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Performance Optimization of a Photovoltaic Generator with an Active Power Filter Application

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Abstract-- Maximum Power Point Tracking (MPPT) for photovoltaic (PV) systems maximizes the power that can be transferred from the PV system to an electrical system here we use the active power filter. To maximize the PV panel output power, perturb and observe (P&O) maximum power point tracking (MPPT) has been implemented into the PV system. Through a boost DC-DC converter, for rapidly changing solar irradiance the (P&O) method is unable to carry out the maximum power point values. This paper presents an intelligent method for the purpose of MPPT, based on fuzzy logic controller (FLC), and applied to a converter circuit. The fuzziness determines the size of the perturbed voltage when there is a rapid changing in solar irradiation. A control scheme is presented which allows better control of the converter current reference using voltage and current from the PV system as inputs to the MPPT perturb and observes method. The performance of the proposed FLC is tested by simulation and the results show that the FLC is faster in finding the maximum power point than the conventional perturbation and observation method. In order to avoid the problems and difficulties of regulation and variation of the DC bus due to losses in the active power filter (transistors and the output filter), a constant voltage on the DC side of the inverter was proposed, it is a photovoltaic generator which is used to ensure constant amount of power force required to maintain the DC voltage side around its reference value.

Index Terms- Photovoltaic; PV system; MPPT; fuzzy logic; perturb & observe.

NOMENCALTURE

APF	Active Power Filter
PID	Proportional-integral-derivative controller
PI	Proportional-integral controller
P_{-pvsup}	photovoltaic power stocks gain
GPV	photovoltaic generator
h	harmonic Range
MPPT	Maximum Power Point Tracking
PV	Photovoltaic

i_{pv}	Output current (solar cell)
v_{pv}	Output voltage (solar cell)
I_d	Diode dark current
I_{SC}	Short circuit current
i	Overall current
$P_{pv}, P_{ideal}, P_{out}$	Photovoltaic, ideal and output power
V_{boost}	Boost voltage
$V_{optimal(t)}$	Optimal voltage
V_{dc}	Dc voltage
V_{s1}, V_{s2}, V_{s3}	Three phase Source voltage
P, q	active and reactive Power
I_{c1}, I_{c2}, I_{c3}	Load currents
I_1, I_2, I_3	Source currents
V_{α}, V_{β}	Alpha-Beta voltage Components
I_{h1}, I_{h2}, I_{h3}	Harmonic Currents
$I_{c\alpha}, I_{c\beta}$	Alpha-Beta current Components
$I_{ref\alpha}, I_{ref\beta}$	Alpha-Beta current reference
$I_{ref1}, I_{ref2}, I_{ref3}$	abc current reference

I. INTRODUCTION

Recently, there is an increasing concern about the environment pollution. The need to generate pollution-free energy has trigger intensive considerable effort toward alternative source of energy. Solar energy, in particular, is a promising option. Some researcher had spent their effort in developing the combined system of an Active Power Filter (APF) and a photovoltaic (PV) system [1]. However, existing hybrid APF configurations with their benefits are not yet implemented for the PV application. Power output of a solar PV module changes with change in direction of sun, changes in solar insolation level and with varying temperature [2]. Hence maximization of power improves the utilization of the solar PV module and increases the interest of the APF.

Table 1: Table of various MPPT methods

MPPT Method	
1	Perturbation & Observation
2	Hill Climbing
3	Incremental Conductance
4	Power Feedback Control
5	Fractional Short Circuit Current
6	Fractional Open Circuit Voltage
7	Computational & Lookup Table
8	Current Sweep
9	Fuzzy Logic
10	Array Reconfiguration

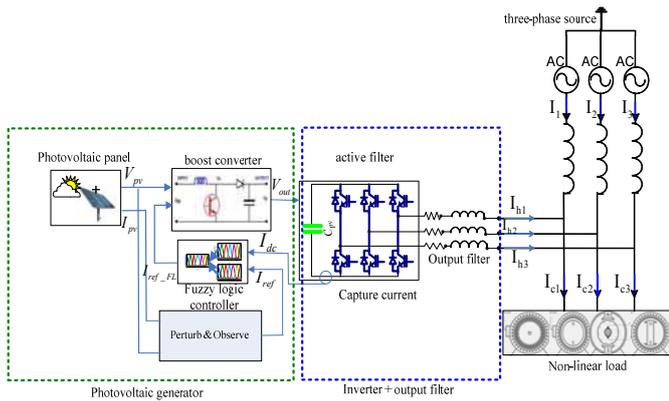


Figure 1. Configuration of the optimal PV system with an APF scheme.

The block diagram of an APF fed by a PV module is shown on Figure 1. A Maximum Power Point Tracking (MPPT) strategy is used for extracting the maximum power from the solar PV module and transferring that power to the load.

Optimal control can be achieved using a DC-DC power converter with a controller capable of MPPT [3]. Techniques for MPPT vary. Some techniques for maximum power point tracking employ changing the bias point and measuring changes in output, while others use predetermined PV models for estimating the MPP. Table 1 show all the MPPT methods referred to in this paper.

The Perturbation and Observation Method (P&O) is one of the most popular MPPT methods because of its simplicity. The P&O method operates by making small incremental changes in voltage and measuring the resulting change in power. By comparing the current power measurement to the previous power measurement, the P&O method selects the direction for the next perturbation. The P&O MPPT method can be implemented using a minimal amount of components; however its speed is limited by the size and the period of the perturbation [4]. The P&O method also has the problems of erroneous responses to quick changing conditions, and in steady state conditions will oscillate around the MPP causing losses. Figure 2 shows the flowchart of this algorithm.

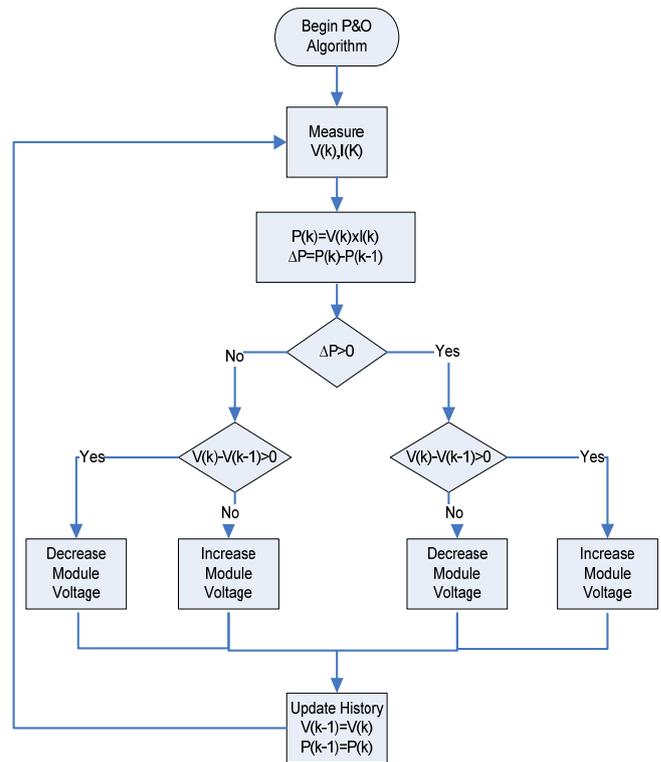


Figure 2. Flowchart of the P&O algorithm

In a situation where the irradiance changes rapidly, the MPP also moves on the right hand side of the curve. The algorithm takes it as a change due to perturbation and in the next iteration it changes the direction of perturbation and hence goes away from the MPP as shown by Figure 3.

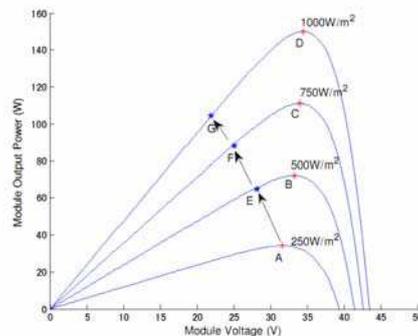


Figure 3. Curve showing wrong tracking of MPP by P&O algorithm under rapidly varying irradiance

II. MPPT USING FUZZY LOGIC CONTROLLER

The oscillation in the P&O method can be minimized by reducing the perturbation step size [5, 6]. But, a smaller perturbation size slows down the MPPT. Another problem is MPPT failure under rapidly changing atmospheric conditions. Fuzzy logic has been used for tracking the MPP of PV systems [7] because it has the advantages of being robust, relatively simple to design and do not require the knowledge

of an exact model. The main components in a FLC are fuzzification, rule-based inferences and defuzzification as shown in Figure 4. The input variables to the FLC are the current from the Perturbe and Observe box in PV array power (E) and the current (dE) whereas the output of FLC is the current reference of boost converter current reference ($I_{ref_FuzzyLogic}$). The current reference is the current that must be drawn from the PV to the boost converter [8].

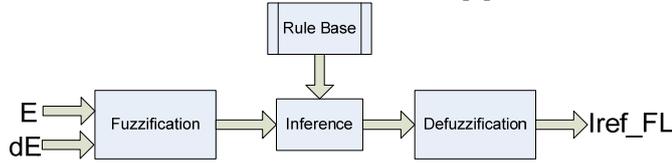


Figure 4. Components of a fuzzy logic controller

The universe of discourse for the first input variable (E) is assigned in terms of its linguistic variable by using seven fuzzy subsets which are denoted by GN, MN, PN, Z, PP, MP and GP. The membership functions for the variable are shown in Figure 5. Figure 6 shows the universe of discourse for the second input variable (dE) which is classified into 7 fuzzy sets, namely as the first. Figure 7 depicts the universe of discourse for the output variable, I_{ref_FL} .

The fuzzy system rule base is created as shown in Table 1 with (E) and (dE) as inputs while I_{ref_FL} is the output. The fuzzy inference of the FLC is based on the Mamdani's method which is associated with the max-min composition. The defuzzification technique is based on the centroid method which is used to compute the crisp output, I_{ref_FL} . The surface of FLC is shown in Figure 8.

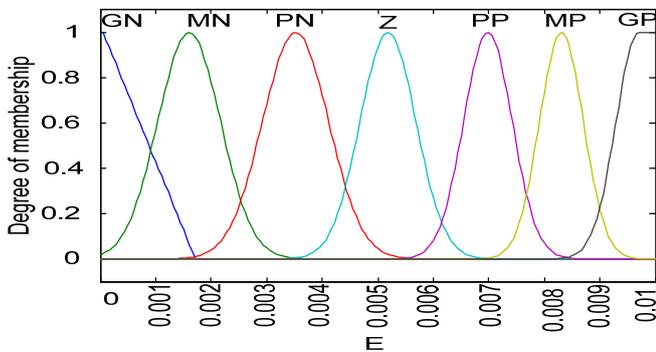


Figure 5. Membership Functions of the 1st Input

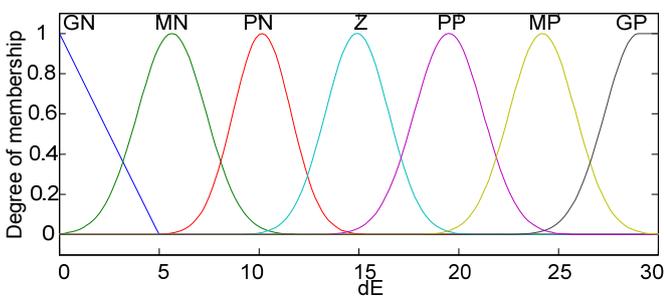


Figure 6. Membership functions of the 2nd input variable

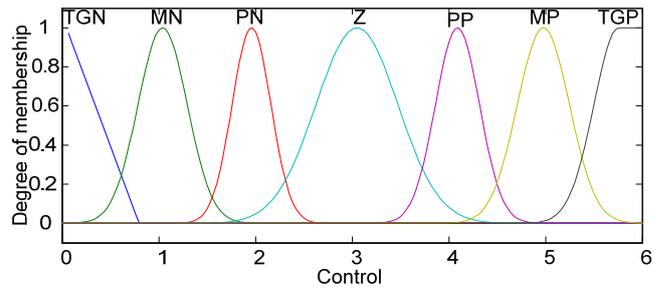


Figure 7. Membership functions of the output variable

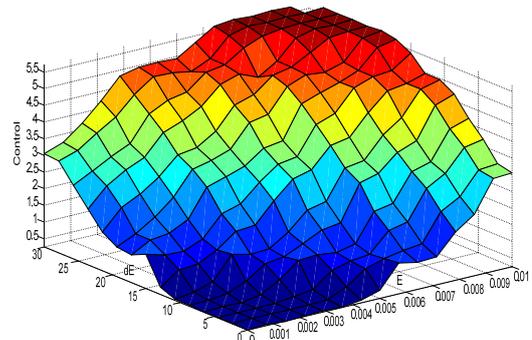


Figure 8. Surface of the fuzzy logic controller

III. SOLAR CELL MODEL USING MATLAB

The simplest solar cell model consists of diode and current source connected parallel. Current source current is directly proportional to the solar radiation. Diode represents PN junction of a solar cell.

$$i_{PV} = I_{SC} - i_D \quad (5)$$

$$i = I_0 \left(e^{\frac{eV}{KT}} - 1 \right) - I_L \Rightarrow$$

$$i = I_0 \left(e^{\frac{V_D}{V_T}} - 1 \right) - I_D \quad (6)$$

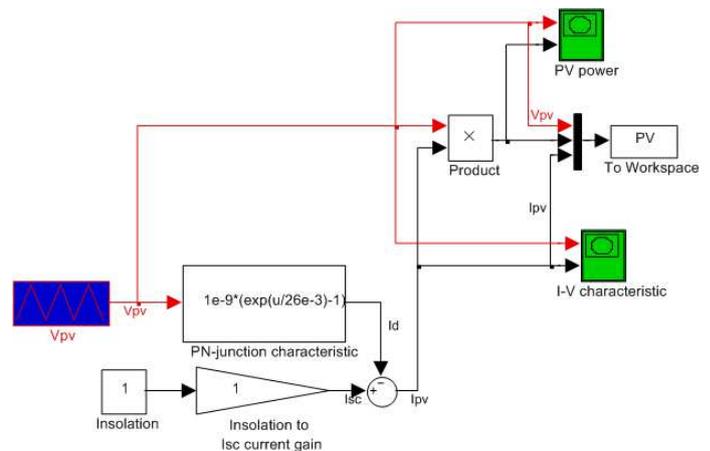


Figure 9. Model of PV using Simulink

The proposed model of photovoltaic using Matlab is shown by Figure. 9. The photovoltaic system consists of:

- a) A 6-module (85 W each) PV array with full sun (1,000 W/m² insolation);
- b) A Boost DC-DC converter that steps-up a DC input voltage;
- c) A capacitor C_{Dc} that provides necessary energy storage to balance instantaneous power delivered to the grid.

IV. RELATIONSHIP BETWEEN THE BLOCKS OF THE SYSTEM [9, 10]

A typical MPPT controller consists of a DC-DC boost converter, chopper controller. A boost converter is designed to step up a fluctuating solar panel voltage to a higher constant DC voltage. The maximum power point of a PV module can be detected by a program carry out using Matlab which is driven by an MPPT algorithm. Once the MPP is obtained, a triggering signal with a specific duty cycle is generated, represented by the reference current and used to trigger the boost converter switches in order to ensure that the converter operates as close as possible to the PV MPP. The system total is shown in the Figure 10.

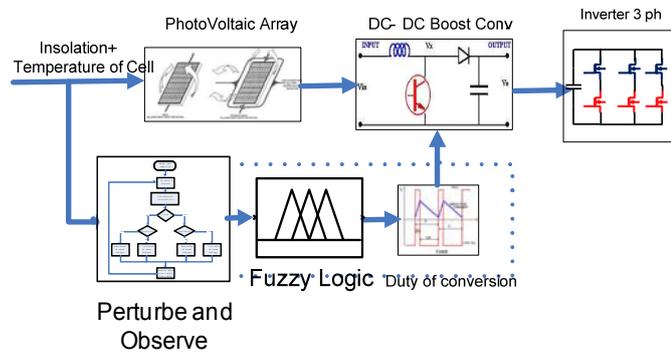


Figure 10. Functional block for all this system using the fuzzy logic technique

V. METHODOLOGY

The proposed MPPT scheme employing FLC has been modeled and simulated using the MATLAB/Simulink software. Figure 8 shows a block diagram of the developed PV system consisting of PV array, boost converter circuit connected to a load and an MPPT controller. The PV array with a capacity of 1 kW consists of 6 PV modules. The fuzzy logic based MPPT controller is simulated with the conventional P&O under the operating conditions of temperature 25 °C with varying insolation (0 to 1000 W/m²). The MPPT controller consists of two main parts, namely, the P&O part then the FLC current controller as depicted in Figure 11.

The FLC with MPPT using P&O algorithm is effective in terms of its tracking capability at a standard condition with fast changing irradiance and ambient temperature of 25°C. It can be observed that the power of the boost converter tracked by P&O method is approximately less than the power achieved by the combination of FLC and the P&O method.

Therefore, the results show good performance of the proposed MPPT using FLC in both transient and steady-state operations.

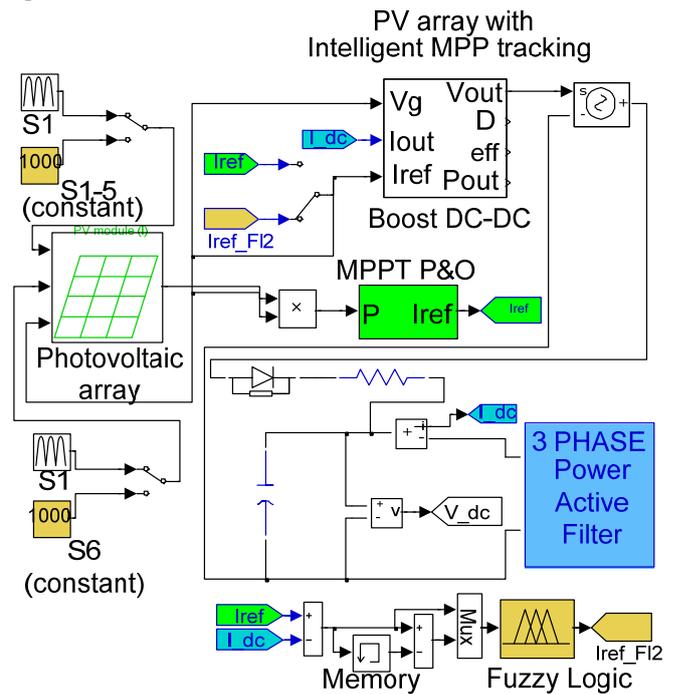


Figure 11. Model of the PV system developed with Matlab/Simulink

Figure 14 show the performance of the PV system using FLC and P&O algorithms under constant temperature of 25°C and fast changing irradiance ([0 400 850 950 1000 950 850 400 0] W/m² at times ([0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08])). The simulation results show that the performance of the P&O and the proposed FLC method are quite similar under these two conditions.

The results of simulation of (FLC_PO) for the MPPT are shown in Figure 12, 13, 14 without MPPT, then with Perturb and Observe (P&Q) method, at the end with a fuzzy logic controller. The variable universe fuzzy control has stronger anti-interference performance than the conventional one, and finds the maximum power point in time of 0.01 seconds. We can see that the variable universe fuzzy control can achieve higher level control precision, better speed tracking performance.

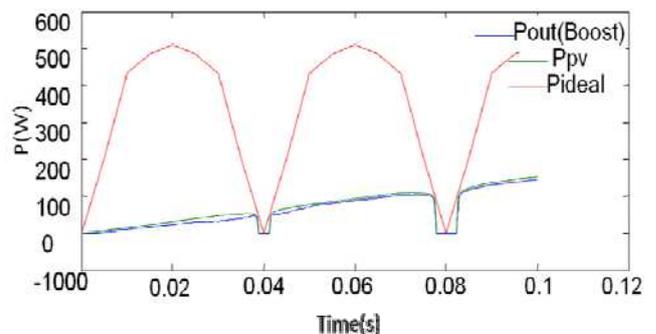


Figure 12. The power of PV systems without MPPT

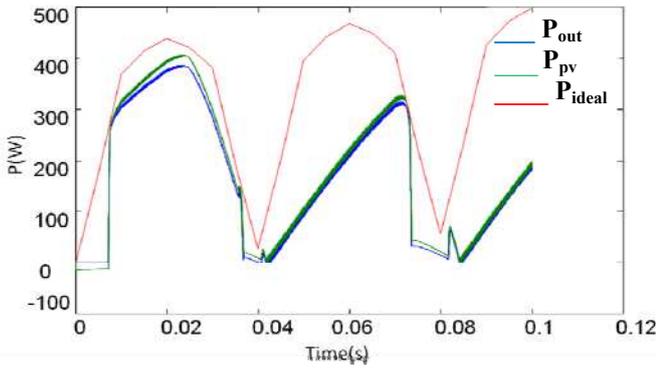


Figure 13. The power of PV systems MPPT using P&O

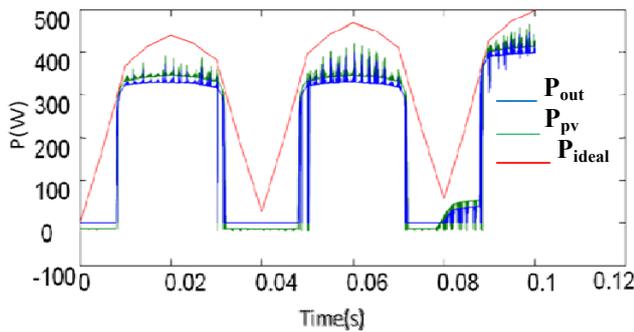


Figure 14. The power of PV systems MPPT using both the P&O and FLC

I. DC ENERGY STORAGE

The DC capacitor serves two main purposes:

- 1) It maintains a DC voltage with a small ripple in steady state and
- 2) It serves as an energy storage element to supply the real power difference between load and source during the transient period [11].

DC link voltage should be higher than maximum peak of the source voltage. DC link voltage can be controlled using proportional-integral (PI) controller [12], proportional-integral-derivative (PID) controller and neural network or a fuzzy logic [13], the control bloc diagram is shown in the Figure 15.

In Figure 15-(a) we can always maximize the value of the reference voltage needed to regulate the terminal voltage of the capacitor, however in Figure 15-(b) provides for return to the case of equilibrium between the source and the load when the load is polluting. By which we can start the regulator optimally to inject additional power from the load side need to compensate reactive power and return to the balancing energy.

In [14], DC link is fed from separate voltage source to stabilize DC-side voltage within a certain range. Switched

capacitor APF that brings new dimension to APF as it reduces components and ratings (particularly capacitor) while performing at low switching frequency is evaluated in [15]. A DC link is used instead of a capacitor and as a battery pack, which is charged from a photovoltaic array in [16]. In Figure 16, the DC voltage after the regulation becomes stable and converges towards the optimal value of the voltage.

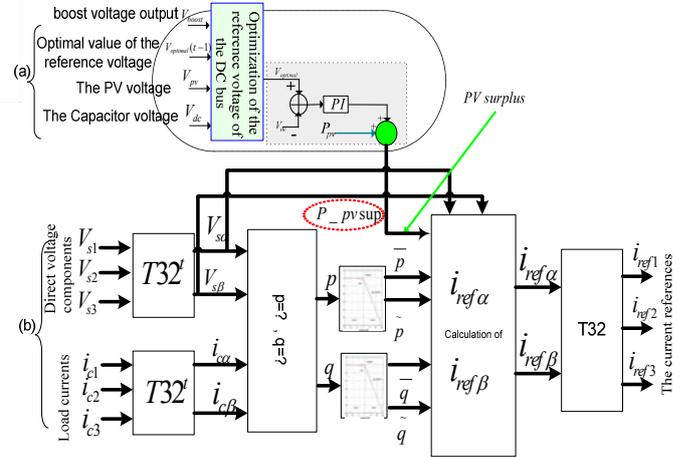


Figure 15. Optimized reference voltage on the DC capacitor

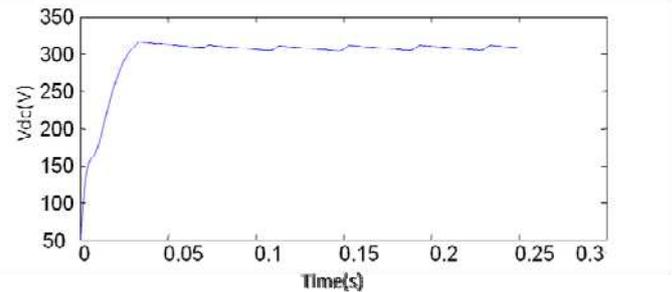


Figure 16. The DC voltage side around its reference value

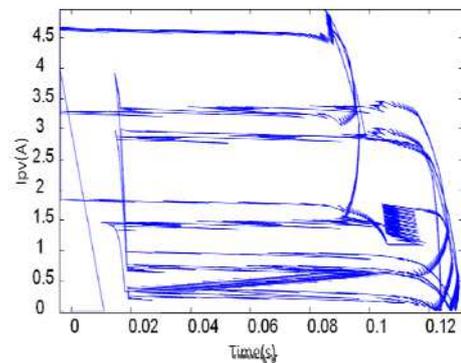


Figure 17. The I_{pv} current as a function of the V_{pv} voltage using the P&O method and for many values of the illumination

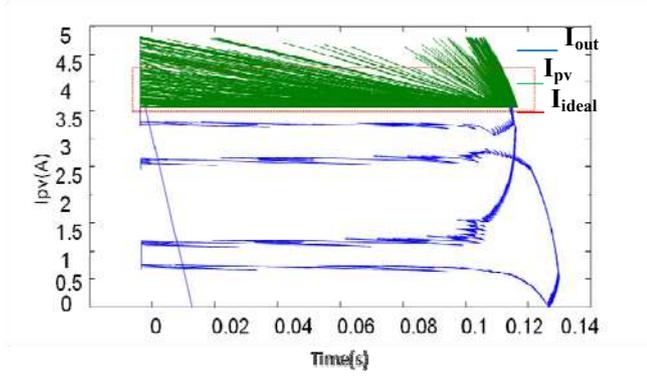


Figure 18. The I_{pv} current as a function of the V_{pv} voltage Using the (P&O_FLC) method

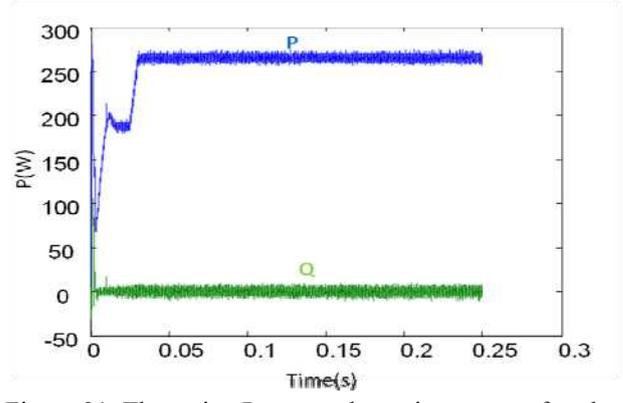


Figure 21. The active Power and reactive power after the compensation scheme using the active power filter with an optimal PV system

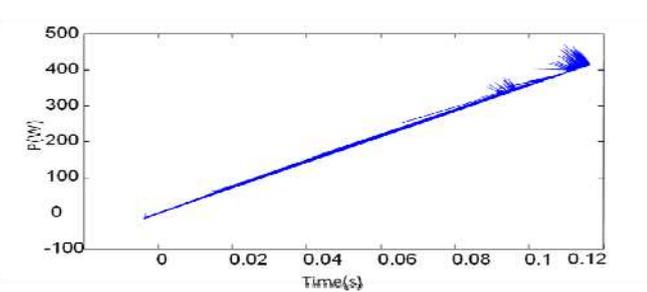


Figure 19. The P_{pv} power as a function of the time Using the (P&O_FLC) method

The relationship between the current and the voltage of the PV is shown in Figure 17 using only the perturb and observe method, however in Figure 18 we can come back to the same point maximum of the power for the same values of irradiation and temperature zone in green, so the relationship between the power of the photovoltaic array as a function of the time becomes semi linear by using the duality of fuzzy logic controller with the P&Q method.

By applying the PV generator on an active power filter we will find the current after the filtering in the Figure 20 and the power active and reactive after the compensation are shown by Figure 21.

II. CONCLUSION

This paper presented an intelligent MPPT control strategy for the PV system using traditional technique of P&O with the fuzzy logic controller. The PV power which is controlled by fuzzy logic is more stable than the conventional P&O MPPT. Simulation results have shown that the proposed MPPT using fuzzy logic and the P&O provides faster tracking of maximum power as compared to the MPPT using the P&O method only. The results have also demonstrated that the MPPT using fuzzy logic gives stable and small oscillation around the maximum power point in addition of the high power of the Boost Converter. In conclusion, the proposed MPPT technique gives an optimal performance than the MPPT using the P&O method.

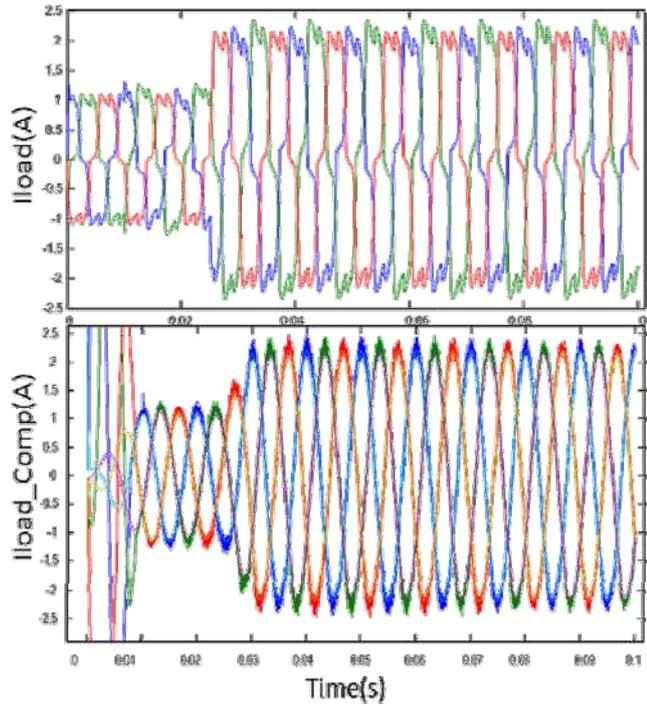


Figure 20. The current of the load before and after the compensation scheme using the active power filter with an optimal PV system

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