

Harmonic Mitigation in Electrical Grid Connected Renewable Energy Sources

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Abstract - This paper presents the photovoltaic system connected to electrical grid with the presence of non-linear load (three-phase rectifier) in the first case, then tries to minimize the harmonic currents generated by this non-linear load with applying the technology of the shunt active power filter (SAPF). In this work, we use the MPPT controller for the Boost converter, the PWM command for the three-phase inverter and, with regard to the shunt active filter, we have chosen the PQ theory for harmonic currents identification, and hysteresis control for the inverter, and the PI controller for the DC bus. The simulation results obtained show the efficiency of this moderne technique given the waveforms of the currents obtained which are very close to the sinusoid shape, and the values of the calculated total harmonic distortion (THD) rates which are in the standard norms.

Keywords— Active Power Filter, Electric Grid, Harmonics, Power Quality ; PV System, MPTT , THD

1. INTRODUCTION

Renewable energy sources (RES) are rapidly gaining an important place in sustainable electricity production because they are less polluting and use resources that are always readily available [1]. Renewable energy sources, which should be a promising alternative energy source, can pose new challenges when connected to electricity grids. In recent years, solar energy has become one of the most important sources of energy in the worlds largest renewable, which requires additional transmission capacity and better ways to maintain system reliability [2],[3]. The integration of renewable energies with traditional conventional power grids plays a predominant role in distributed generation systems and especially photovoltaic systems connected to the low voltage grid (dealt with in our works) are particularly popular [5],[6].

The rapid growth in the use of non-linear loads and their generalization in power grids such as use of electronic equipment, information technology equipment, power electronics used in many applications, energy-efficient lighting, led to a complete change of electric loads nature. These loads are the major causers of deterioration of the power quality (power quality problems) [7].

Due to their non-linearity, all these loads cause disturbances in the voltage/current waveforms [8], [9]. A load is define as a non-linear if it fed by a sinusoidal voltage, but the current absorbed by this load no sinusoidal, this type of loads receiver generates harmonic currents [10], [11].

In this paper, we analyze a three-phase rectifier as a nonlinear load connected with the system of integration

studied. To deal with the problems of harmonic currents, as well as how to reduce them, the shunt active filter (SFAP) is an interesting alternative. In our work, we present three simulations scenarios (we use MATLAB simulink) : the first is to simulate the system of integration without the non-linear load, the second is to simulate the integration system with the polluting load (PD3), the third encompasses the two preceding scenarios with the association of the shunt active filter. In each scenario, we focus on waveforms of currents that propagate in the PV system (PV current), and currents that propagate into the grid (grid current).

Our goal is summarized in the analysis of the quality of the waveforms of currents and harmonics while determining the values of the total harmonic distortion rates (THD) that exist in each scenario and see its harmonic spectrum.

2. SYSTEM DESCRIPTION

The structure of the integration system studied is shown in Figure 1.

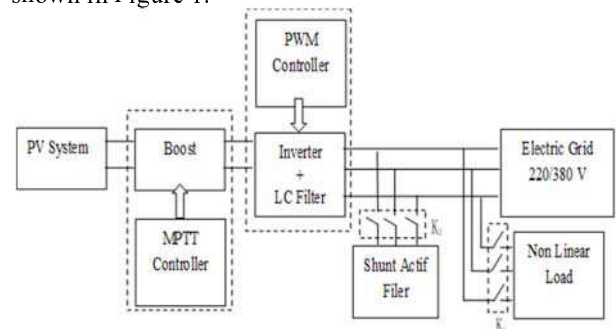


Fig. 1 Studied System

2.1. The Photovoltaic System

A photovoltaic field based on MSX 60W PV panels is considered and simulated from a modeling of the elementary cell with a single diode shown in Figure 2. The photovoltaic cell is like a generator of electric current whose behavior is equivalent to a current source in bypass with a diode. Several cells are connected in series and in parallel for constitute a PV panel, hence the presence of two resistors, series and parallel, which model the loss of contact and parasite in the PV module respectively [1,9]. In order to obtain a generalized mathematical model of a GPV, all the losses caused by the association of the panels serial and parallel are included, which allows to obtain the following equation.

$$I = N_{pp}I_p - N_{pp}I_0 \left[\exp\left(\frac{V + R_s I (N_{ss}/N_{pp})}{V_t d N_{ss}}\right) - 1 \right] - \frac{V + R_s I (N_{ss}/N_{pp})}{R_p (N_{ss}/N_{pp})} \quad (1)$$

Where :

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

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

a : diode constant

In our work we use series and parallel associations of 11,8 kW connected to a network of 220 / 380V.

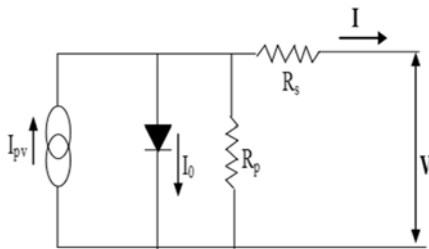


Fig. 2 Model of a photovoltaic solar panel

2.2. The Boost converter

A boost converter is a switching power supply that converts a DC voltage into another DC voltage of higher value [5], [8].

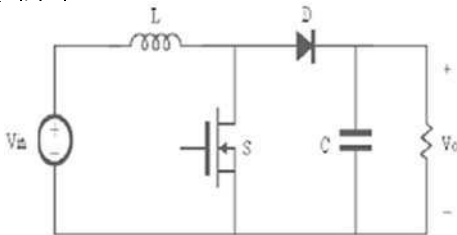


Fig. 3 The Boost Converter

2.3. MPPT Controller

The extraction of the maximum power is a step essential in the field of energy conversion of photovoltaic solar system. To increase the yield of the GPV, a maximum power point tracking (MPPT) is applied to the DC / DC converter (Local MPPT) in the case of a dual power stage and to the DC / AC (global MPPT) converter with a single stage conversion. In this article we use P&O

method with one of the popular methods to track the maximum power point and probably the most frequently used in practice for its simplicity and ease implementation in real time [5], [8].

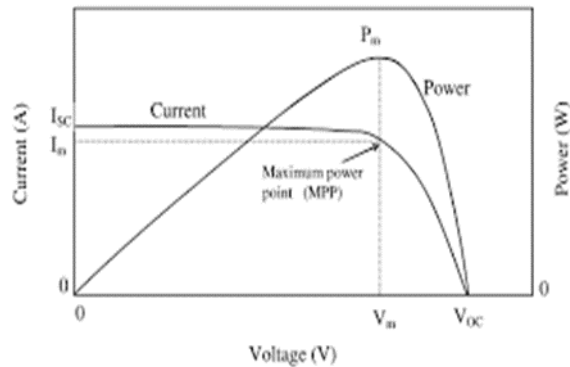


Fig. 4 (I-V) ,(P-V) Curves and MPPT

The algorithm is based on the disruption and observation of the voltage of the photovoltaic panel until optimal power is achieved with a fixed disturbance step such as the describes the flowchart of Figure 5.

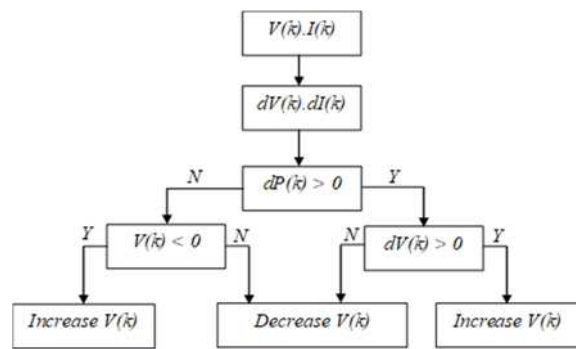


Fig. 5 Algorithm P&O

2.4. The inverter

The inverter is a static converter that allows the transformation of the continuous type energy into an alternative energy. The form of the voltage of the output of the inverter must be closer to a sinusoid, is that the harmonic rate is very low, and it depends mainly on the control technique used. The PWM command used for this inverter is intended to allow the best reproduction of the reference currents, thanks to the control commands applied to the power switches. On the other hand this control is used to push the harmonics to the higher frequencies for improves the quality of the current [6,7].

2.5. The Filter

It is necessary to use a connection filter of inductive nature (L or LCL) the function of this filter makes it possible, on the one hand, to convert the compensator into a current dipole from the point of view of the network. And on the other hand to reduce the dynamics of the current. In order to make it easier to control.

The filter LC eliminates switching harmonics. To be able to connect the voltage inverter in parallel with the network and make it work as a power source.

The type filter (L) reduces the harmonics around the switching frequency. To achieve this, the value of this inductor must be relatively high [7].

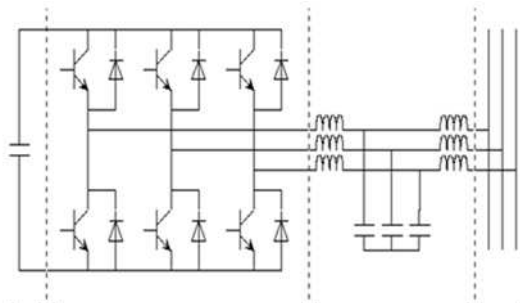


Fig. 6 Three phase inverter and filter

2.6. The non-linear load

We use a three-phase rectifier PD3 diodes charging on a load RL which absorbs non-sinusoidal currents which degrades the power quality.

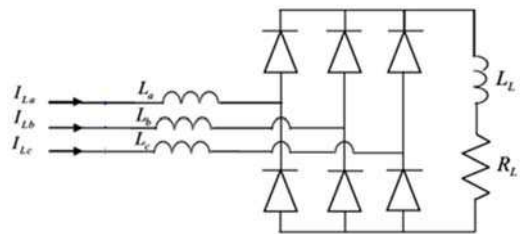


Fig. 7 Non-linear Load

2.7. Electric Grid 220/380

With a frequency $f = 50$ Hz connected to the balanced load RL type smoothing filter.

2.8. The shunt active power filter (SAPF)

This filter injects into the network disturbing currents equal to those absorbed by the polluting charge, but in phase opposition with these. The grid side current is then sinusoidal. Thus the objective of the shunt active power filter is to prevent the harmonic currents produced by polluting loads, to flow through the impedance of the network, located upstream of the connection point of this filter. The instantaneous real and imaginary powers (PQ) method was used to generate the reference currents, the hysteresis control for the inverter, and a proportional regulator (PI) to control the DC bus.

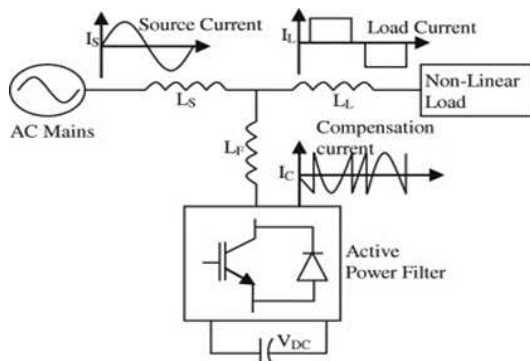


Fig. 8 Proposed Shunt Active Power Filter

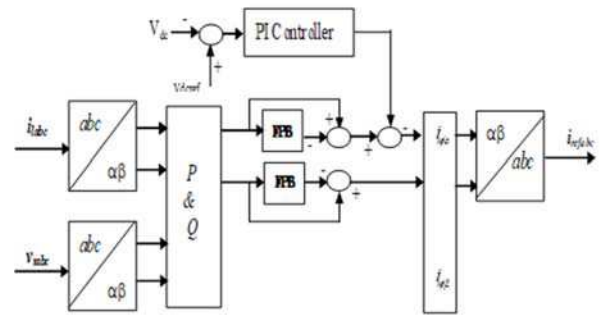


Fig. 9 PQ Theory with PI controller

3. SIMULATION RESULTS

3.1. Simulation Results of scenario 1

We focused in this simulations on the analysis of the propagation of currents in the integrated system renewable energies (in our case solar energy) in electric grid and ; that is to say the currents that propagate into the electrical grid (called Grid current), and the currents that propagate into the field of the photovoltaic system (called PV current).

In the following figures we present the waveforms of these currents, as well as their harmonic spectrum and value of total harmonic distortion rates obtained (THD).

(Case 1 : K_1 open & K_2 open in figure 1).

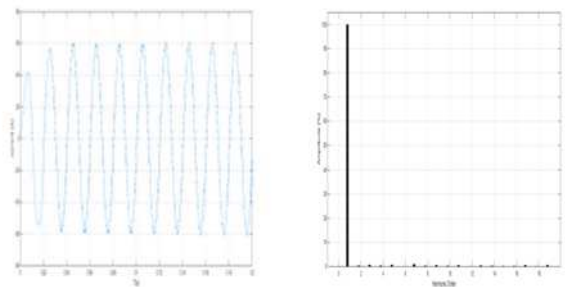


Fig. 10 PV current and its harmonic spectrum

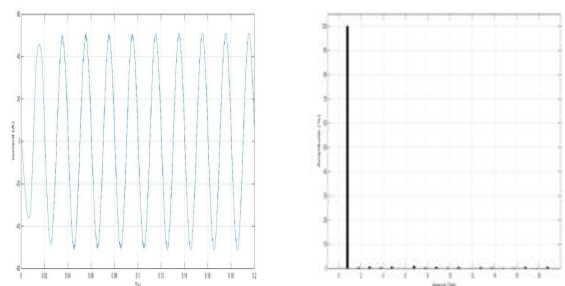


Figure 11 : Grid current and its harmonic spectrum

Table 1 – Total Harmonic Distorsion

TOTAL HARMONIC DISTORSION	THDI(%)
GRID CURRENT	2.98 %
PV current	3.15 %
IEEE512-1992	5 %

In the simulation results we find that the waveforms of currents either that they propagate into the electrical

grid or that they propagate into the photovoltaic field are acceptable, and close to the sinusoid.

The total harmonic distortion rates of the currents calculated (THDi) are below the IEEE 512-1992 standard (**5%**), where we note **2.98%** and **3.15%** (Table 1).

We can generalize these results obtained by the non-existence of a non-linear load, and also the LCL filter which minimizes the large disturbances due to the different commutations, and the PWM control of the three-phase inverter which interest in pushing harmonics back to higher frequencies.

3.2. Simulations Results of scenario 2

We present in the following figures the waveforms of currents (Grid & PV), as well as their harmonic spectrum and their total harmonic distortion rates obtained in the presence of a non linear load (three phase rectifier PD3).

(Case 2 : K_1 close & K_2 close in figure 1).

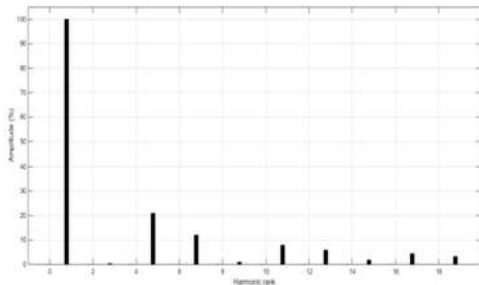


Fig.12 Harmonic Spectrum of PD3

Table 2 – Harmonic Currents & THD of PD3

THDi [%]	Characteristic harmonics [%]			
	h_5	h_7	h_{11}	h_{13}
27.23	20.92	12.01	7.89	5.83

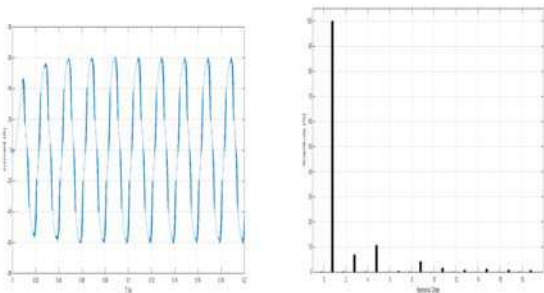


Fig. 13 PV current and its harmonic spectrum

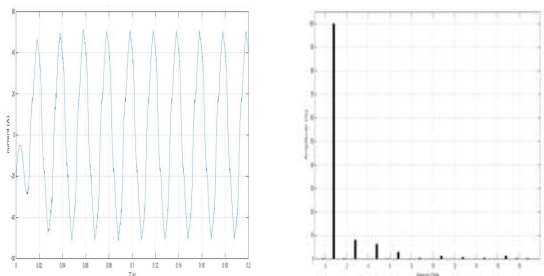


Fig. 14 Grid current and its harmonic spectrum

Table 3 – Total Harmonic Distorsion

	THDi [%]	Characteristic harmonics [%]			
		h_5	h_7	h_{11}	h_{13}
Grid current	12.57	10.68	0.39	1.56	0.84
PV current	11.57	5.19	2.41	1.03	0.57
IEEE512-1992	5	4	4	4	2

In the simulations results obtained we clearly notice the degradation of the waveform of the current either propagating towards the PV system, or that it propagates towards the electrical grid and it essentially returns to the existence of the non linear load that injects disturbances (see table .2).

From table 3 we shows that the total harmonic distortion rate of the currents exceed the standard used, **11.57%** for the PV current and **12.57%** for the Grid current. However, for the characteristic harmonics we note that the harmonic 5 exceeds the norm, but the others remain below the norm. The photovoltaic system plays a harmonic compensation role with the control of the inverter (PWM), and the LCL filter but remains insufficient (see table 3), where we notice a decrease in the overall distortion rate as well as the percentages of the characteristic harmonics injected by the non-linear load.

3.3. Simulation Results of scenario 3

We present in the following figures the waveforms of PV current, and Grid current, as well as their harmonic spectrum and their total harmonic distortion rates obtained by combining a shunt active power filter, and with the presence of a non-linear load (three-phase rectifier PD3).

(Case 3 : K_1 close & K_2 close in figure 1).

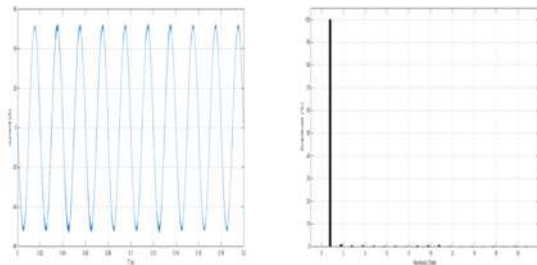


Fig.15 PV current and its harmonic spectrum

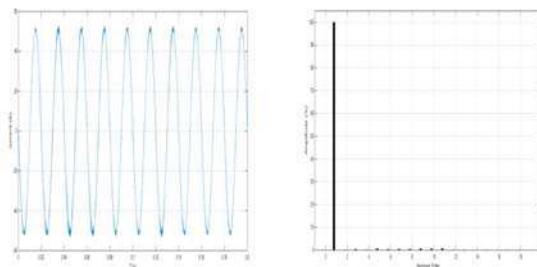


Fig.16 Grid current and its harmonic spectrum

Table 4 – Total Harmonic Distorsion

	THDi [%]	Characteristic harmonics [%]			
		h_5	h_7	h_{11}	h_{13}
Grid current	1.56	0.28	0.26	0.59	0.06
PV current	1.91	0.6	0.39	0.6	0.1
IEEE512-1992	5	4	4	4	2

In the obtained simulation results we notice big improvements on the waveforms of the electric currents propagated (into the PV field , and into the electric grid); and their wayforms become very close to a sinusoid.

From Table 4 it can be seen that the total harmonic distortion rate of the currents decreases completely, where we note **1.91%** for the current PV and **1.56%** for the Grid current , and they are lower than the norm used, and the same thing for all the characteristic harmonics (5,7,11 and 13). The advantage of the use of the active filtering is a total elimination of the harmonic disturbances, and all the phenomena which degrade the power quality even in the case where there are changes of the load, or change of the conditions climate; therefore our SAPF fully adapts with these changes, and we note that the risk of the appearance of the phenomenon of resonance is zero.

4. CONCLUSION

In this article, we presented the operation of Electrical Grid Connected Renewable Energy Sources (solar energy) .To better study the impact of power quality; we have applied three simulations scenarios: the first is to simulate the integration of the photovoltaic system connected to the electric grid (low voltage).The second scenario consists in simulating the previous integration but with the presence of the pollutant load (PD3 rectifier). The third is to simulate all the integration of scenario number 2 with addition the shunt active power filter (SAPF).

In all these simulations we concentrate on the quality of the current circulating in the different directions (to the PV field , and to the electric grid). The results of the last simulation give us a better quality of the current, and a minimum value of the THD at below the standard used; so we can say that our method is very efficient and well successful.

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