

$$I = I_{ph} - I_s \left(e^{\frac{q(V+IR_s)}{nKT}} - 1 \right) - \frac{V + IR_s}{R_{sh}} \quad (1)$$

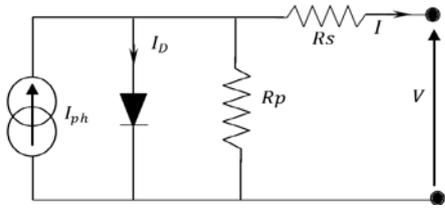


Figure 2. Solar cell circuit model (Single-diode).

B. MPPT control algorithms

To increase the efficiency of the PV system, it is required to operate at the maximum power point (MPP). Several methods have been developed for PV systems [8, 9], and for all conventional MPPT techniques, the main problem is how to obtain optimal operating points (voltage and current) automatically at maximum PV output power under variable atmospheric conditions. The main aspects referred to these algorithms are low response speed, errors in Tracking under rapidly changing atmospheric conditions [10].

On the other hand fuzzy logic has received much attention from a number of researchers in the area of power electronics [6, 11-13]. Fuzzy logic control is somewhat easy to implement, because it does not need exact mathematical model of the plant.

C. Fuzzy MPPT Controller

There are three stages in this control algorithm, namely fuzzification, inference method and defuzzification. The fuzzification makes it possible to transform real variables into fuzzy variables. The actual voltage and current of PV array can be measured continuously and the power can be calculated [2, 6]. The input variables of proposed controller are an error (E) and a change in error (CE). At a sampling instant k, these variables are expressed as follows [12]:

$$E(n) = \frac{(P(n) - P(n-1))}{(V(n) - V(n-1))} \quad (3)$$

$$CE(n) = E(n) - E(n-1) \quad (4)$$

Where; n is the sampling time, P(n) is the instant power of the PV generator, and V(n) is the instant corresponding voltage.

These inputs are chosen so that the instant value of E(n) shows if the load power operation point is located on the right or in the left compared to the P_{max} actual position. While ΔE (n) expresses the moving direction of this operation point. The output variable is the pulse width modulation (PWM) signal called D, which is transmitted to the boost DC/DC converter to drive the load [11].

Table 1 shows the rule table of a fuzzy controller, where all the entries of the matrix are fuzzy sets of error (E), change of error (CE) and change of duty ratio (ΔD) to the converter.

TABLE I. FUZZY CONTROL RULE TABLE

ΔE/E	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	PS	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

The fuzzy rules shown in Table 1 are employed for controlling the DC-DC converter such as the maximum power of the PV generator is reached. As an example, the rule in Table 1: If (E is NB) and (CE is NB) then (D is ZE).

It is necessary to transform this fuzzy information into deterministic information, this transformation is called defuzzification. The membership functions for the variable are shown in Figure 3.

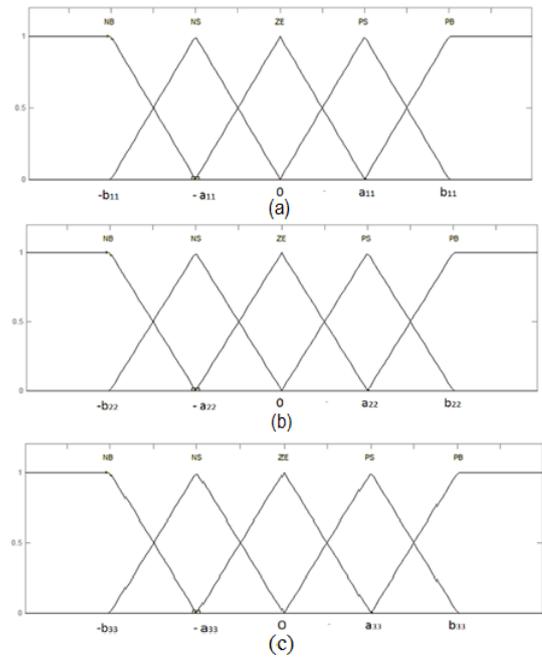


Figure 3. Membership functions for: E (a), CE (b), and ΔD (c).

III. PROPOSED INVERTER CONTROL TECHNIQUE

The proposed system consists of PV system, Boost chopper, DC-link capacitor, two-level voltage source inverter (VSI) connected at the PCC to a three-phase grid through the interface inductances. The compensator reference current is calculated from the sensed grid current drawn by the nonlinear load.

In the literature, many control techniques have been proposed for the extraction of harmonics currents [14-16]. The p-q theory was proposed in 1983 by Akagi[14], transforms a three-phase system from phase coordinates to α-β coordinates according to Eqs. (4) and (5).

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad (5)$$

The instantaneous active and reactive power can be expressed in the matrix form as follows:

$$\begin{bmatrix} P \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (6)$$

The instantaneous active and reactive power includes AC and DC values corresponding to the fundamental and harmonics current, respectively;

$$\begin{cases} P = \bar{P} + \tilde{P} \\ q = \bar{q} + \tilde{q} \end{cases} \quad (7)$$

The DC value of p and q are extracted from the positive-sequence component of the load current, whereas the AC value of p and q are created from the harmonics component of the load current.

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} P \\ q \end{bmatrix} \quad (8)$$

The reference compensating current in the a-b-c coordinates that can be obtained from Eqs. (5) and (8) is as follows:

$$\begin{bmatrix} I_{ref1} \\ I_{ref2} \\ I_{ref3} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (9)$$

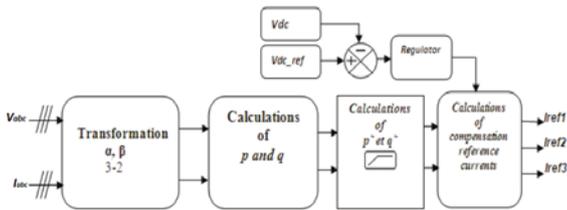


Figure 4. Block diagram for the p-q theory.

IV. RESULTS AND DISCUSSION

As shown in Figure 5, for this test, we have varied by steps, both the irradiation S and temperature T at very short times.

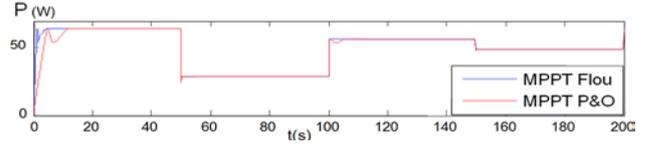


Figure 5. Responses of the two MPPT controllers (fuzzy and P&O), irradiation G and temperature T are variables.

The main aspects referred of the P&O algorithm are, oscillations around the mpp in steady state; low tracking speed; Simulation results confirm that the fuzzy controller operates much better than the P&O controller.

Figure 6 shows the source current waveform deformed before filtering. The shunt APF supplied by PV array is injected current (iInj) as shown in Figure 8. The active filter has imposed a sinusoidal source current waveform instantaneously as illustrated in Figure 9. The obtained current and voltage waveforms are in phase as illustrated in Figure 10 (b). Figure 11 shows the spectrum analysis of the source current with/without a PV-SAPF. The current THD (total harmonic distortion) is reduced from 31.34% to 3.27% on the grid network, which confirms the good quality of filtering after using the PV-SAPF, the simulation results show a good filtering of harmonic currents and a perfect compensation of reactive power.

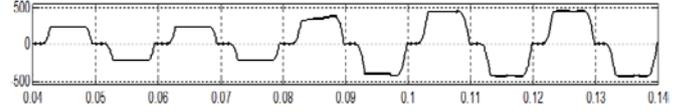


Figure 6. Supply current of phase-a before the insertion of SAPF PV system.

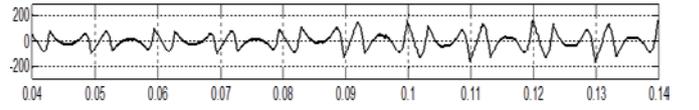


Figure 7. Reference current Iref1 of phase-a.

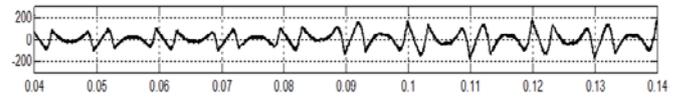


Figure 8. Harmonic current of phase-a generated by the SAPF PV system.

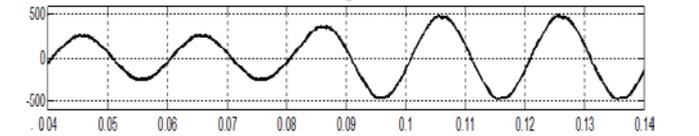


Figure 9. Supply current of phase-a after the insertion of SAPF PV system.

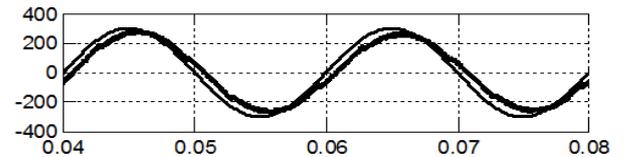


Figure 10. Power factor of phase-a before the insertion of SAPF PV system.

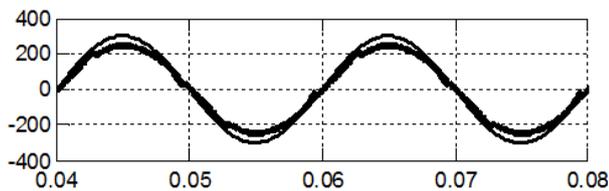


Figure 11. Power factor of phase-a after the insertion of SAPF PV system.

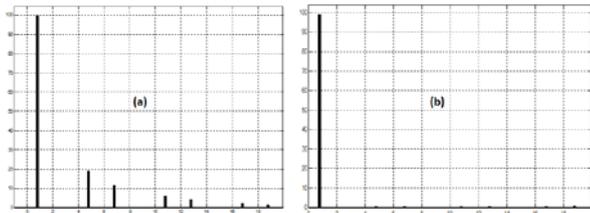


Figure 12. Harmonic spectrum of supply current (a) before, (b) after the insertion of SAPF PV system.

CONCLUSIONS

The present article presents an analysis and simulation of a three-phase SAPF fed by PV systems. An MPPT fuzzy logic controller is employed to feed the grid by the maximum allowable PV power. The proposed system has been simulated in MATLAB/SIMULINK software. This system is used to eliminate harmonics and to compensate reactive power generated by nonlinear loads. Performances of the shunt APF are related to the current references quality. This method is very important because it allows harmonic currents and reactive power compensation simultaneously. Simulation results show that the current obtained after filtering and the voltage waveforms are in phase. Also, the current THD is reduced from 33.34% to 2.87% which confirms the good filtering quality of harmonic currents and the perfect compensation of reactive power which improve the power quality.

REFERENCES

- [1] J. Lu, X. Xiao, J. Zhang, Y. Lv, and C. Yuan, "A Novel Constant Active-current Limit Coordinated Control Strategy Improving Voltage Sag Mitigation for Modular Multi-level Inverter-based Unified Power Quality Conditioner," *Electric Power Components and Systems*, vol. 44, pp. 578-588, 2016.
- [2] R. Belaidi, A. Haddouche, and H. Guendouz, "Fuzzy logic controller based three-phase shunt active power filter for compensating harmonics and reactive power under unbalanced mains voltages," *Energy Procedia*, vol. 18, pp. 560-570, 2012.
- [3] T.-J. Park, G.-Y. Jeong, and B.-H. Kwon, "Shunt active filter for reactive power compensation," *International Journal of Electronics*, vol. 88, pp. 1257-1269, 2001.
- [4] S. K. Jain, P. Agarwal, and H. Gupta, "A Dedicated Microcontroller based Fuzzy Controlled Shunt Active Power Filter," *Intelligent Automation & Soft Computing*, vol. 11, pp. 33-46, 2005.
- [5] K. Srikanth, T. K. Mohan, and P. Vishnuvardhan, "Improvement of power quality for microgrid using fuzzy based UPQC controller," in *Electrical, Electronics, Signals, Communication*

and Optimization (EESCO), 2015 International Conference on, 2015, pp. 1-6.

- [6] B. Bendib, H. Belmili, and F. Krim, "A survey of the most used MPPT methods: Conventional and advanced algorithms applied for photovoltaic systems," *Renewable and Sustainable Energy Reviews*, vol. 45, pp. 637-648, 2015.
- [7] Y. Bouzelata, E. Kurt, N. Altin, and R. Chenni, "Design and simulation of a solar supplied multifunctional active power filter and a comparative study on the current-detection algorithms," *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 1114-1126, 2015.
- [8] K.-H. Chao and C.-J. Li, "An intelligent maximum power point tracking method based on extension theory for PV systems," *Expert Systems with Applications*, vol. 37, pp. 1050-1055, 2010.
- [9] B. Subudhi and R. Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," *Sustainable Energy, IEEE transactions on*, vol. 4, pp. 89-98, 2013.
- [10] M. S. Hamad, A. Fahmy, and M. Abdel-Geliel, "Power quality improvement of a single-phase grid-connected PV system with fuzzy MPPT controller," in *Industrial Electronics Society, IECON 2013-39th Annual Conference of the IEEE*, 2013, pp. 1839-1844.
- [11] C. Larbes, S. A. Cheikh, T. Obeidi, and A. Zerguerras, "Genetic algorithms optimized fuzzy logic control for the maximum power point tracking in photovoltaic system," *Renewable Energy*, vol. 34, pp. 2093-2100, 2009.
- [12] A. Messai, A. Mellit, A. Guessoum, and S. Kalogirou, "Maximum power point tracking using a GA optimized fuzzy logic controller and its FPGA implementation," *Solar Energy*, vol. 85, pp. 265-277, 2011.
- [13] C.-Y. Won, D.-H. Kim, S.-C. Kim, W.-S. Kim, and H.-S. Kim, "A new maximum power point tracker of photovoltaic arrays using fuzzy controller," in *Power Electronics Specialists Conference, PESC'94 Record., 25th Annual IEEE*, 1994, pp. 396-403.
- [14] H. Akagi, Y. Kanazawa, and A. Nabae, "Generalized theory of the instantaneous reactive power in three-phase circuits," in *IPEC*, 1983, pp. 1375-1386.
- [15] S. Luo and Z. Hou, "An adaptive detecting method for harmonic and reactive currents," *Industrial Electronics, IEEE Transactions on*, vol. 42, pp. 85-89, 1995.
- [16] M. Benhabib and S. Saadate, "New control approach for four-wire active power filter based on the use of synchronous reference frame," *Electric Power Systems Research*, vol. 73, pp. 353-362, 2005.