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PV integrated series active filter for sag voltage and harmonic compensation

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ABSTRACT

The use of loads in the past few days is becoming vast, giving an alarm signal to the power system and electronics engineers in terms of power quality. Due to the large amount of non-linear power electronics, utilities frequently experience voltage and harmonic distortions every day. In this paper, the combination of the Series active power filter SAPF with a PV source is deliberated. The PV based on the SAPF aims to compensate voltage deviations or disturbances that occur in the system caused by power quality issues. The proposed system consists of a PV source connected to the DC link through two dc-dc converters, the first extracts the maximum power of the PV source through pulse with modulation PWM signals generated from the maximum power point tracker MPPT controller. Thus, the second converter is used to regulate the high voltage side of the converter through closed control loops using Fuzzy Logic Controller FLC, in addition to a voltage source inverter VSI and a series injection transformer. Despite of fluctuations of the DC link during the compensation of the needed energy, MPPT and closed control loops generate PWM signals to the switching devices of dc-dc boost converters in order to extract maximum PV power and to maintain the bus voltage within its limits and around its reference values respectively. The proposed topology is simulated in Matlab Simulink software, where simulation results show that the proposed PV based SAPF can efficiently reduce problems of voltage sag and harmonic.

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1. INTRODUCTION

Power supply and energy quality have been critical issues in power systems recently. The photovoltaic generator (PV) connected to the grid is becoming increasingly popular because of its reliable performance and its ability to generate energy from clean energy resources [1]. The continuous output voltage of the photovoltaic panels is connected to a DC / DC boost converter using a maximum power point tracking controller (MPPT) to maximize the energy produced [2]. The development of a means to compensate for disturbances in the distribution system is also urgent. In this case, the photovoltaic generators must provide the utility with a distorted compensation capacity, which makes the currents injected / absorbed by the utility to be sinusoidal [3]. Therefore, the compensation function can be performed by an fexible control of dc/ac VSC.The proliferation of electronic equipment pollutes electricity distribution networks with harmonics, distorting waveforms of voltage and current. At the same time, the user monitors the impact of excessive warming and accelerated aging on the electrical installations of the electrical equipment. This phenomenon has another influence on the operation of the application; In addition, it has a direct influence on the supply of sensitive loads. Finally, this has an impact on the electrical power available in the installation because there is overconsumption due to harmonics [4, 5]. The serial active filter (SAPF) is used and implanted between the delivery point (PCC) and the load to be protected. So we can say that the active filter series (SAPF) is a solution adapted to the compensation of disturbing voltages, harmonics [6]. In this study, an SAPF was adopted and modeled to improve power quality influenced by disturbances. The proposed system is powered by the PV containing a combination of two serial boosts, sharing a common DC voltage generated by the PV. The document is organized as follows: The configuration of SAPF powered by the PV will be presented in section 2. It also highlights the required units such as power source, linear load, SAPF and control engineering algorithms. Then, the main results of the simulation, current and voltage waveforms and THD analyzes will be discussed in section 3. Finally, the document will be completed by the concluding remarks.

2. DESCRIPTION SYSTEM

2.1. Principle of operation

The serial active filter is coupled in series with the load. It is regulated in order to reach the disturbed and essential harmonic voltages of the load [7-10]. Therefore, the utility wants to provide only the active part of the fundamental element of the charging current, which avoids the problems of energy pollution along the power line. In this proposed system, solar energy is integrated into the SAPF system to maintain its capacitor voltage. This type of configuration works both in interconnected mode and in isolated mode. Figure 1 shows the general block diagram of the integrated PV SAPF system. The main purpose of using PV in SAPF is: The capacitor voltage must be kept within its limits for stable and continuous operation of the voltage source inverter and also to eliminate the difficulty related to variable DC bus voltage.

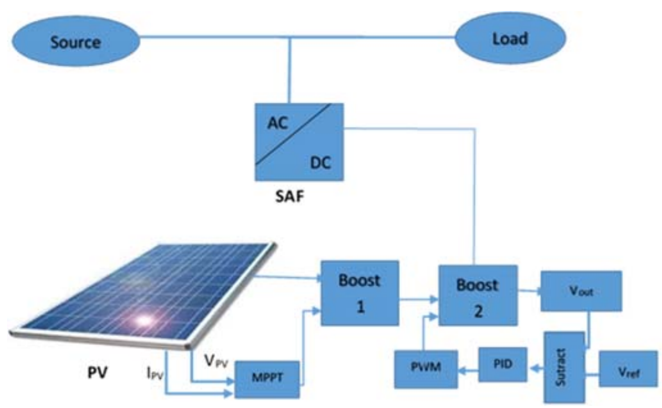


Figure 1. Overall block diagram of PV-SAPF

The proposed work presents a grid connected PV system for residential application. Figure.1 shows the typical structure of a two-stage single-phase grid-connected photovoltaic PV system.

SAPF [11-13] injects a voltage component that is connected in series with the supply voltage, thus offsetting the voltage bends and swells on the load side. The control response is of the order of 3 ms, guaranteeing a secure voltage supply in transient conditions. The main function of an SAPF is the protection of sensitive loads against voltage drops / swells from the network. SAPF is located on the basis of sensitive loads. If a fault occurs on other lines, the SAPF inserts the serial voltage and compensates the charging voltage to the default value. The momentary amplitudes of the voltages of the three injected phases are controlled so as to eliminate any detrimental effect of a bus fault on the charging voltage.

3. MODELLING OF PV ARRAY

A Solar cell is the basic unit of a photovoltaic PVsystem. Combination of solar cells in series forms a PV panel or PV module. These modules when connected in series and parallel form PV arrays. Modelling of PV array has been done considering single diode of PV cell [14].

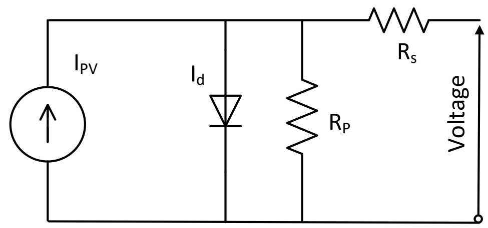


Figure 2. Single-diode model of the theoretical PV device

Figure 2: shows the equivalent circuit of the ideal photovoltaic cell. The basic equation which describes the I-V characteristics of ideal PV cell is given as [15]:

$$\mathrm{I} = I_{PV,cell} - I_d \quad (1)$$

That is

$$I = I_{PV,cell} - I_{0,cell}\left[exp\left(\frac{qV}{aKT}\right) - 1\right] \quad (2)$$

Where

$$I_d = I_{0,cell}\left[exp\left(\frac{qV}{aKT}\right) - 1\right] \quad (3)$$

Where
IPV, cell: Current generated by incident light.
Id: Shockley diode current in A,
I0, cell: Reverse saturation current of diode in A,
q: electron charge [1.602×10−19C],
k: Boltzmann constant [1.308×10−23 J/K],
T[K]: temp.of p-n junction
But practically (1) requires an inclusion of additional parameters as follows:

$$I = I_{PV} - I_{0,cell}\left[exp\left(\frac{V+R_S I}{V_t a}\right) - 1\right] - \left(\frac{V+R_S I}{R_P}\right) \quad (4)$$

Where
R_S: $series\ resistance\ of\ PV\ device$
R_P: shunt resistance of PV device

$$V_t \frac{N_S KT}{q} \quad (5)$$

Ns: Number of PV cells in series.
All PV array data sheets brings the basic information about the PV cell such as:
1) The nominal open circuit voltage $V_{0C,\ n}$
2) Nominal short circuit current, $I_{sc,\ n}$
3) Voltage & current at maximum power point, V_{mp}, I_{mp}
4) Maximum peak output voltage, $I_{\ max}$

3.1. Maximum power point tracking (MPPT)

Many methods for maximum power point tracking MPPT were developed to allow the system to extract the maximum power from the photovoltaic generator (PV generator). The principle of this control algorithm is to generate disturbances by reducing or increasing the duty cyclic D and observe the effect on the power output of PV generator. The problem with this algorithm summarized with two points:

a. The oscillation around the maximum power point under normal operating conditions.

b. The poor convergence of the algorithm in the case of abrupt changes in temperature and/or illumination.

3.2. Algorithm of P&O

The P&O is the simplest method which senses the PV array voltage and the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't step at the MPP and keeps on perturbing in both the directions.

As shown in Figure.3 the P&O algorithm operates by periodically perturbing the operating voltage and comparing it with the previous instant. If the power difference ΔP and the voltage difference ΔV, both in the positive direction then there is an increase in the array voltage. If either the voltage difference or the power difference is in the negative direction then there is a decrease in the array voltage. If both the voltage and power difference are in the negative direction then there is a increase in the array voltage. Similarly the next cycle is repeated until the Maximum Power Point is tracked.[16]

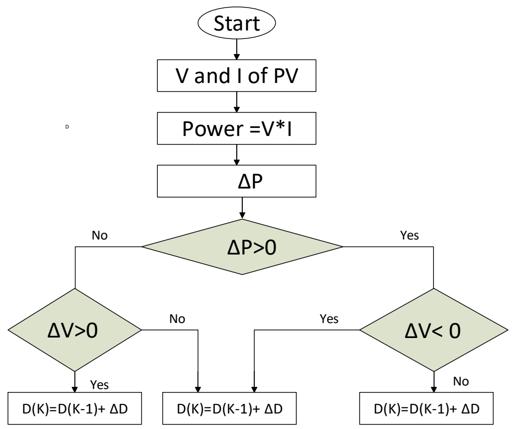


Figure 3. Algorithm P&O

4. SYSTEM CONTROL

All power systems must have a control strategy that describes the interactions between its parts.The controll strategie used in this work are PI, FLC controllers. This control is described as follow:

4.1. Fuzzy logic controller FLC

The controller used in this paper is the FLC in order to improve the behavior of the SAPF. The structure of a fuzzy control, shown in the Figure 4, can be broken down into three major modules.

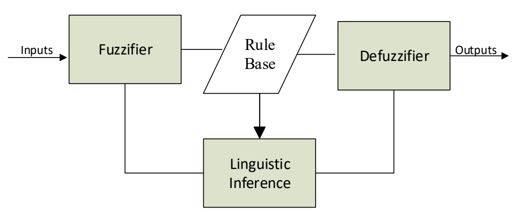


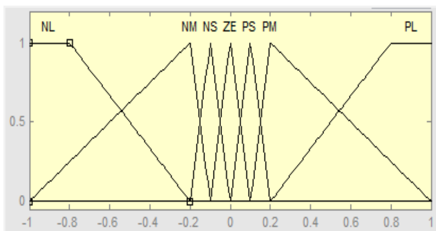
Figure 4. Fuzzy controller

The first of these modules deals with the inputs of the system: it is the fuzzification. It allows to associate to each of the actual inputs, by means of membership functions, a degree of belonging for each of the fuzzy subsets defined over the entire speech.

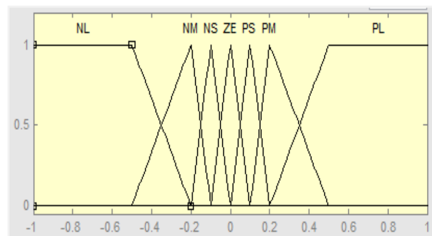
The second module consists of the inference engine and the rule base. This consists of the rules of the type: "If Then" and will make it possible to go from the degrees belonging to the input quantities to the degrees belonging to the fuzzy subsets of the magnitude control. The inference engine will allow you to generate a conclusion from the inputs and active rules. It then calculates the degrees of membership of the fuzzy subsets corresponding to the control of the system.

Finally, the last module, the de-Fuzzification interface, will make it possible to transform the degrees of belonging of the fuzzy command subassemblies into numeric magnitude. This is the inverse transformation of the fuzzification module.rules in the rule base aims to compute the fuzzy output functions. Finally, by de-fuzzifying the fuzzy output functions, we get "crisp" output values.

These outputs are determined using the inference engine and the rule base (if-then rules) as follow: IF e AND Δe, THEN Kp AND Ki. The variation of Kp and Ki constants depend on (e and Δe). The membership function curves of e, Δe, Kp and Ki are shown in Figure 5 and Figure 6, where all memberships' functions have triangular shape [17].



(a)



(b)

Figure 5. Membership function, (a) curves of the input e, (b) curves of the input Δe

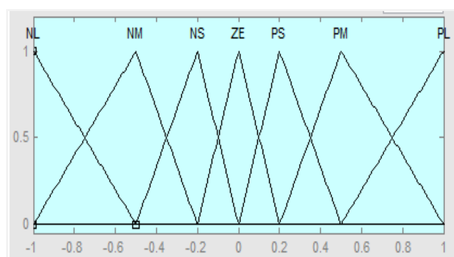


Figure 6. Membership function curves of the input Kp and Ki

Thus, the fuzzy subset for e and Δe are (NL; NM, NS, ZE, PS, PM, PL). Table 1 presents the fuzzy logic control rules for the variables Ki and Kp.

Table 1. Rule base for fuzzy controller

de(n) e(n)	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	NZ	PS
NS	NB	NB	NM	NS	NZ	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

In addition, a 3D curve of the relation between inputs and outputs of the FL controller is also plotted and shown in Figure 7.

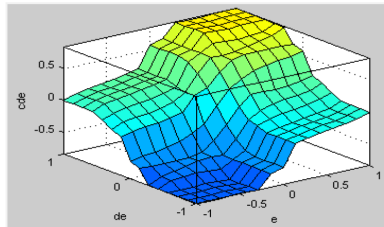


Figure 7. The relation surface between inputs and output of FLC

5. SIMULATION RESULTSNAND DISCUSSIONS

To confirm the effectiveness of the proposed SAPF fed by PV system controlled by Fuzzy Logic, simulations were developed in MATLAB\Simulink.the parameters which have been used in the simulation are shown in Table 2,in these simulation we use two DC DC (boost converter) the first one to extract the maximum power of the PV and the second used to regulated the DC voltage.the Total Harmonic Distortion (THD) of the source Voltage was found to be 33.33% befor the implementation of the SAPF-PV. Figure 9 shows the injected voltage waveforme at 1.2 sec.after the implementation of the proposed inverter, ,the THD valueis reduced to 2.94% as shows in Figures 16, Figure17 and Figure 15 shows the output of DC voltage of the second Boost.

Table 2. Electrical parameters

Parameters	Value	Parameters	Value
Source voltage fréquence f	50 Hz	Imax	1.83 A
Source voltage Vs	5.7 v RMS	VOC	27.6 V
Load resistance RL	12,3 Ω	ISC	2.06 A
CF(LC filter)	1 nF	Irradiation	1000 W/m^2
LF(LC filter)	9 mH	Temperature	25^0 c
Transformer	12V/230V1kVA	L1	3.2 mH
dc-bus capacitor C	22000uF	C1	8.62e-05 F
reference vdc voltage	vdc=75v	L2	1.7e-03 H
Kp,Ki Simulation results	Kp =7,2- Ki=33	C2	2200e-6 F
Vmax	19.7 V		

5.1. Case of SAG voltage

The sag phenomena was applied on the source voltage during the period between [1.2–2] second, which is corrected via the injected voltage of the SAPF as shown in Figure 8. The injected voltage of the SAPF via the injection transformer is viewed in Figure 9. Consequently, the magnitude of the load voltage was kept stable despite of the applied sag phenomena as illustraited in Figure 10. During the sag phenomina, in the DC side, the DC voltage across the input capacitance of the inverter was maintained around its nominal value of 75V_{DC} shown in Figure 11 through two stage DC-DC converters associated with the PV source, where the first converter aims to extract the maximum power of the PV, and the second is used to regulate the output DC voltage connected to the inverter.

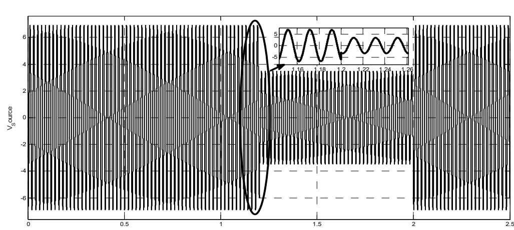


Figure 8: The source voltage (SAG)

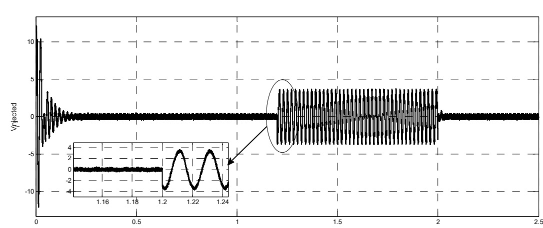


Figure 9: The voltage Injected (SAG)

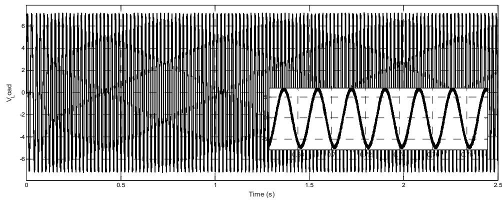


Figure 10: The Load voltage (SAG)

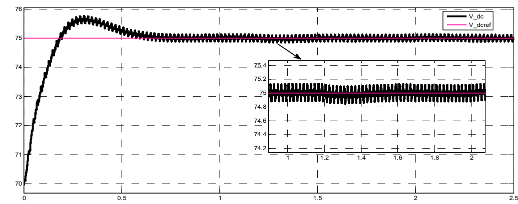


Figure 11: The DC voltage (SAG)

5.2. Case of harmonic voltage

In the second case, the AC programmable source was used to generate the 5th order harmonic with the magnitude and the angle phase of 0.2 pu and 35° respectively. The applied harmonic were nearly eliminated using the SAPF by injecting the complementary voltage as seen in Figures 12 and 13. The regulated voltage at the DC side was maintained and regulated as seen in the first case of the sag phenomena as shown in Figures 14 and 15. In Figures 16 and 17, before the application of the disturbance, the total hamrmonics distortion THD was about 33.33%, where after the correction it was about 2.94%, which provide improved THD values and ameliorated power quality.

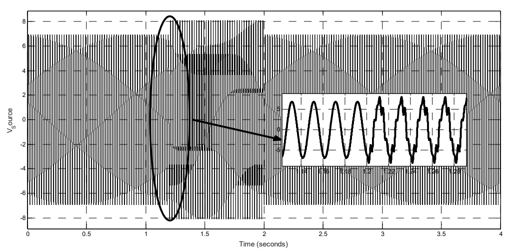


Figure 12: The source voltage (Harmonic)

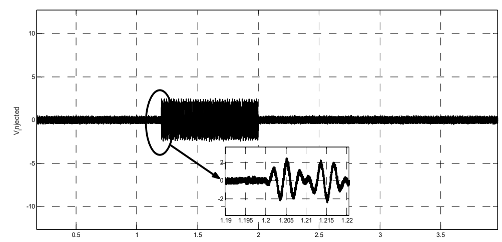


Figure 13: The injected voltage (Harmonic)

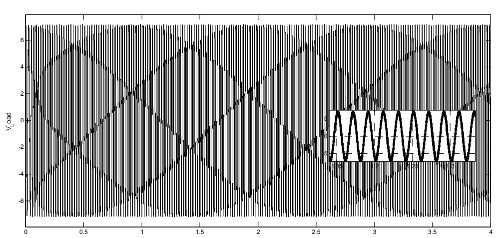


Figure 14: The Load voltage (Harmonic)

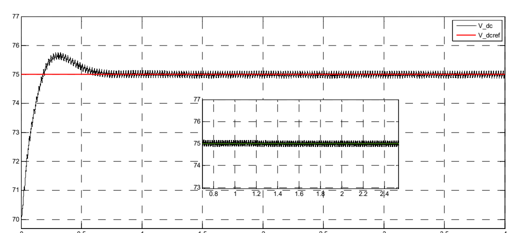


Figure 15: The DC voltage (Harmonic)

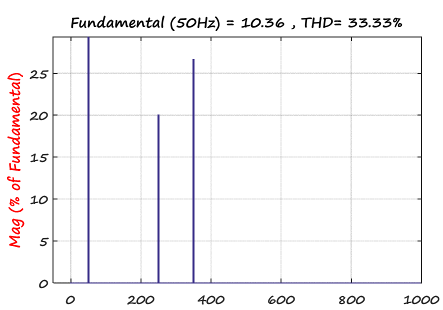


Figure 16: The FFT of source voltage befor using SAPF-PV (Harmonic)

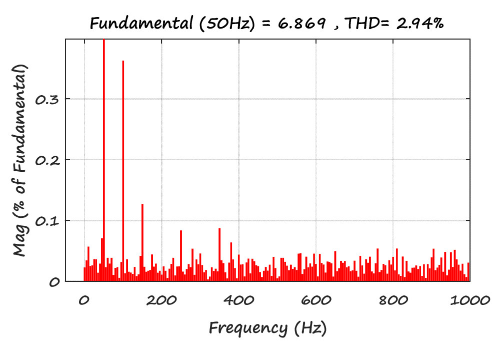


Figure 17: The FFT of source voltage after using SAPF-PV (Harmonic)

6. CONCLUSION

In this paper, the design and simulation of a new SAPF system wich was fed by a renewable energy source is proposed. The proposed system also incudes two conventional boost converter to compensate the reactive power ,harmonic, voltage sags at load.The PV system includes an MPPT algorithm to extract the maximum power of the panel.the second Boot was controlled by fuzzy logic controller.the simulation work carried out under Matlab simulink,from this simulation we can see that the THD of the source voltage is reduced from 33,33% to 2,94% with the SAPF-PV,the future work is an experimental results to comper with simulation works.

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