Fuzzy logic controller of photovoltaic panel-unified power quality conditioner with voltage compensation and stability

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ABSTRACT

The intensive use of non-linear loads is further contributing in the increase of power quality problems. They cause voltage distortions and current harmonics in an electrical distribution network. To minimize these problems, the unified power quality conditioner (UPQC) is used. The intermediate circuit voltage of this filter can deviate from its source during a transient event during a harmonic disturbance in voltage (voltage dip) or in current during the connection and disconnection of polluting loads. In a particular point in operating time, the stabilization of dc-bus and the compensation ability is necessary to maintain around its reference. The combination of a UPQC conditioner with a photovoltaic (PV) system connected to the intermediate element of the two converters of the DC bus (DC Link) is the adequate solution. The photovoltaic (PV) system is fitted with a fuzzy MPPT controller regulated by an algorithm (P and O) to control a boost converter. This converter is controlled by fuzzy logic related to the capacitor terminal of UPQC. The simulation results show that the UPQC conditioner based on the proposed photovoltaic system can be used for voltage disturbance compensation and the protection of non-linear loads connected to a distribution network.

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1. INTRODUCTION

The quality of power has become increasingly important given the widespread use of power electronic equipment. The quality of energy quite often, they refer to the quality of the voltage. common disturbances that cause the power quality failure of an electrical system are: (voltage dip, over voltage, momentary interruptions, transients, voltage imbalance, harmonics, voltage fluctuations). energy, is based on two aspects, namely the quality of the current and the voltage including the transient phenomenon. There is always a challenge to keep power quality within acceptable limits [1].

The proliferation of power electronics-based equipment has had an impact on power quality [2]. In the presence of a non-linear load connected or disconnected to a distribution network can cause harmonic disturbances in voltage (voltage dip) or in harmonic distortion current. The major solutions to the problems of energy quality are based on the “active power filters” system. The unified power quality conditioner (UPQC) conditioner is one of the attractive modern solutions very promising to compensate for several major power quality problems controlled by MLI [3]–[5]. This filter is an energy conditioning device composed of two active filters (FAP) harmonic current compensator and one (FAS) voltage controller which are connected back-to-back via a common DC capacitor. the clearance, the voltage at the terminal of the capacitor moves away from its reference disrupting stability. Integration of PV solar power system with UPQC forming UPQC PV system to make intermediate capacitor voltage stable and eliminate DC bus voltage variations during operation and in presence of disturbances (voltage dip or harmonic) [6]-[8]. The work presents a photovoltaic system connected to a UPQC connected to the PCC connection point of the grid supplying a non-linear load. The connected photovoltaic system will have many challenges, namely voltage stability, reactive power compensation and operational reliability. Using a photovoltaic generator with maximum power point tracking (MPPT) control and storage battery which are connected to an adaptation stage represented by a DC/DC boost converter which is designed to deliver a modulated voltage to maintain the fixed link voltage DC Link of the UPQC, this one is filtered to reduce the harmonic rate. The maximum power point tracking (MPPT) control is an essential control for optimal operation of the photovoltaic system. The principle of this control is based on the automatic variation of the duty cycle α by bringing it to the optimum value so as to maximize the power delivered by the photovoltaic (PV) panel and at the same time minimize the error between the operating power and the power optimal.

2. DESCRIPTION OF THE SYSTEM

The PV system that is produced aims to compensate for a voltage disturbance on the source side of the electrical network connected to a non-linear load and reduce the voltage total harmonic distortion (THD), attain current harmonics on the load side by meeting IEEE 1159 1995 standards with a voltage dip that exceeds 100 ms. However, the combination of photovoltaic source and power conditioner shown in Figure 1 involves a storage battery which should also be able to save the excess energy generated by PV and be used as a back-up power supply. The MPPT adaptation stage will be controlled by blur to follow the maximum power of solar energy.

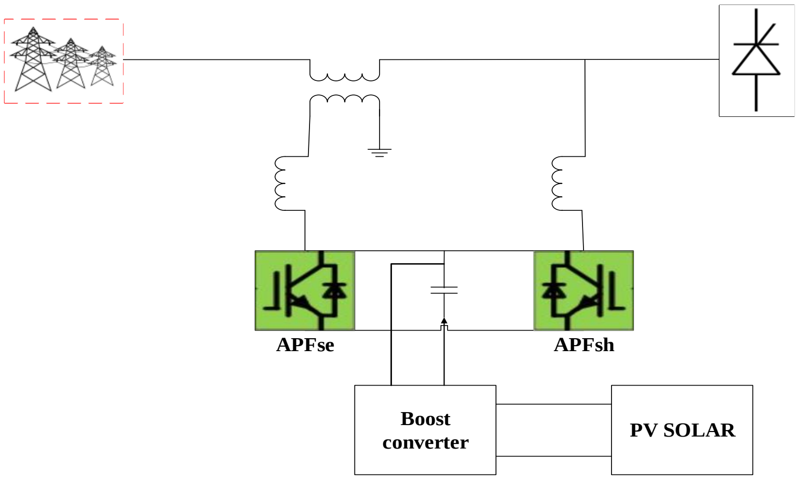


Figure 1. Basic block diagram for PV-UPQC system

3. UNIFIED POWER QUALITYCONDITIONER

Basically, a UPQC is a system that is used to simultaneously compensate for distortion, unbalance and voltage dip in an electrical distribution network so that the voltage on the load side is fully balanced and serves to compensate for harmonics. current generated by the nonlinear load so that the source current is perfectly sinusoidal [9], [10]. UPQC is compound of two filters, one is shunt (FAP) is used for the compensation of the harmonics of the currents on the load side and the other series (FAS) to attenuate the distortions of the voltage on the source side, which are connected back-to-back to a system. intermediate represented by a direct current link capacitor (DC link). To provide the network with better energy quality, an analysis of voltage or current disturbances causes the intervention of the conditioner. UPQC has proven to be the best solution to reduce this power quality problem.

3.1. Shunt active filter

The three-phase parallel active filter consists mainly of a voltage inverter with three arms, each arm is made up of two semiconductors controllable on opening and closing and bidirectional in current of the type

(IGBT) operate in a complementary way. The conduction of one semiconductor causes the blocking of the other to avoid the short circuit of the voltage source. It is likened to a current source which compensates in real time the harmonic currents generated by non-linear polluting load by injecting at the connection point harmonics of currents in phase opposition with the identified harmonic disturbances [11]. In order to connect the compensator to the network and make it fulfil the role of a current source, we have used a passive filter of an inductive type to ensure the dynamics of the injected current and prevent the components due to commutation from propagating on the electrical network. The quality of filtering depends on the effectiveness of the method used for the identification of harmonic currents.

The instantaneous active and reactive power method (P, Q) is used to exact the current harmonics. This method of identification consists in eliminating the DC component of the instantaneous powers, which is relatively easy to achieve [12]. In the presence of harmonics, this method uses the α-β transformation for the voltages and the currents, We denote by (V_α, V_β) and (I_α, I_β) the orthogonal components of the α-β reference associated respectively with the connection voltages of the active filter parallel (V_s) and to the currents absorbed by the polluting loads (I_{ch}). The α-β transformation allows writing the following relation of the voltages:

$$\begin{bmatrix} V_\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{S1} \\ V_{S2} \\ V_{S3} \end{bmatrix} \tag{1}$$

And the relationship of the currents below:

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{ch1} \\ I_{ch2} \\ I_{ch3} \end{bmatrix} \tag{2}$$

Active and reactive powers:

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{3}$$

By inverting the (3) we obtain currents

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} \tag{4}$$

The disturbing harmonic currents in the reference [αβ] :

$$\begin{bmatrix} I_{c\alpha h} \\ I_{c\beta h} \end{bmatrix} = \frac{1}{\nabla} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} \bar{P} \\ 0 \end{bmatrix} + \frac{1}{\nabla} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} 0 \\ \bar{q} \end{bmatrix} + \frac{1}{\nabla} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \tag{5}$$

Active current reactive current harmonic currents. The reference currents in the three-phase reference are:

$$\begin{bmatrix} I_{ref1} \\ I_{ref2} \\ I_{ref3} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{c\alpha h} \\ I_{c\beta h} \end{bmatrix} \tag{6}$$

3.2. Serie active filter

The series active filter (SAF) is a suitable solution for compensating voltage harmonics and protecting sensitive loads against the majority of voltage disturbances in the electrical network [8]. It will therefore include as a voltage source that will oppose disturbing voltages (voltage dips, overvoltage, imbalance and harmonics) coming from the source and that caused by disturbing currents through the impedance of the network. It is inserted at the network connection point via an injection transformer. The FAS does not allow compensation for the harmonic currents consumed by the load. Its constitution includes a three-phase voltage inverter based on controllable power switches on starting and blocking of the type (GTO or IGBT) and a decoupling filter. This filter includes an inductor parallel to a capacitor which are dimensioned to attenuate the switching frequency of the semiconductors of the inverter and eliminate the switching harmonics for good compensation quality [13]. The voltage extraction method (dq) is used to calculate the disturbing voltages which will be injected in phase opposition by the inverter to clean up the dips and overvoltage created at the terminals of the load to be protected. The method will be based on the calculation of the symmetrical components in the (dq) rotating frame of park. This method consists, at first, of writing the relationship of the voltages from the three-phase reference through the reference (αβ) in (1). By passing to the direct and quadrature, rotating reference (dq) provided by the PLL we obtain the following relationship:

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\theta_d & \sin\theta_d \\ -\sin\theta_d & \cos\theta_d \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{7}$$

By inverting (7) we obtain the disturbance voltage components in (dq):

$$\begin{bmatrix} \tilde{V}_\alpha \\ \tilde{V}_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta_d & -\sin\theta_d \\ \sin\theta_d & \cos\theta_d \end{bmatrix} \begin{bmatrix} \tilde{V}_d \\ \tilde{V}_q \end{bmatrix} \tag{8}$$

Finally, and from the phase (θ_d) supplied by the PLL, a three-phase unitary system having the form:

$$\begin{bmatrix} V_{ref1} \\ V_{ref2} \\ V_{ref} \end{bmatrix} = \begin{bmatrix} V\cos\theta_d \\ V\cos\left(\theta_d - \frac{2\pi}{3}\right) \\ V\cos\left(\theta_d + \frac{2\pi}{3}\right) \end{bmatrix} = \begin{bmatrix} V cos\theta_d \\ -\frac{1}{2} * \sin(\theta_d) - \frac{\sqrt{3}}{2} * \cos(\theta_d) \\ -\frac{1}{2} * \sin(\theta_d) + \frac{\sqrt{3}}{2} * \cos(\theta_d) \end{bmatrix} \tag{9}$$

3.3. Intermediate DC bus system (DC link)

The important parameters of the DC bus or an intermediate system of a UPQC are voltage and capacitance. The DC bus must be designed so that, faced with types of disturbances such as a voltage dip switched to the network for its sizing, the bus voltage is always sufficiently high and stable to generate the necessary compensation voltage. The capacitor must be dimensioned so that it ensures that the voltage V_{dc} will be above the minimum value Vdc min necessary to generate the compensation voltage requested by the filter control in the face of the voltage dip. This control intends to protect the load. The characteristics of the voltage dip (duration ΔT, depth e) effect on the calculation of the compensation energy and the minimum value of the bus voltage V_{dcmin} [14].

The compensation energy injected by the filter is therefore:

$$\Delta w = e.P_{ch}.\Delta t \tag{10}$$

e : Depth of voltage dip
P_{ch} : Power absorbed by the load
Δt : The duration of the voltage dip

The value of the DC bus capacitor is expressed by (11).

$$C_{dc} = \frac{2\Delta w}{V_{dc}^2 - V_{dcmin}^2} \tag{11}$$

If the severity of the voltage dip increases, it will no longer be possible to perform purely reactive compensation, the minimum bus voltage must be:

$$(V_{dc})min = 2\sqrt{2}V_{ch}\sqrt{2(1-e)(1-\cos\varphi)+e^2} \tag{12}$$

V_{ch} : Voltage at the terminal of the load to be protected
Cosφ : Power factor

If the DC bus is recharged by the FAP of the UPQC itself and the compensation cannot be carried out exclusively with reactive energy, the voltage compensation is limited in time and will be carried out with an energy already stored in the bus. The operation of UPQC over a period of time will depend on the severity of the voltage drop, the DC bus characteristic and the compensation system control strategy, we have used the parallel active filter (FAP) itself as a means of the bus load. The compensation capacity of the series active filter (FAS) will depend on the stable value of the DC bus with a compromise between depth and duration of the disturbance to be compensated. In reality, the solution of an independent external source represented by a photovoltaic chain (PV) will be dimensioned. It takes into account voltage disturbances of more than 60% depth and duration greater than 100 ms. Because it ensures a fairly wide autonomy duration to UPQC with the delivery of a stable output voltage to the DC link intermediate system in the presence of the voltage dip and the discharge of the capacitor.

4. PHOTOVOLTAIC GENERATOR AND THE ADAPTATION STAGE WITH THE CONTROLLER MPPT

A solar cell is the basic unit of a photovoltaic system. The combination of solar cells in series forms a PV panel or PV module. Connecting these modules in series or in parallel forms photovoltaic generators. The photovoltaic system is formed by the GPV and its adaptation stage. The photovoltaic effect is a direct conversion of light radiation into electricity based on the photoelectric phenomenon through photovoltaic panels which perform this transformation of energy. Photovoltaic technology is sufficiently mature and mastered to take on a real boom and a challenge in the field of energy applications, as well as power optimization. GPVs behave like non-linear generators which have an optimum operating point. This latter depends on the ambient temperature of the panel and the variation of the load [15]–[20].

4.1. PV modeling

The solar photovoltaic system is based on light energy. When the luminous arrays strike a solar cell, it will be converted to electrical energy. To take into account all the dissipative phenomena during the conversion of light energy by solar cells, the equivalent diagram is represented by a source. This source models the photovoltaic current (I_{ph}), a diode current (I_d), a current supplied by the cell (I) and two resistors. One resistor is in series (R_s) and the other is in parallel (Rp) as shown in Figure 2.

The current delivered by the cell is:

$$\mathrm{I} = I_{ph} - I_d - I_p \tag{13}$$

The current (I_p) flowing through the resistor (R_p) :

$$I_p = \frac{V_d}{R_p} = \frac{V+IR_s}{R_p} \tag{14}$$

The current of the junction (I_d)is given by (15).

$$I_d = I_s\left[exp\left(\frac{V+IR_s}{V_T}\right) - 1\right] \tag{15}$$

With I_s : diode saturation current V_T

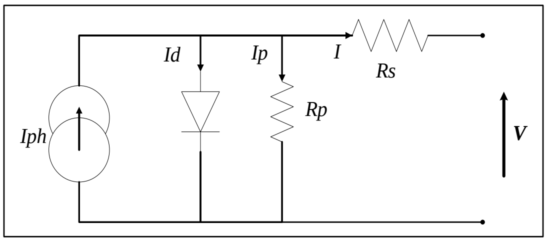


Figure 2. Simplified equivalent circuit of a PV cell

4.2. Boost DC/DC converter topology with fuzzy logic MPPT controller

In this section a DC-DC boost converter is chosen. The topology of the electrical circuit is shown in Figure 3. The mathematical model of the parallel chopper is obtained by the application of the Kirchhoff laws on the basic schematic of the converter shown in Figure 3. Following the state of the switch S, we write:
For $t \in [0, DT]$:

$$\frac{dI_{pv}}{dt} = \frac{V_{pv}}{L} \ , \ \frac{dV_o}{dt} = -\frac{V_o}{RC} \tag{16}$$

For $t \in [DT, 0]$:

$$\frac{dI_{pv}}{dt} = \frac{V_{pv} - V_o}{L}, \quad \frac{dV_o}{dt} = \frac{I_{pv}}{C} - \frac{V_o}{RC} \tag{17}$$

The voltage transfer gain for a boost converter, it is given by the following;

$$V_o = \frac{1}{1-D} V_{pv} \tag{18}$$

$$I_o = (1 - D) I_{pv} \tag{19}$$

The value of the inductor influencing the performance of the boost converter during the state can be given by the (20) [21].

$$L = \frac{V_{pv} \cdot D}{\Delta I_L \cdot f} \tag{20}$$

Where:
ΔIL : estimated inductor ripple current
F : switching frequency in Hz
D : duty cycle

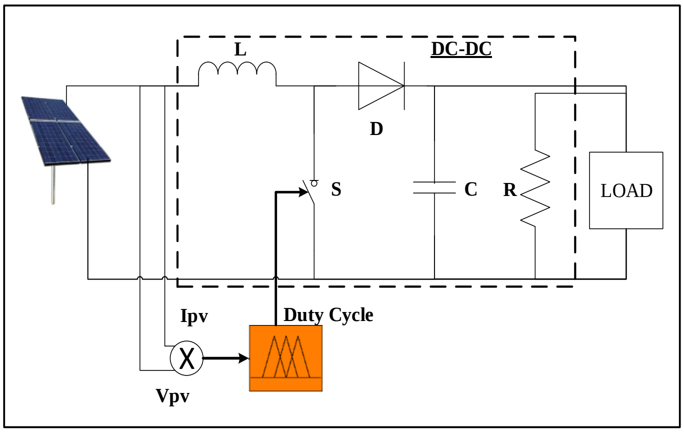


Figure 3. Boost converter

The choice of the value of the capacitor can be written in (21).

$$C = \frac{I_o \cdot D}{\Delta V_o \cdot f} \tag{21}$$

ΔV_o : Estimated output ripple voltage

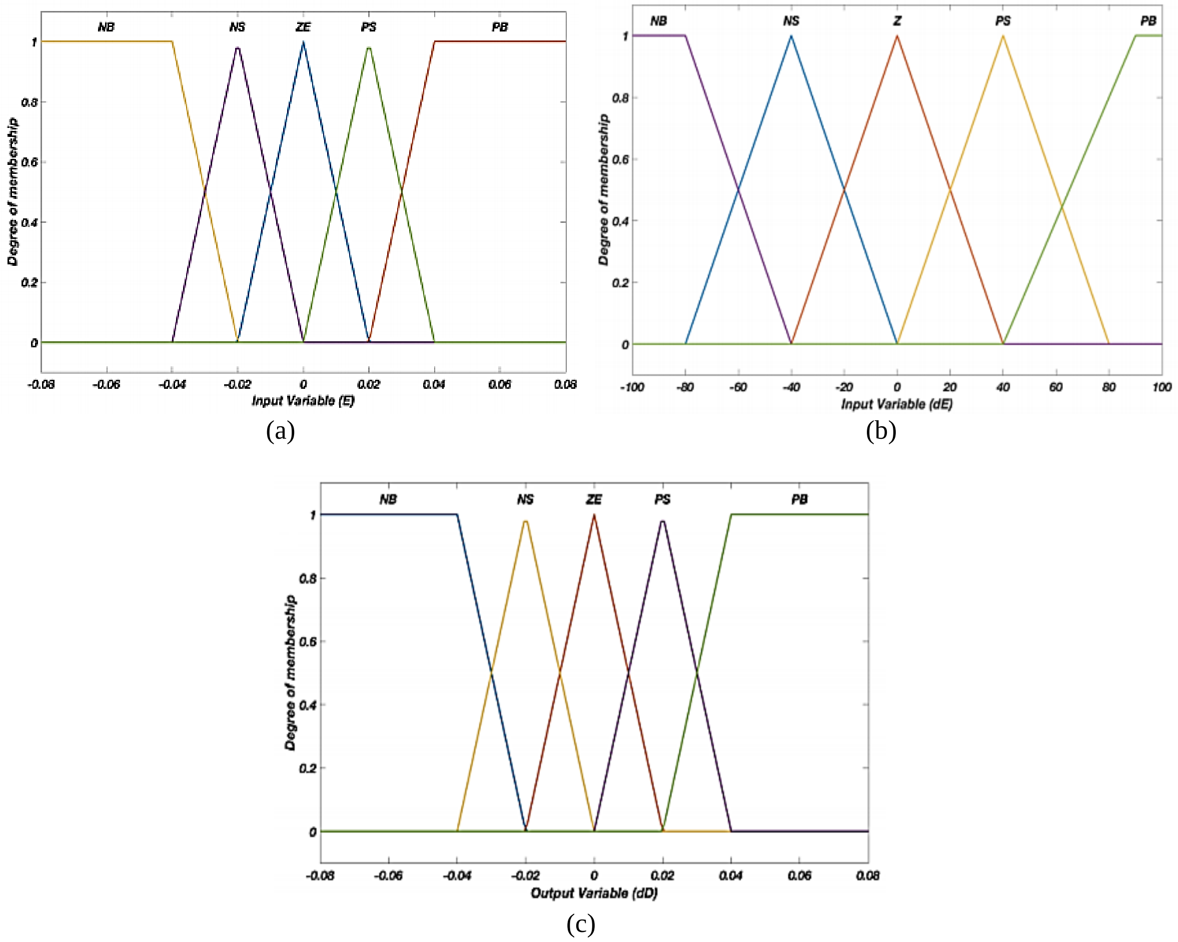
The MPPT control determines the optimum operating point (MPP) from the current, voltage or power measured in the system. This control can react depending on the operation of the GPV. Nowadays, the MPPT technique has become the focus of a large number of researches in order to improve the dynamic performance of PV systems. The objective is In this paper, we present a reminder of the fuzzy sets and a general overview on the fuzzy logic as well as its application for the optimization of a photovoltaic system. Fuzzy logic is a new approach based on artificial intelligence. It represents an improvement of the classic IC (incremental conductance) algorithm in terms of robustness, stability and ease of implementation. Like other controllers, the main task of the FL controller is to reach the MPP. However, the performance of this command depends primarily on human expertise. The rules developed from the expertise of the human operator are expressed in linguistic form. From the relation of maximum power point (ΔP/ΔV=0) the fuzzy controller has two inputs the first will be the variation of the power with respect to the voltage named the error E, the second is the variation ΔE which represents the direction and speed of convergence. The two controller inputs are defined by the following [22]–[25].

$$E(k) = \frac{P_{pv}(k) - P_{pv}(k-1)}{V_{pv}(k) - V_{pv}(k-1)} \tag{22}$$

$$\Delta E(k) = E(k) - E(k-1) \tag{23}$$

It is the follow-up of the variation of the maximum power point. Where our system must be able to evolve, quickly and efficiently. The output represents the step of the duty cycle which generates the PWM modulation signal.

The error and the change of error (E, DE) are the input variables in FLC. After accomplishing all required processes, the desired output from the final interface process is the duty cycle (DD). The universe of discourse for input variables as well as for the output variable is divided into five fuzzy sets: negative big (NB), negative small (NS), null error or zero (ZE), positive small (PS)and positive big (PB). The fuzzy algorithm tracks the MPP based on the rule-base consisting of25 rules as shown below. The membership functions of the inputs (E, DE) and output (DD) are presented in Figure 4. The implemented fuzzy rules in the present work are given in Table 1. Due to the linearity of their structure, membership functions of the triangular and trapezoidal type are preferred over the others.



(a) (b)

(c)

Figure 4. The membership functions of (a) error membership, (b) variation of error membership, and (c) duty cycle membership

Table 1. Table of fuzzy rules

E ΔE	NB	NS	ZZ	PS	PB
NB	ZZ	ZZ	NS	PS	PB
NS	ZZ	ZZ	ZZ	PS	PB
ZZ	NB	NS	ZZ	PS	PB
PS	NB	NS	ZZ	ZZ	ZZ
PB	NB	NS	PS	ZZ	ZZ

5. SIMULATION RESULTS AND DISCUSSION

The performance of PV-UPQC is simulated in MATLAB/Simulink using simpower systems toolbox. The load used is a nonlinear load. It consists of full bridge rectifier and RL load R=4 Ω, L=700 mH. The grid is modelled with a source impedance of 0.1 mH and 0.1 Ω. The PV module is modelled based on sun power SPR-305-WHT. The PV module and PV array characteristics are given in Table 2.

The Simulink models of PV/energy-UPQC are simulated in MATLAB. These models are shown in Figure 5. It consists of series APF, shunt APF, solar PV and boost converter. Under the steady state, the system operates efficiently without any disturbance in the waveforms. The PV-UPQC system is subjected to voltage fluctuations like voltage swell and voltage sag.

Table 2. Boost sizing components

Parameters	value
L	3 mH
Cs	150 uF
Switching frequency FSW	10 Khz

Table 3. PV Panel characteristics

Parameters	Value
Voltage peak power (V_{mpp})	54.7 V
Current peak power (I_{mpp}) Short circuit current Isc	5.58 A
	5.96 A
Open circuit voltage V_{oc}	64.2 V
STC: irradiance	1000 W/m²
Cell temperature	25 deg.C

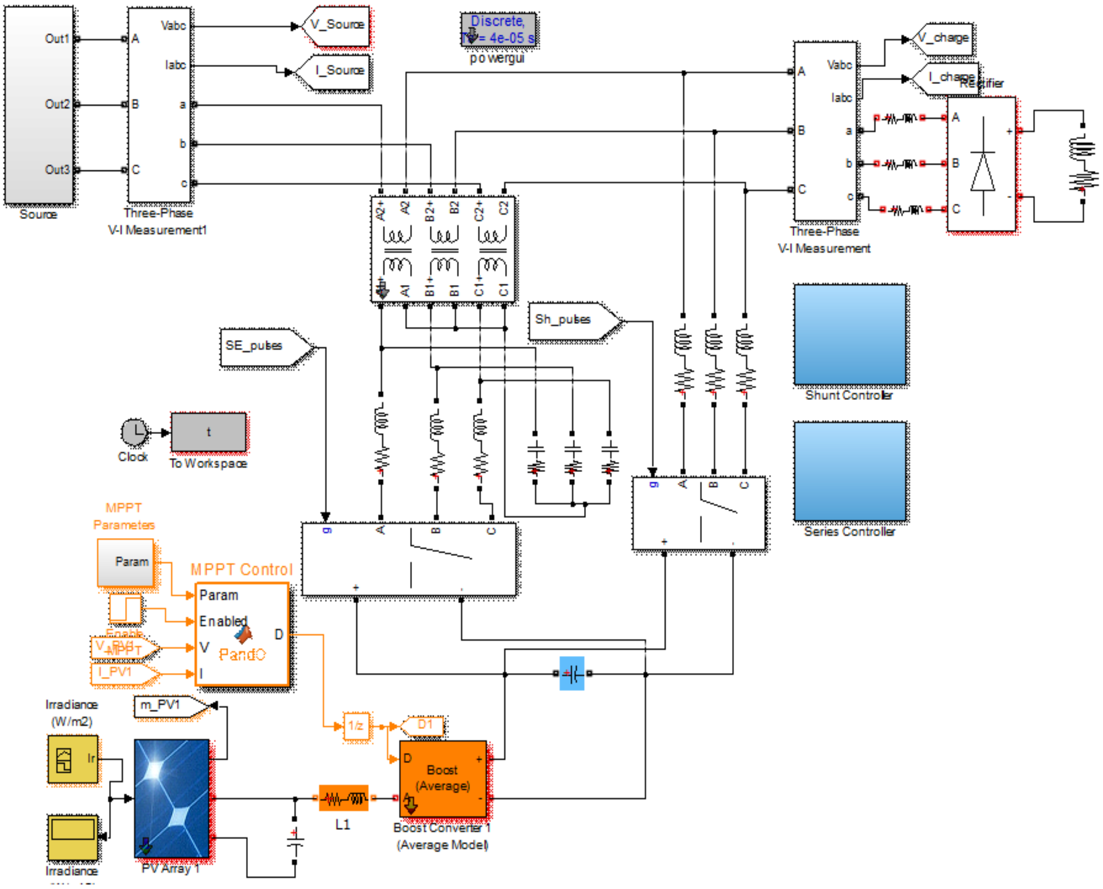
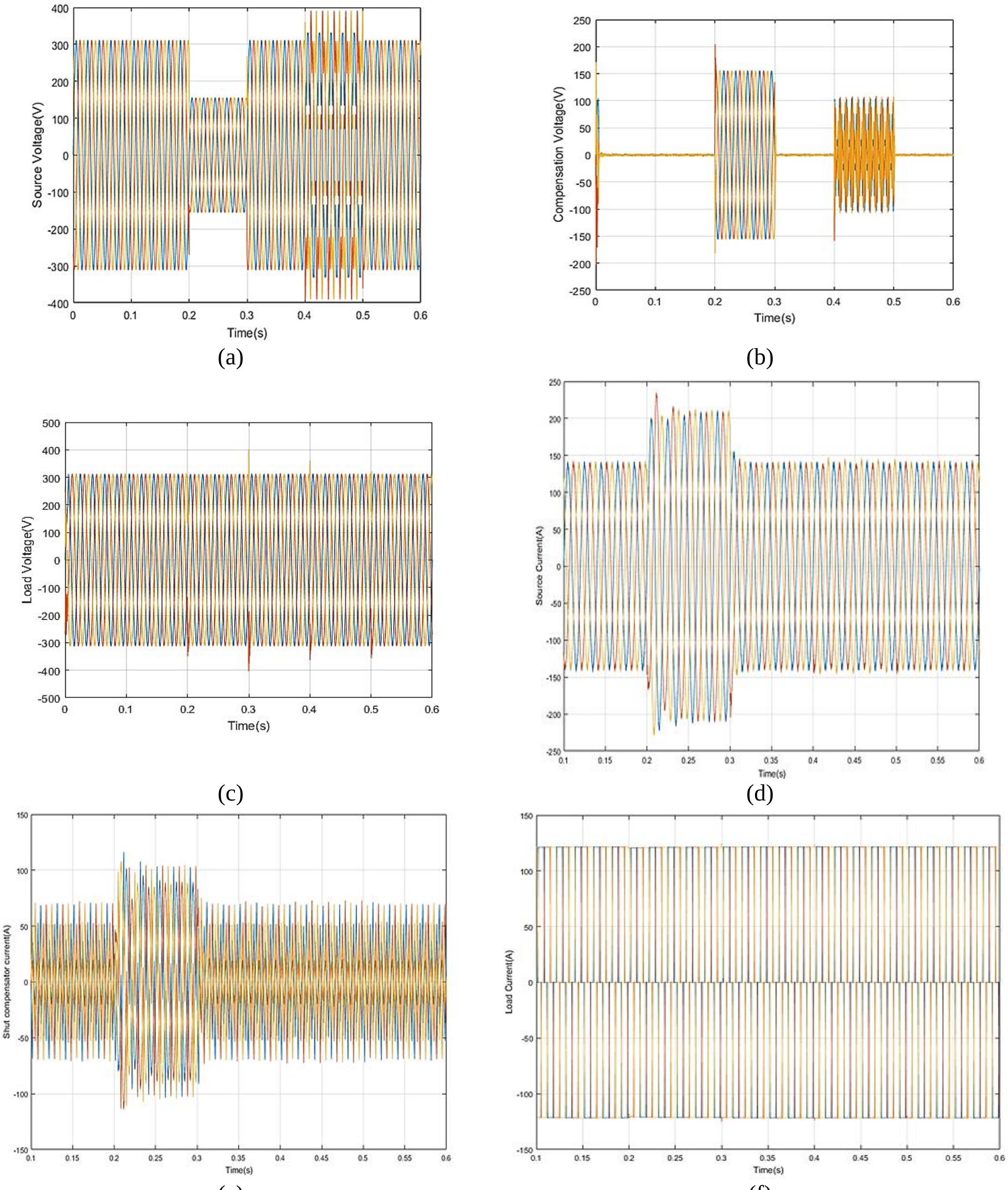


Figure 5. Simulink models of PV/energy-UPQC

The simulation results are shown in Figure 6 where voltage sag is clearly shown from 0.1-0.3 sec. Figure 6(a). The series active filter injects voltage from 0.1 sec.to 0.3 sec shown in Figure 6(b). The load voltage is compensated to actual value as shown in Figure 6(c). His voltage variations with respect to the voltage swell can be inferred from the graphs of Figure 6 at 0.4-0.5 s. The THD of the source voltage after connecting the UPQC is 0.23%. The THD of the source current before connecting the PV is 1.33% Figure 7(a). The harmonic spectrum of the source current after connecting the PV is illustrated in Figure 7(b). The THD of the source current after connecting the PV is 0.93%. The DC link capacitor voltage is held constant at its reference shown in Figure 8.



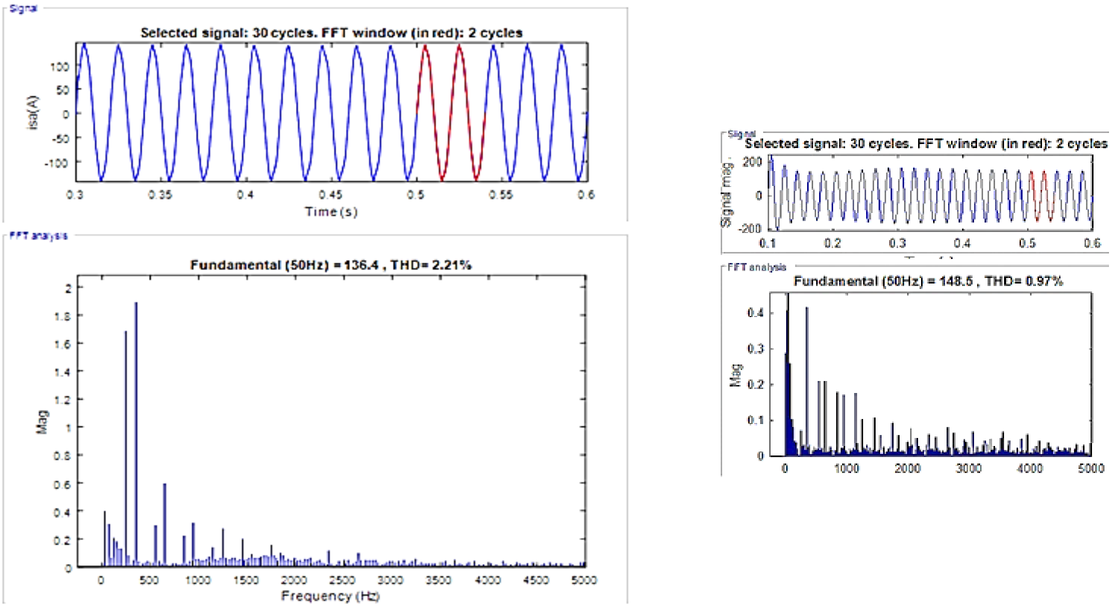
(a) (b)

(c) (d)

(e) (f)

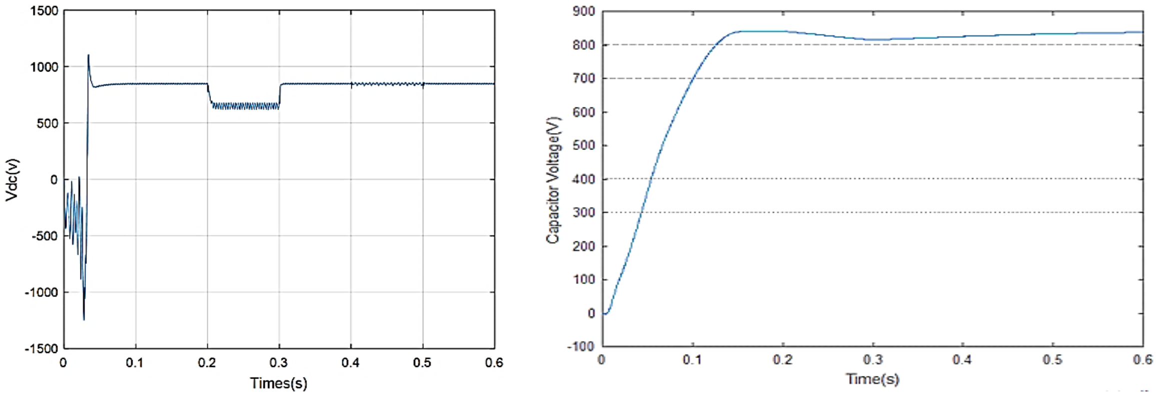
Figure 6. The simulation results, (a) source voltage, (b) series compensator voltage, (c) load voltage, (d) source current, (e) source current, (f) load current

The simulation results are shown in Figure 6 where voltage sag is clearly shown from 0.1-0.3 sec. as shown in Figure 6(a). The series active filter injects voltage from 0.1-0.3 sec shown in Figure 6(b). The load voltage is compensated to actual value as shown in Figure 6(c). His voltage variations with respect to the voltage swell can be inferred from the graphs of figure 6 at 0.4-0.5 s. The THD of the source voltage after connecting the UPQC is 0.23%. The THD of the source current before connecting the PV is 2.22% Figure 7(a). The harmonic spectrum of the source current after connecting the PV is illustrated in Figure 7(b). The THD of the source current after connecting the PV is 0.97%. The DC link capacitor voltage is held constant at its reference as shown in Figure 8.



(a) (b)

Figure 7. The total harmonic distortion of (a) the source current and (b) the source current with PV



(a) (b)

Figure 8. Appearance of the voltage at the terminal of the capacitor (a) before connection and (b) after connection

6. CONCLUSION

In this paper, we have proposed the design and simulation of a new UPQC system which was fed by a renewable energy source. The proposed research is based on designing a photovoltaic generator (PVG) fed to the dc link capacitor of UPQC. To improve the efficiency of photovoltaic systems, we have optimized the classical structure P&O and INC by integrating an intelligent technique called fuzzy logic A complete set of simulation results have been presented to validate the effectiveness of the proposal done proposed method with the integration of MATLAB. By observing simulation waveforms, the dynamic performance of the grid voltages/currents, load voltages/currents, PV output power, and dc-bus voltage showed the impact of the proposed PV-UPQC system over the power quality issues. The results clearly demonstrated that the proposed

PV-UPQC system is capable of mitigating voltage sags, voltage swells, and load harmonics. The proposed PV-UPQC can solve the power quality problems during the occurring of power quality phenomenon. Moreover, it can generate photovoltaic power under a stable operation of power grid.

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