A ONE INPUT FUZZY LOGIC CONTROLLER FOR MAXIMUM POWER POINT TRACKING OF A PHOTOVOLTAIC SYSTEM

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Abstract: In this paper, we designed a new one input fuzzy logic controller for maximum power point tracking of a photovoltaic system. The platform of MATLAB/Simulink was used. To assess the one input fuzzy logic controller, a number of simulations were implemented under the insolation variation, the load variation, and various power of photovoltaic system. A comparison between the proposed one input and the two inputs one was carried out to show its interests.
Key words: Maximum Power Point Tracking (MPPT), Perturb & Observe (P&O) method, Fuzzy Logic Controller method, Photovoltaic System, MATLAB/ Simulink.

I. INTRODUCTION

In recent years, the growth of energy demand and of the pollution from use of fossil fuels are pushing the public to use renewable energies. In this context, solar energy is one of the major renewable energy sources that appears as a solution to our problems of energy production. Moreover, this energy resource seems to be the most promising, and inexhaustible. However, the generation of this kind of energy is non-linear. It varies and depends on insolation and ambient temperature. Therefore, the operating point of photovoltaic doesn't always coincide with the point of maximum power (PPM). For this, we used a mechanism research called "maximum power point tracker (MPPT)" to extract the maximum power.

In the literature, the fuzzy logic control method has shown its advantage in terms of performance, robustness and flexibility. This method could quickly respond to the variation of environmental conditions, by keeping photovoltaic (PV) system working at maximum power point at all times, and eliminate the oscillation power around PPM. There are always two inputs in a MPPT fuzzy logic controller (Fig.1) [1-6]. This causes complexity in fuzzification, fuzzy rules and defuzzification.

In this paper, we would like to present a new one input MPPT fuzzy logic controller (Fig.2). By using only one input dP/dV, the structure of the proposed MPPT controller is simple. To show the control performance, numerical simulations and experiments were performed under the variation of environmental condition and load.
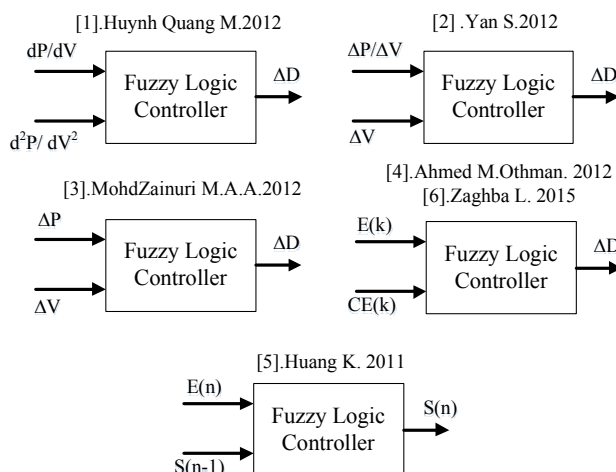

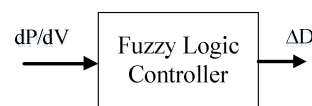Fig.1. Two inputs MPPT fuzzy logic controller in the literature

Fig.2. the proposed one input MPPT fuzzy logic controller

II. ONE INPUT FUZZY LOGIC CONTROLLER

Our main idea is to combine Perturb and Observe (P&O) method (Fig.4) [7, 8] in a one input fuzzy logic controller, in order to take into account the direction of variation of perturbation. The input of fuzzy logic controller is a derivative of dP/dV. And the output is different between the current duty cycle and the previous duty cycle ΔD of boost converter DC/DC (Fig.3).
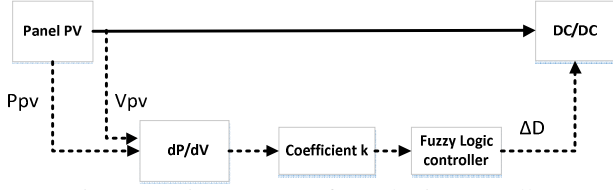
Fig.3. One input MPPT fuzzy logic controller

The rules table easily enables action on the control surface. If we choose a high value of output ΔD, we can quickly achieve the PPM. But it leads us above the point of maximum power (PPM). This also causes oscillations around the PPM. On the contrary, if we choose a small value of output ΔD, the response time of our fuzzy logic controller is slow. But, we can easily reach the PPM.

To solve this problem, we used thirteen membership functions of input dP/dV, and thirteen constant values of output ΔD. The PPM was quickly reached, but was not exceeded. There were no oscillations anymore. When the operating point was far to the left hand side of the PPM, the value of dP/dV was very positive, the duty cycle was shortened rapidly to increase the voltage toward the PPM. When the operating point was close to the left hand side of the PPM, the value of dP/dV was positive but small, the duty cycle slowly decreased. When the operating point was the PPM, the value of dP/dV was zero, the duty cycle was kept constant, there are no longer oscillations anymore around the PPM (Fig.5).

There are three mains advantages to this method. By using only one input dP/dV, the structure of the proposed MPPT controller is simple. The value of input dP/dV converges exactly to zero. And, it depends on the position of the operating point (near or far from the PPM): if it is near the value of output ΔD is small, if it is far the value of output ΔD is big. This improves the response time compared to using the traditional method P&O.

After the derivative dP/dV is calculated, it is converted into thirteen linguistic variables dP/dV = {N6, N5, N4, N3, N2, N1, Z, P1, P2, P3, P4, P5, P6}. The domain of the input dP/dV is set to be [-1; 1]. A coefficient k will be used to adapt to each level power of panel PV (Fig.6).

The output ΔD was generated by thirteen value constants ΔD = {+2%, +0.2%, +0.1%, +0.01%, +0.006%, +0.005%, 0%, -0.005%, -0.006%, -0.01%, -0.1%, -0.2%, -2%}. This algorithm based on the Takagi-Sugendo method that was used to determine the output. For the defuzzification, the weighted average (wtaver) was used (table.1).
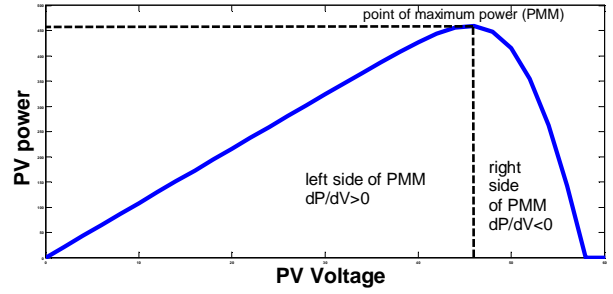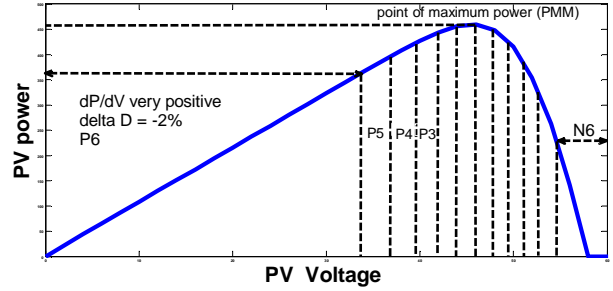

Fig.4. description of the P&O method
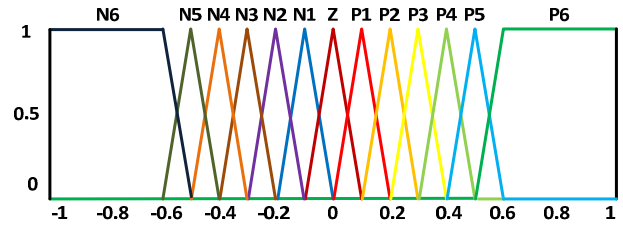

Fig.5. description of the proposed method

Fig.6. Membership function for input of dP/dV

Table.1. Rule based of output ΔD for fuzzy logic control

dP/dV						
N6	N5	N4	N3	N2	N1	Z
+2%	+0.2%	+0.1%	+0.01%	+0.006%	+0.005%	0%

dP/dV					
P1	P2	P3	P4	P5	P6
-0.005%	-0.006%	-0.01%	-0.1%	-0.2%	-2%

III. PHOTOVOLTAIC SYSTEM MODELING

The model of PV panel was used as in [1] to compare between on input fuzzy logic controller and two input ones (Fig.7).

The parameters of PV panel are summarized in table.2 (assuming the cells always work in a constant ambient temperature 25^0C). By changing the number of module connected in series Ns and parallel Np. The power of PV panel also changes.

The model of PV system which consists of PV panel generator, a DC/DC boost converter, a MPPT controller, and a resistive load (Fig.8, 9).
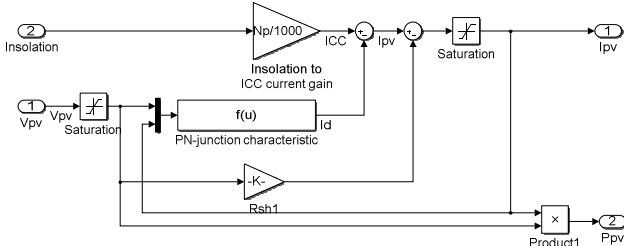
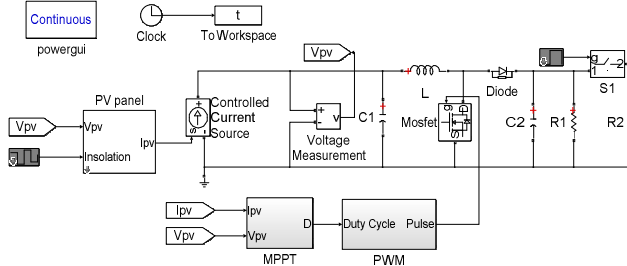Fig.7. model of PV panel in *MATLAB/Simulink*
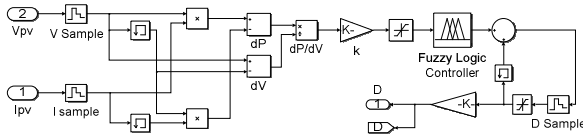

Fig.8. model of PV system in *MATLAB/Simulink*

Fig.9. model of the proposed MPPT fuzzy logic controller

Table.2. Parameters of PV panel

Parameters(in 1000 W/m²) of a module	Values
Short-circuit current	1A
Open-circuit voltage	19.44V
Optimal voltage	15.12V
Optimal current	0.902A

IV. RESULT AND ANALYSIS OF SIMULATION

In order to verify the feasibility of our controller, insolation was modified, a resistive load 100 Ω was fixed, and another resistive load 100 Ω was switched. We tested our one input fuzzy logic controller in a number of cases during a long period of 25 seconds, and during a short period.

1. PV system of small power

In this case, we chosen Ns=3, Np=12. The coefficient k of MPPT controller was 1/9. The maximum power of PV panel at 900 W/m² was 459.5 W.

During a long period of 25 seconds, the insolation variation and load variation were illustrated in Fig.10 and 11 to verify the response of the proposed MPPT fuzzy logic controller.
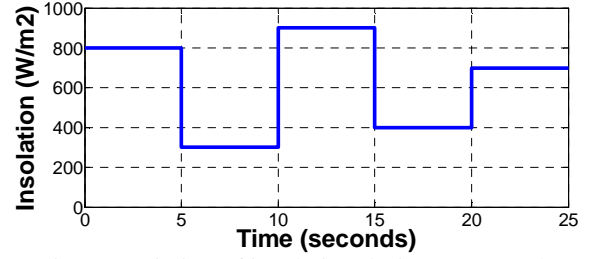

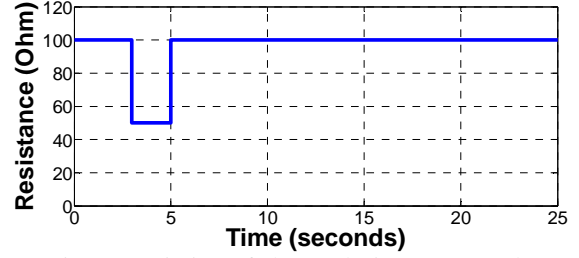Fig.10. variation of insolation during 25 seconds

Fig.11. variation of charge during 25 seconds

According to Fig.12, during the first five seconds, the insolation was 800 W/m² (the optimal voltage of PV panel was V_{opt} = 46.1 V, the maximum power of PV panel was P_{max} = 410.1 W). Our MPPT controller increased voltage of PV panel (V_{pv}) from zero to V_{opt} that enabled maximum power extraction. It needed 0.2 seconds for our system to reach permanent regime. From Fig.14 when the insolation was changed, there were small oscillations of dP/dV value from -0.3 to 0.3 during 0.5 seconds. This leads a small oscillation of PV panel power (Fig.13). After 0.5 seconds, the dP/dV value was controlled to zero. The operating point was reached exactly to the PPM. It proved the accuracy of our controller.
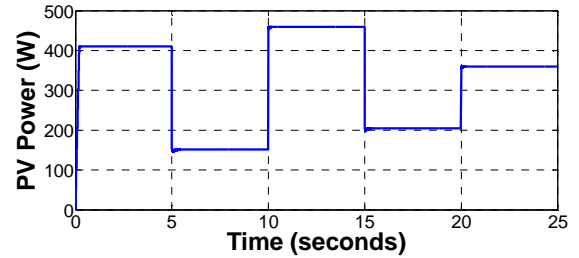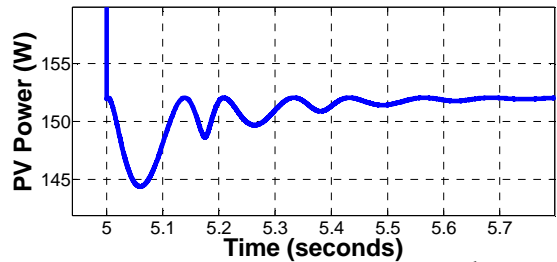

Fig.12. power of PV panel
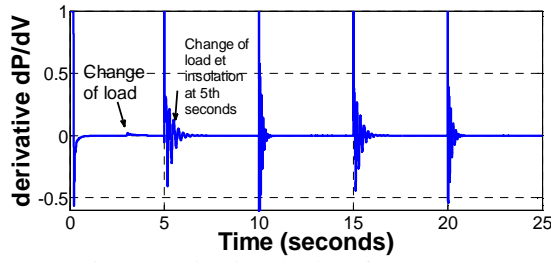

Fig.13. zoom in power of PV panel at 5th seconds

Fig.14. derivative dP/dV of PV panel

When the isolation was changed from 800 W/m^2 to 300 W/m^2 (from 5th second to 10th second), our MPPT controller decrease V_{pv} to 45.5 V to extract the maximum power. We found the same phenomenon under different insolation variation (increased de 300 W/m^2 to 900 W/m^2, then down to 400 W/m^2, then increased to 700 W/m^2). We noted that V_{pv} always followed the V_{opt} for each level of the insolation (Fig.15).
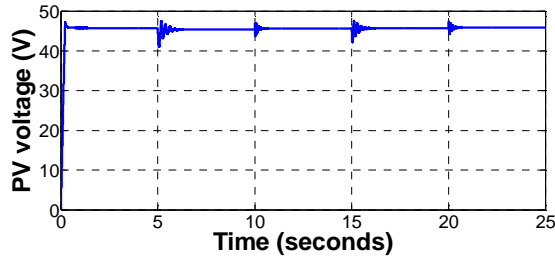

Fig.15. voltage of PV panel

Under a load variation at 3rd second, a load variation and an insolation variation at the same time 5th second, we noted that our controller always managed to keep V_{pv} around its optimal value. The duty cycle D of boost converter was changed to extract the maximum power. After reaching the PPM, the duty cycle was kept constant. So, there was not power oscillation around PPM. It proved the proper operating of our MPPT controller under the load variation and the insolation variation (Fig.16).
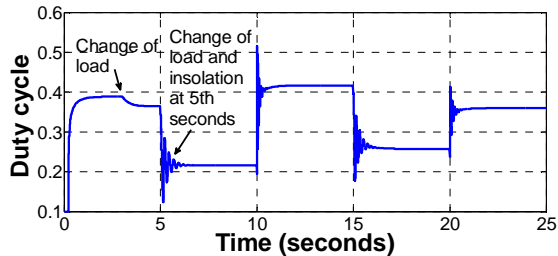

Fig.16. duty cycle of boost converter

At 5th, 10th, 15th, 20th, 25th second, when the insolation was changed, there were significant oscillations of the duty cycle D (Fig.16), and of the input dP/dV (Fig.14). But, there were only small oscillations of PV panel power and PV panel voltage

(Fig.13 and 15). It proved the stability of our controllers.

For summarize, the simulations showed good results in terms of performance, robustness and flexibility of our MPPT controller. It always followed the PPM under variation of atmospheric condition and of the load.

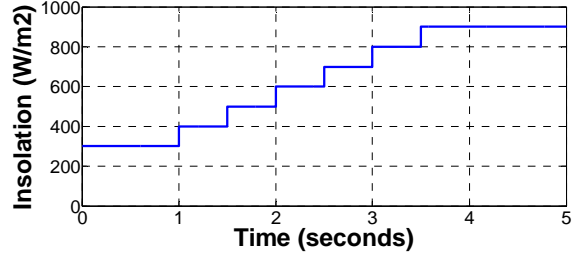Under the rapid insolation variation Fig.17 and 18.
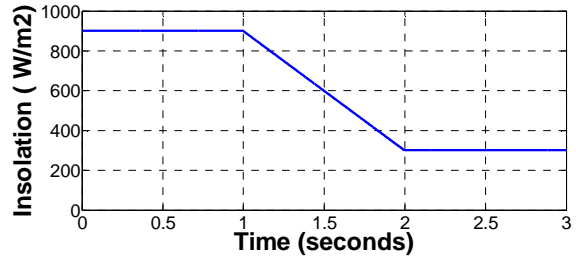

Fig.17. increase of insolation during 5 seconds

Fig.18. linear decrease of insolation during 3 seconds

The simulations results show the power curve of PV panel, from 0.3s to 5s in fig.19, and from 0.2s to 5s in fig.20, the power extracted is 99.9% of the maximal power.
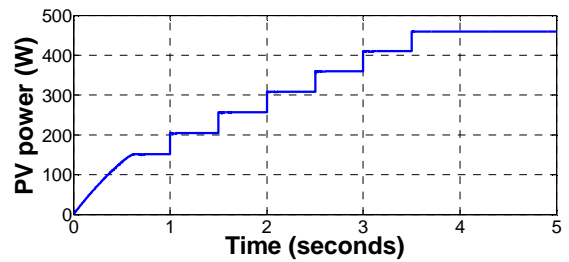

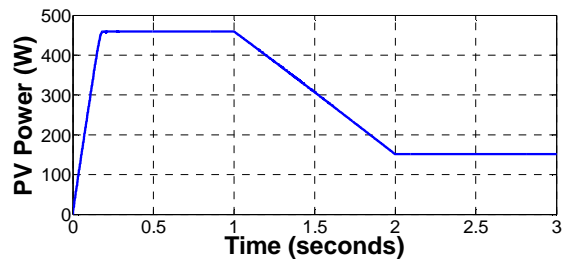Fig.19. PV power under increase of insolation during 5 seconds

Fig.20. PV power under linear decrease of insolation during 3 seconds

For summarizing, we conclude the proposed MPPT fuzzy logic controller operates very well under the rapid insolation variations.

2. PV system of high power

In this case, we chosen Ns=20, Np=30. The coefficient k of MPPT controller was 1/20. The maximum power of PV panel at 900 W/m^2 was 7.688 kW.

The insolation variation and the load variation are illustrated in Fig.10, 11, and 18 to verify the response of the proposed MPPT controller.

The same way in the PV system of small power, the simulation results in Fig. 21, 22, 23,24,25 and 26 show our MPPT controller operates very well under the variation of atmospheric condition and load in the PV system of high power.
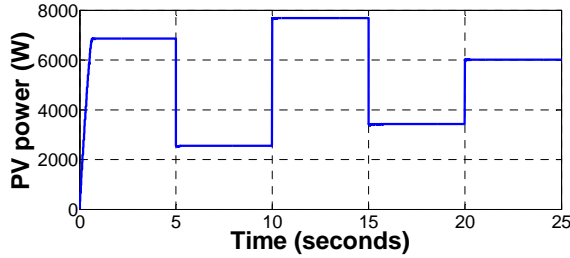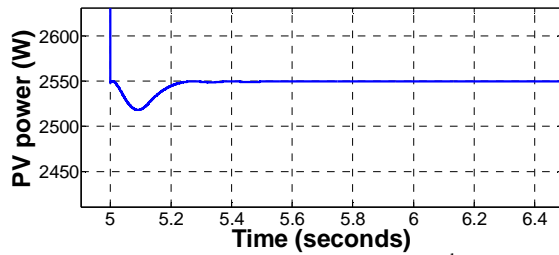

Fig.21. power of PV panel

Fig.22. zoom in power of PV panel at 5th seconds
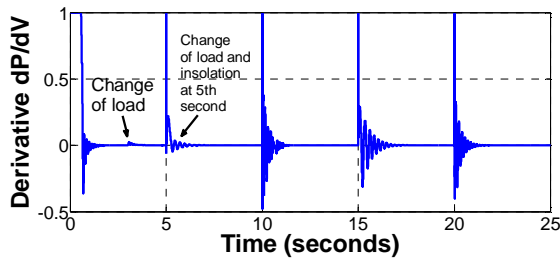

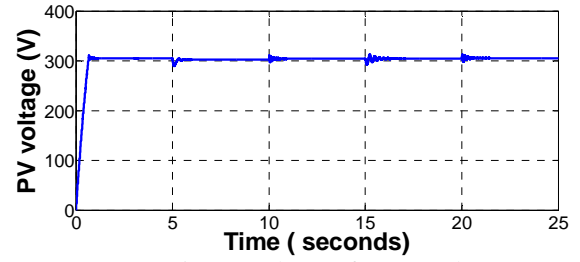Fig.23. derivative dP/dV of PV panel
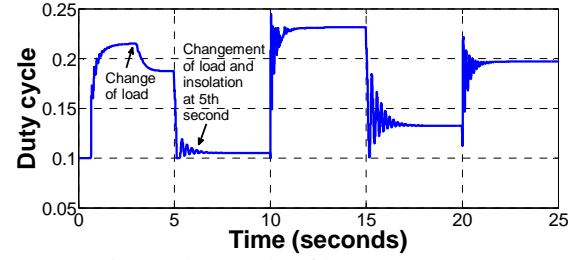

Fig.24. voltage of PV panel
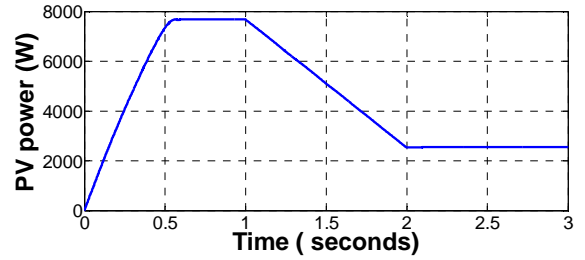

Fig.25. duty cycle of boost converter

Fig.26. PV power under linear decrease of insolation during 3 seconds

V. COMPARISON

To compare between on input MPPT fuzzy logic controller and two input ones. A simulation was performed with the same PV panel and the same resistive load during 50 seconds.

The parameters of the proposed MPPT fuzzy logic controller were used in this paper. The simulations type is continuous (Fig.9).

The two inputs ones were used as in [1]. The simulation type was discrete (Fig.27).

While there is a variation insolation and load, one input MPPT fuzzy logic controller work with a faster response time, more accurate, and more stable than two inputs one (Fig.28).
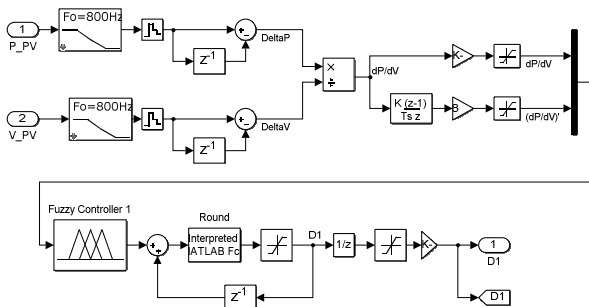
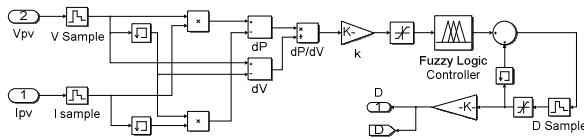Fig.27. model of two inputs MPPT fuzzy logic controller in [1]

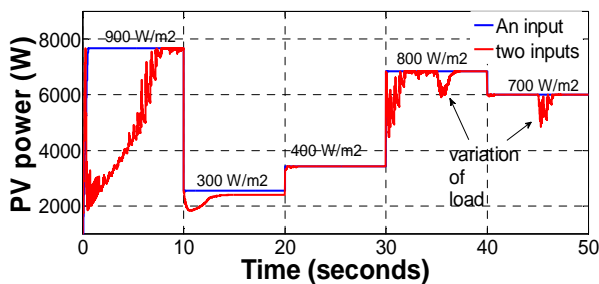Fig.9. model of the proposed MPPT fuzzy logic controller
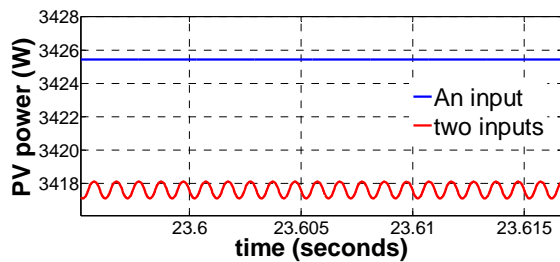

Fig.28.power of PV panel

Fig.29.zoom in power of PV panel

When the operating point reaches the PPM, there is any more oscillation in case of the one input MPPT. But, there is still a small oscillation in case of the two inputs MPPT (Fig.29).

In this simulation, we can conclude that one input MPPT fuzzy logic controller is better than two inputs one in terms of in terms of performance, robustness and flexibility.

VI. CONCLUSION

In this paper, we built a new simple one input MPPT fuzzy logic controller. There are three mains advantages of proposed method. By using only one input dP/dV,

the structure of the proposed MPPT controller is simple. The value of input dP/dV converges exactly to zero. And, it depends on the position of the operating point (near or far from the PPM): if it is near the value of output ΔD is small, if it is far the value of output ΔD is big. This improves the response time compared to using the traditional method P&O.

We tested our fuzzy logic controller under the insolation variation, the load variation, and different power of photovoltaic system. A comparison between the proposed MPPT fuzzy logic controller and two inputs one were be also performed to show its interests.

Simulation results clearly showed that the one input MPPT fuzzy logic controller operated with fast time response, no overshoot, low oscillation, and was more stable with noise in the PV system as compared with two inputs MPPT fuzzy controller in [1]. The proposed MPPT fuzzy logic controller also worked well at rapid insolation variations.

REFERENCES

1. Huynh Quang M., Nollet F., Essounbouli N., Hamzaoui A.: *Fuzzy Control for Stand Alone Wind/ Photovoltaic System.* In: 2nd International Conference on Systems and Control (ICSC12), Marrakech, Morocco, juin 2012.

2. Yan S., Yuan J., Leixu.: *Fuzzy logic control of MPPT for photovoltaic power system.* In: 9th International Conference on Fuzzy Systems and knowledge Discovery (FSKD 2012).

3. MohdZainuri M.A.A., MohdRadzi M.A, AzuraCheSoh.: *Adaptive P&O- Fuzzy Control MPPT for PV Boost Dc-Dc Converter.* In: IEEE International Conference on Power and Energy, Malaysia, 2012.

4. Ahmed M.Othman, Mahdi M.M.El-arini.: *Real world maximum power point tracking simulation of PV system based on Fuzzy Logic Control.* In: NRIAG journal of Astronomy and Geophysics.2012.

5. Huang K., Li W., Huang X.: *MPPT of solar energy generating system with fuzzy control and artificial neutral network.* In: International Conference of Information Technology, Computer Engineering and Management Sciences, 2011.

6. Zaghba L., Terki N., Borni A., Bouchakour A., Benbitour Née Khennane Messaouda.: *Adaptive intelligent MPPT controller comparison of photovoltaic system under different weather conditions of Ghardaia site (South of Algeria).* In: Journal of Electrical Engineering, Volume 15/2015, Edition 3, 2015.

7. Surya Kumari Ms.J., Sai Babu Ch.: *Design and investigation of improved perturb & Observe MPPT algorithm for photovoltaic systems.* In: Journal of Electrical Engineering, Volume 14/2014, Edition 2, 2014.

8. Mamatha G.: *Assessment of different MPPT techniques for PV system*. In: Journal of Electrical Engineering, Volume 16/2016, Edition 1, 2016.

9. Ganesh G., Vijay Kumar G.: *Performance analysis and MPPT control of a standalone hybrid power generation system*. In: Journal of Electrical Engineering, Volume 15/2015, Edition 1, 2015.

10. Josephine R.L., Padmabeaula A., Dhayal R.A., Helen Catherine R.L.: *Simulation of incremental conductance MPPT with direct control and fuzzy logic methods using SEPIC converter*. In: Journal of Electrical Engineering, Volume 13/2013, Edition 3, 2013.

11. Abouobaida H., Khayat M.El., Cherkaoui M.: *Low cost and high efficiency experimental MPPT based on hill climbing approach*. In: Journal of Electrical Engineering, Volume 14/2014, Edition 4, 2014.

12. Deepika S., Sathishkumar R.: *Modeling and simulation of a hybrid green source generation with MPPT control for standalone power system.* In: Journal of Electrical Engineering, Volume 13/2013, Edition 4, 2013.

13. Pradeep A., Kumar Yaday, Thirumaliah S., Haritha G.: *Comparison of MPPT algorithms for DC-DC converters based PV systems.* In: IJAREEIE, vol.1.1, Issue 1, July 2012.

14. Nissah Zainudin H., Mekhilef S.: *Comparaison study of maximum power point tracker techniques for PV systems*. In: Proceeding of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010, paper ID 278.

15. Murtaza A.F., Ahmed Sher H., Chiaberge M.: *Comparative analysis of maximum power point tracking techniques for PV applications*. In: Multi Topic Conference (INMIC), 16th International, 2013.