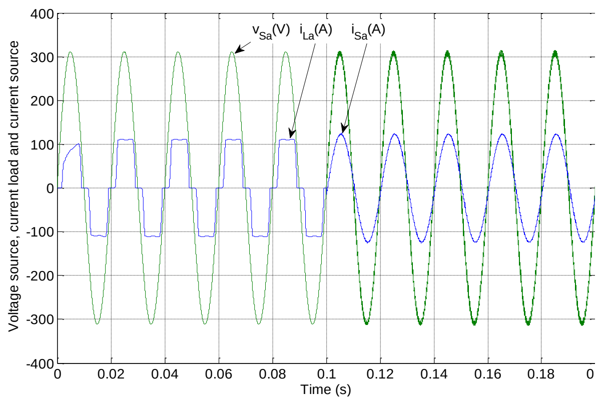

Fig 11. Phase shift between load and source currents and source voltage

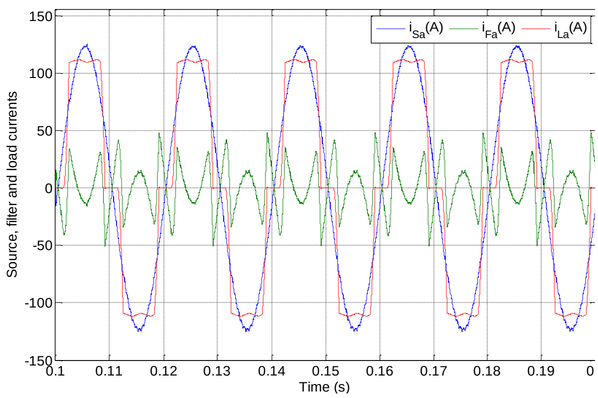

Fig 12. Forms of source, filter and load currents

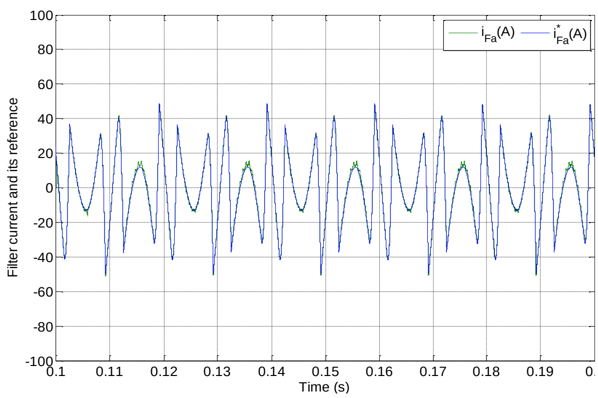

Fig 13. Forms of filter current and its reference

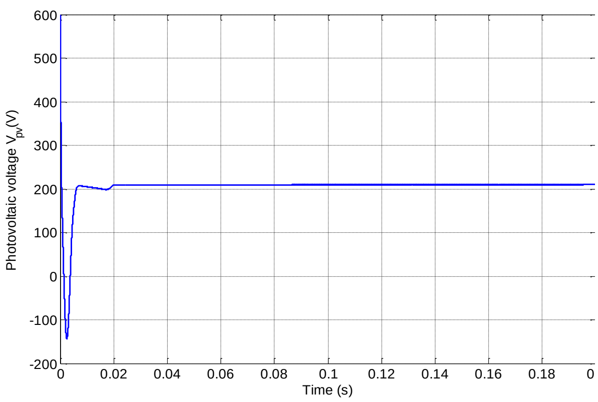

Fig 14. Form of photovoltaic voltage

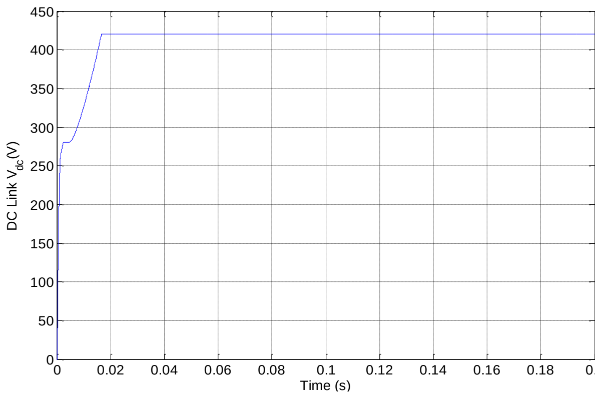

Fig 15. Form of DC link voltage

Figure 6 shows the three source voltages v_{sa}, v_{sb} and v_{sc} offset from each other by 2π/3 and their amplitudes of value 310 V. We notice that the system keeps almost the same sinusoidal form whether it is before or after active power filtering.

Figure 7 shows the two load and source currents before and then after SAPF respectively. We can clearly see that after closing the breaker at time 0.1 s, the line current has improved and becomes quasi-sinusoidal due to the intervention of the SAPF.

Figures 8 and 9 represent the spectral analyzes of the load current which carries a very high THD with a value of 23.56%, this value is unacceptable by the supplier of the electrical network then by the source current which carries a lower THD with a value of 0.99 %, this value is acceptable because it is less than 5%.

Figure 10 shows the two previous THDs but as a function of time.

Figure 11 shows the phase shift between load i_{La} and source i_{Sa} currents and source voltage v_{Sa}. The phase shift between i_{La} and v_{Sa} is a bit big compared to i_{Sa} and v_{Sa}. This means that the power factor is improved and converges towards unity.

The waveforms of the source, the filter and the load currents are shown in the Figure 12. This Figure clearly show us that the sum of the load and filter currents is the source current, it is the harmonic compensation.

Figure 13 shows the forms of the filter current i_{Fa} and its reference i_{Fa}^*. We see that i_{Fa} almost absolutely follows the path of i_{Fa}^*, which means that the error e tends to zero.

Figure 14 shows the form of photovoltaic voltage V_{pv} with the system in function. The system stabilizes at the value of 210 V.

Finally, Figure 14 shows the form of DC link voltage V_{dc}. The system stabilizes at the value of 420 V in output the DC-DC converter.

6. Conclusion

The uses of nonlinear loads are widely used in the grid-connected electrical system, which induces great problems in the power source lines on the one hand, such as harmonics which distorts the signals of electric currents and the malfunction of the load itself on the other hand. The system proposed in this article is very effective and feasible to remedy these problems. This is the parallel active power filtering system controlled by the SRF technique mounted in series with the PWM control. The continuous source of the inverter is provided by a photovoltaic system of good choice and an MPPT regulator which is cost-effective, it is the sliding mode regulator. As the simulation results show us using the MATLAB / Simulink tool, the filtering system used gives better performance whether the source currents become sinusoidal (i.e. the THD_{iSa} is less than 5% according to international recommendations IEEE 519-92 and the power factor tends towards unit), and that it is the PV system that plays the role of continuous source of the SAPF.

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8. References

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