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Optimization of New Fuzzy Logic Controller by Genetic Algorithm for Maximum Power Point Tracking in Photovoltaic System

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Abstract

Maximum power point tracking (MPPT) is the main solution to reduce the power loss in the photovoltaic (PV) system when temperature and solar irradiance variation occurs. This paper proposes a new intelligent control technique using fuzzy logic controller (FLC) and optimization of its parameters by Genetic Algorithm (GA) to obtain the maximum available power of PV module under unstable conditions. Performance of the conventional fuzzy logic controller is compared with new and optimized maximum power point tracker. Simulation results demonstrated better operation of the optimized fuzzy logic controller under variable weather conditions in comparison with conventional FLC.

Keywords: *Fuzzy, Genetic Algorithm, MPPT, Photovoltaic.*

1. Introduction

Photovoltaic energy is a sort of solar energy that is available in almost all parts of the world and has the least maintenance since it attracts researchers toward this kind of clean and renewable energy. Despite abundant advantages, PV module has low energy conversion efficiency [1]. To overcome the problem, maximum power point tracking technique is necessary [2, 3].

The sunlight intensity is time variant and sometimes changes rapidly in a day, because of this, the optimum operation point of PV module moves from one curve to another. So the maximum power point tracker must track the maximum point as rapidly as possible in order to alleviate the oscillation of output power of PV module [4]. Among the proposed methods, intelligent control is surrogated the conventional algorithms like P&O, INC and so on [5-7]. Fuzzy logic control is an intelligent method which has simplicity and effectiveness in linear and nonlinear systems. Also this control has high implication in maximum power point tracking in photovoltaic systems [8]. For example the ref. [9] corroborated that the FLC reach to maximum power point eight times better than conventional P&O algorithm.

In this paper intelligent control method using new fuzzy logic controller optimized by genetic algorithm is proposed to obtain better performance of energy conversion. The simulation results of optimized FLC compared with new and traditional FLC under variable weather conditions.

2. PV cell model and characteristics

2.1. Equivalent model of PV cell

Accurate mathematical model is necessary to represent the electric characteristics of PV module [10]. The conventional equivalent circuit of solar cell is expressed by one or two diode whereas representing by a photocurrent source, parallel diode, shunt resistance (Rsh) and series resistance (Rs) as seen in ***Figure 1***. The current source (Iph) models the sunlight energy conversion, the shunt resistance represents the consequence of leaks, the series resistant represents the various resistances of connections and the diodes model the PN junctions [11].

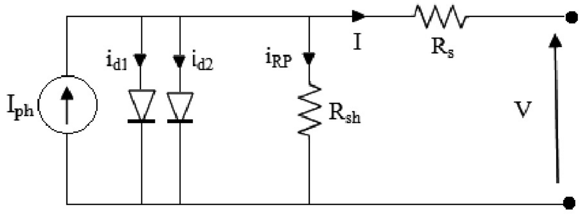


Figure 1. Equivalent circuit of PV cell [12]

The photocurrent generated by the PV module is given by equations 1 and 2:

$$I = I_{ph} - I_{d1} - I_{d2} - I_{RP} \quad (1)$$

$$I = I_{ph} - I_{S1} \times (\exp \frac{q.(V + R_S.I)}{A_1.k.T} - 1) - I_{S2} \times (\exp \frac{q.(V + R_S.I)}{A_2.k.T} - 1) - \frac{V + R_S.I}{R_{Sh}} \quad (2)$$

Where V and I is the PV module voltage and current; q is the electronic charge; $I_{s1,2}$ is saturation current of diodes; $A_{1,2}$ is ideality factor of PV junctions; K is Boltzmann's constant and T the cell temperature.

2.2. Electric characteristics of PV cell

The output power of PV module is dependent on two parameters, sunlight intensity and PV cell temperature. Solar irradiance has direct relation and temperature has reverse relation with output power of PV module. It means increasing the sunlight intensity; the output power rises up. Increasing the temperature; the power comes down. ***Figure 2*** and ***Figure 3*** show the output characteristics of PV module under variable sunlight intensity and different temperatures.

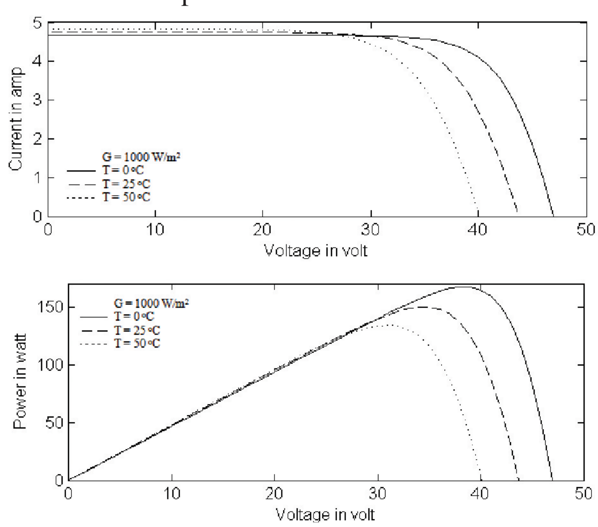


Figure 2. *I-V and PV characteristics of a PV module for different temperature*

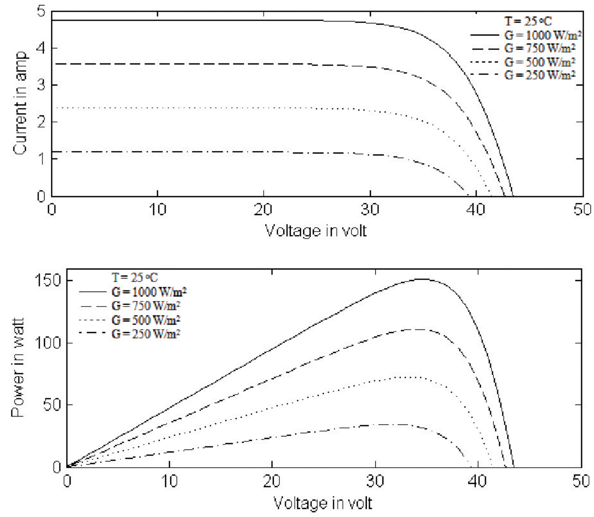


Figure 3. *I-V and PV characteristics of a PV module for varied sunlight intensity*

3. MPPT Technique

Figure 4 shows nonlinear characteristic of PV module, load characteristic, and the maximum power point. As it seems there is just an optimum operation point in PV module curve. If the electrical load connects to the PV module directly and resistance is equal to division of voltage into current of the module, then it is possible to obtain maxim power [13]. But if the load resistance is not equal, reaching to maximum power is impossible. However under variable weather conditions, the MPP moves from one curve to another so the resistance of electrical load must change to obtain maximum power and this is not executive. Therefore in constant load situation an intermediate part is required. This part is maximum power point tracker. Maximum power point tracker is a DC/DC converter which is associated with control unit. It is usually embedded between PV module and the load [14] as seen in ***Figure 5***.

There are several MPPT techniques as hill-climbing, P&O, Incremental Conductance. These are conventional methods and have some drawbacks such as [15]:

- Converging to maximum operation point is slow.
- Oscillation of PV power amplitude around MPP is considerable that cause power losses.
- When the irradiance changes quickly, the system response is slow and moves away from MPP.

To conquer these drawbacks, modern MPPT techniques such as Fuzzy Logic Controller, neural network and intelligent method are proposed [16, 17].

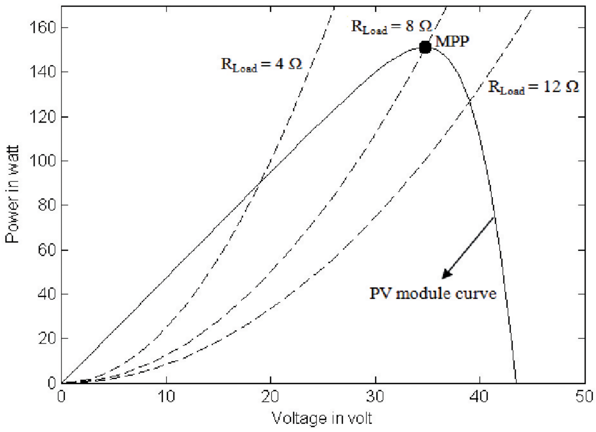


Figure 4. Photovoltaic module and load characteristics

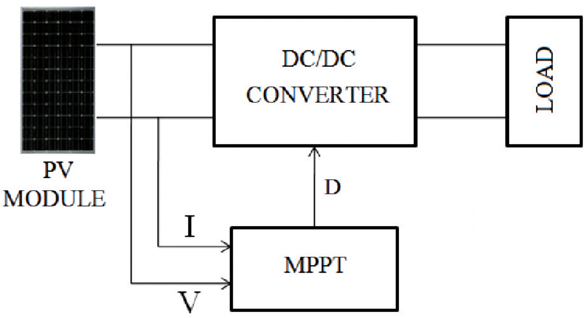


Figure 5. Stand-alone photovoltaic system [12]

4. Fuzzy Logic Controller

Fuzzy logic controller properly performs in nonlinear systems. It is on the basis of designer knowledge rather than accurate mathematical model [1]. FLC consists of four categories as fuzzification, inference engine, rule base and defuzzification. In the first section, numerical input variable are converted into fuzzy variable known as linguistic variable [1]. Inference engine defines controller output in order to fuzzified input, rule base and fuzzy inference methods. Rule base section consists of "if A and B and C then D" forms. Finally output linguistic terms are converted to numerical variable in defuzzification section. *Figure 6* shows the fuzzy inference system.

Conventional fuzzy maximum power point tracker consists of two inputs and on output. But as shown in *Figure 7* V_{pv} is added to input in proposed method to enhance the accuracy of tracking the optimal point. Equations (3-5) express the inputs of FLC; E, CE and V_{pv}. The defuzzification uses center of gravity to compute the output of FLC (ΔD) as equation (6).

$$INPUT1: E(t) = \frac{P_{pv}(t) - P_{pv}(t-1)}{V_{pv}(t) - V_{pv}(t-1)} \quad (3)$$

$$INPUT2: CE(t) = E(t) - E(t-1) \quad (4)$$

$$INPUT3: V(t) \quad (5)$$

$$\Delta D = -\frac{\sum_{j=1}^{n} \bar{y} D_j}{\sum_{j=1}^{n} D_j} \quad (6)$$

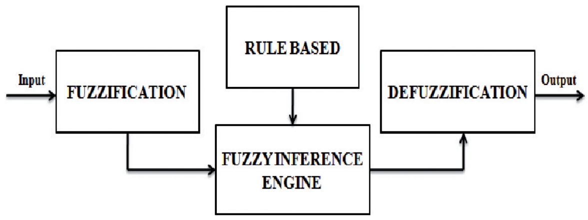
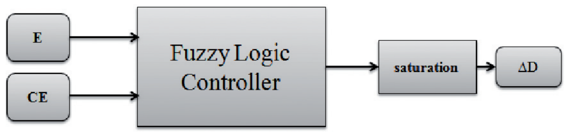
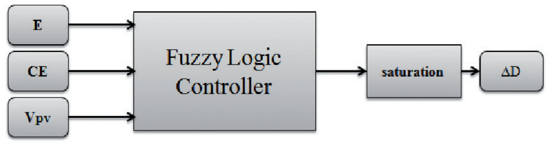


Figure 6. Fuzzy inference system [18]



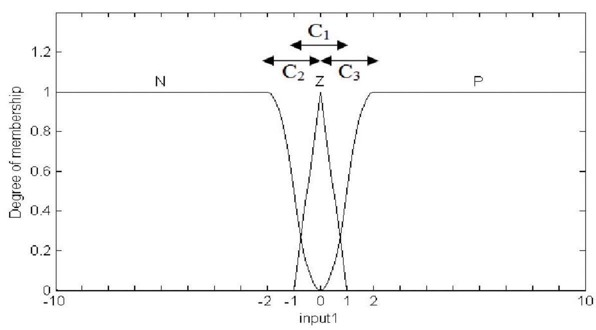
(7-a) [19]



(7-b)

Figure 7. Configuration of MPPT algorithm with Fuzzy Logic Controller, a) conventional method, b) proposed method

Figure 8 shows fuzzy membership functions for E, CE, Vpv and ΔD. The terms N,Z,P,L and G respectively mean negative, zero, positive, little and great. The output membership functions are nominated as mf1 to mf9. The extent of membership functions parameter are {-10, 10}, {-10, 10}, {30, 40} for inputs and {-1, 1} for the output.



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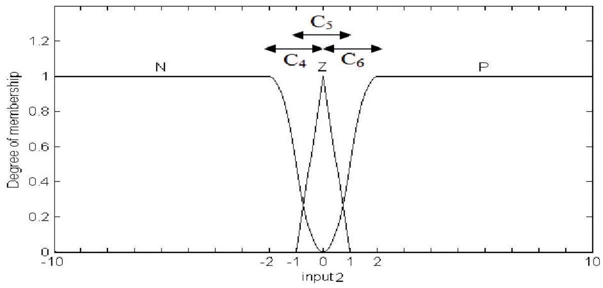

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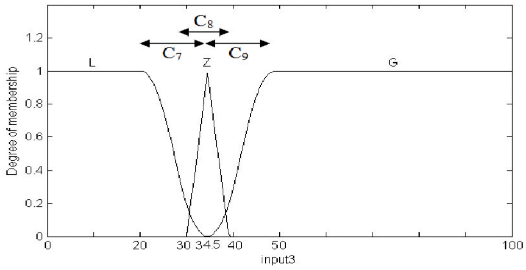

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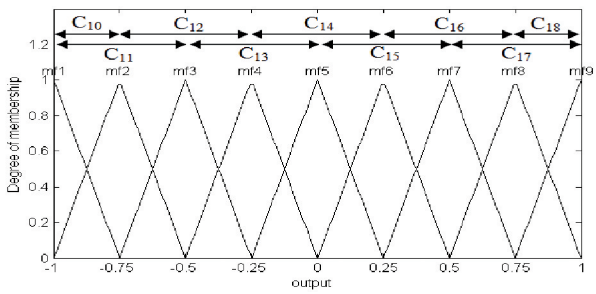


(8-d)

***Figure 8.** Membership functions, a) first input, b) second input, c) third input, d) output*

The fuzzy inference is carried out by mamdani's method. The control rules are indicated in ***Table 1***.

TABLE 1. Fuzzy rules

input1	input2	input3	input
N	N	Z	Mf4
N	N	G	Mf1
N	Z	Z	Mf3
N	Z	G	Mf1
N	P	Z	Mf5
N	P	G	Mf4
Z	N	Z	Mf4
Z	N	G	Mf2
Z	Z	Z	Mf5
Z	P	L	Mf8
Z	P	Z	Mf6
Z	P	G	Mf4
P	N	L	Mf7
P	N	Z	Mf5
P	Z	L	Mf7
P	Z	Z	Mf6
P	P	L	Mf9
P	P	Z	Mf7

5. Optimization of Fuzzy Logic Controller by Genetic Algorithm

Genetic algorithms search the best access to solve the problem in order to natural selection and genetics theory. This algorithm produces some random responses and coding each one as a chromosome. The fitness of each chromosome is defined by evaluation of fitness function. Each chromosome has higher value of fitness is preserved and other is eliminated. Frequently two chromosomes that have a higher value are selected as parents. These parents exchange their genes and generate new population. Pairs of chromosomes in the new population are chosen randomly for exchange of genetic material, this is called crossover. After producing two new chromosomes which replaces its parents, in mutation operator randomly chosen bits in the offspring are flipped [20]. Here if the terminating state is satisfied then the algorithm stops otherwise back to second stage and repeats the further stage. The genetic algorithm structure is shown in ***Figure 9***.

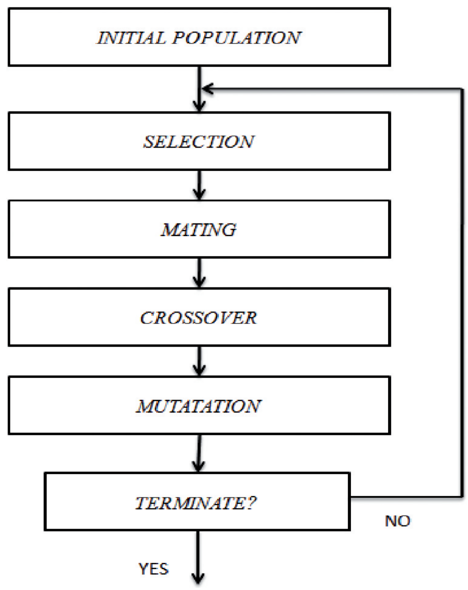


***Figure 9.** Genetic algorithm structure [21]*

In our work the purpose is to find the optimum membership function parameters due to generate optimal duty cycle. So determining the fitness function of the GA is the most important part. For each individual chromosome the fitness value should be determined in the population. To alleviate the output power of PV module the fitness function is described in equations (7-8):

$$fitness = \int |e(t)|\,dt \tag{7}$$

$$e(t) = P(t)_{STC} - P(t)_{PV} \tag{8}$$

P (t) $_{ref}$ is the output power of PV module under STC (Standard Test Condition), 1000 w/m^2 irradiance and temperature 25°C. ***Table 2*** summarized the parameters used in GA.

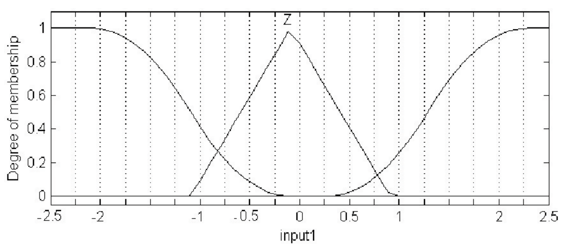
TABLE 2. Options of genetic algorithm

Parameter	Value
Population size	40
generation	120
Selection method	Roulette wheel
Fitness scaling	Top
Rate of crossover	0.8
Mutation method	Gaussian

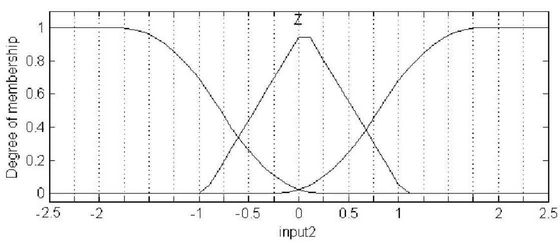
The population consists of a set of individuals. Each individual is composed of four chromosomes: E(t), CE(t), V(t), ΔD as described in ***Table 3***. The parameters (C_1-C_{18}) indicate the genes in genetic algorithm. The optimized membership functions are shown in ***Figure 10***.

TABLE 3. Chromosomes of membership function

Chromosome 1								
	C_1			C_2			C_3	
Chromosome 2								
	C_4			C_5			C_6	
Chromosome 3								
	C_7			C_8			C_9	
Chromosome 4								
C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}



(10-a)



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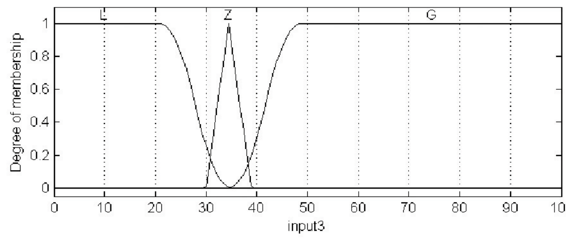

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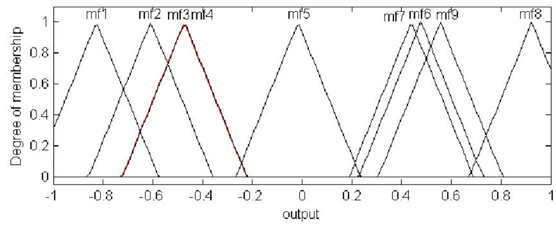


(10-d)

Figure 10. *Optimized membership functions, a) first input, b) second input, c) third input, d) output*

6. Simulation and results

Photovoltaic system consists of PV module, MPPT controller, DC/DC converter with resistive load and pulse width modulator. "BP SX150" photovoltaic panel and MATLAB software is used for simulation. ***Table 4*** provides the following information on BP SX150S PV module [22]. DC/DC converter parameter's value is shown in ***Table 5***.

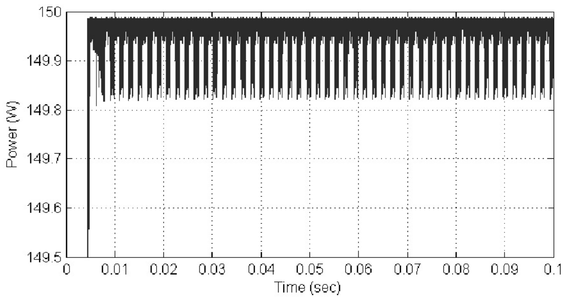
TABLE 4. BP SX 150S data sheet [22]

Model	BP SX 150S
Maximum power (Pmax)	150W
Voltage at Pmax (Vmp)	34.5V
Current at Pmax (Imp)	4.35A
Short-circuit current (Isc)	4.75A
Open-circuit voltage (Voc)	43.5V
Temperature coefficient of Isc	(0.065±0.015)%/°C
Temperature coefficient of Voc	-(160±20)mV/°C
Temperature coefficient of power	-(0.5±0.05)%/°C
NOCT	47±2°C

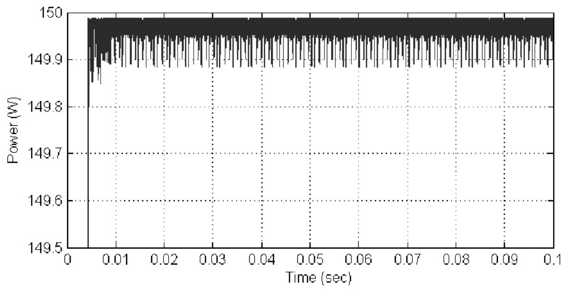
TABLE 5. DC/DC converter configuration

L	168 μH
Cin	15 μF
Cout	500 μF
Switching frequency	25 kHz

The simulation is run under standard test condition. As seen in ***Figure 11***, the proposed fuzzy logic controller performance is better than the conventional FLC. Also, the optimized proposed FLC reduce the oscillations of photovoltaic module output power.



(11-a)



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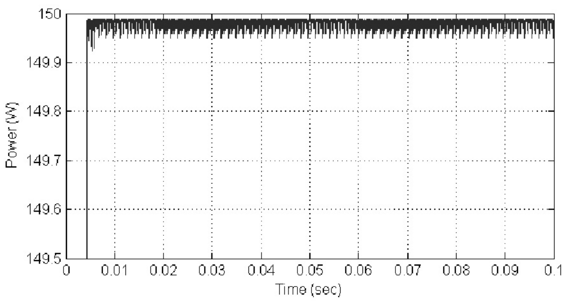


(11-c)

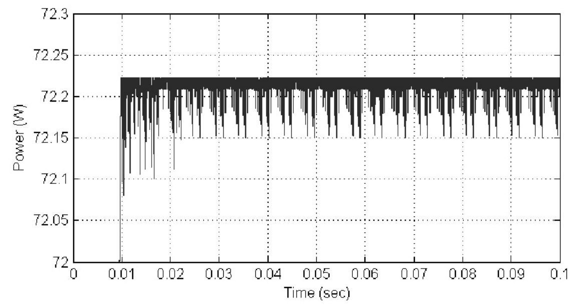
Figure 11. *Output power of PV module under 1000 W/m² irradiance and 25°C temperature, a) conventional fuzzy controller, b) proposed controller, c) optimized proposed controller*

Figure 12 shows the performance of controllers under 500 W/m² irradiance with 25°C temperature and ***Figure 13*** expresses controllers operation under 1000 W/m² irradiance with 50°C temperature. It is obvious that output power of PV module oscillations decreased by proposed controller and grew better by optimized FLC.

Also, the pick-to-pick oscillation of output power of PV module is compared in ***Table 6*** with different weather conditions and different MPPT controllers.

TABLE 6. Pick-to-pick oscillation of PV output power (watt)

Controller / Conditions	conventional FLC	proposed FLC	opt proposed FLC
T = 25 °C G = 1 kW/m²	0.16	0.1	0.03
T = 25 °C G = 0.5 kW/m²	0.07	0.05	0.03
T = 50 °C G = 1 kW/m²	0.18	0.18	0.09



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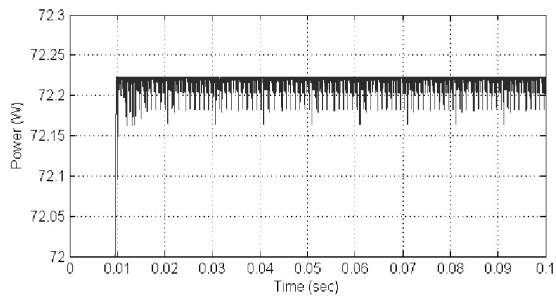

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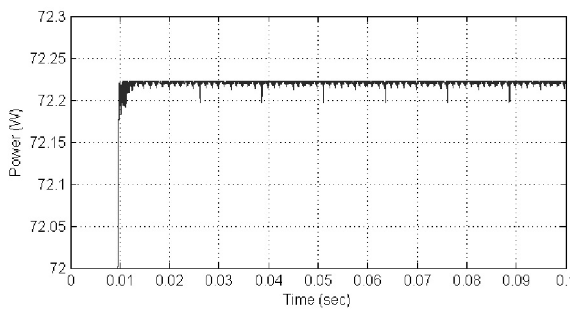
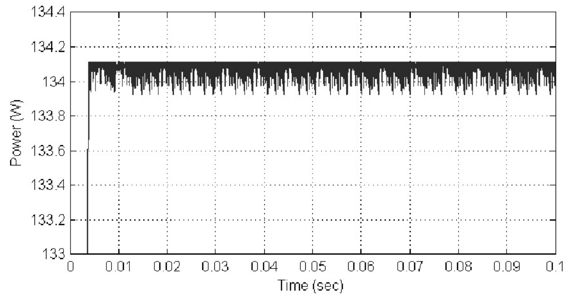
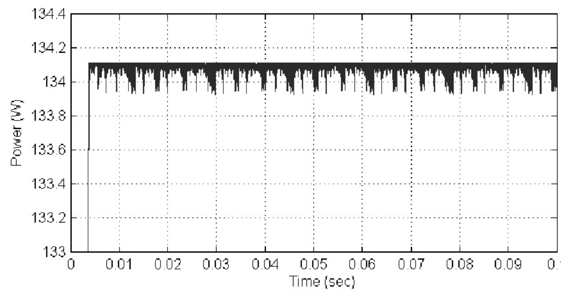


(12-c)

Figure 12. *Output power of PV module under 500 W/m2 irradiance and 25°C temperature, a) conventional fuzzy controller, b) proposed controller, c) optimized proposed controller*



(13-a)



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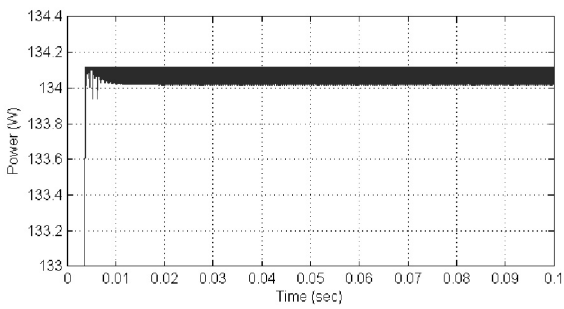
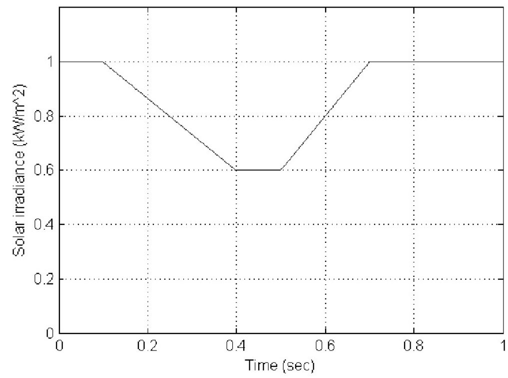


(13-c)

Figure 13. *Output power of PV module under 1000 W/m² irradiance and 50°C temperature, a) conventional fuzzy controller, b) proposed controller, c) optimized proposed controller*

Also, performance of optimized fuzzy logic controller is studied under variable solar irradiance and temperature simultaneously. It is considered that the solar irradiance changes from 1000 w/m² to 600 w/m² and 600 w/m² to 1000 w/m² in t=0.1 sec to t= 0.4 sec and t=0.5 sec to t=0.7 sec. Also, temperature changes from 25°C to 20°C and 18°C in t=0.1, t=0.4 and t=0.7. The PV output power, voltage and current variation under unstable condition is shown in ***Figure 14***.



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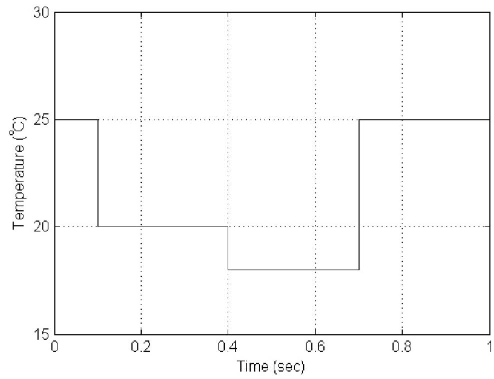

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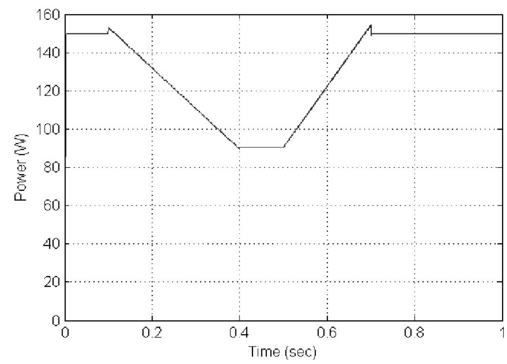

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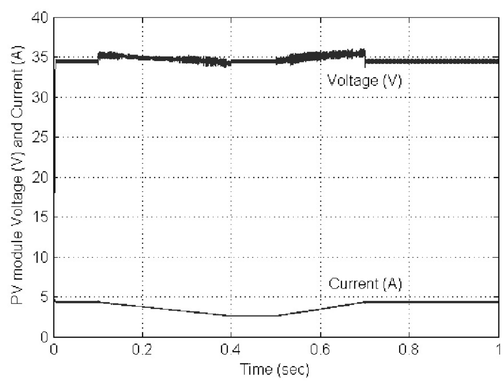

(14-d)

Figure 14. *Proposed mppt controller, a) solar irradiance variation, b) temperature variation, c) PV power, d) voltage and current of PV module*

Conclusion

Maximum power point tracker has a significant rule in PV systems because of low efficiency of PV modules, crisis of energy and incremental cost of fossil fuel. In this paper an intelligent maximum power point tracking technique for photovoltaic system is proposed to obtain the maximum available power. At first the performance of conventional fuzzy logic controllers is compared with proposed method. Then the parameters of membership functions of new mppt fuzzy logic controller are optimized by Genetic Algorithm. Simulation results indicate that the proposed method reduces the fluctuations near the optimal power point in comparison with conventional fuzzy logic controller. Also, the optimized proposed controller operates better than proposed controller which is not optimized.

References

[1] Mei Shan Ngan, Chee Wei Tan, "A Study of Maximum Power Point Tracking Algorithms for Stand-alone Photovoltaic Systems", IEEE applied powet electronics colloquium, 2011.

[2] Salas V, Olıas E, Barrado A, Lazaro A. Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems. Solar Energy Materials & Solar Cells,90:1555-78, 2006.

[3] Wilamowski BM, Li X. Fuzzy system based maximum power point tracking for PV system. In: 28th Annual Conf. of the IEEE Ind. Electron. Society, pp. 3280-84, 2002.

[4] A. Messai, A. Mellit, A. Guessoum, S.A. Kalogirou, "Maximum power point tracking using a GA optimized fuzzy logic controller and its FPGA implementation", Solar Energy 85, 265-277, 2011.

[5] Bahgat, A.B.G., Helwa, N.H., Ahmad, G.E., El Shenawy, E.T., "Maximum power point tracking controller for PV system using neural networks", Renewable Energy 30, 1257-1268, 2005.

[6] Mellit, A., Kalogirou, S.A., "Artificial intelligence techniques for photovoltaic applications", a review. Progress in Energy and Combustion Science 34, 574-632, 2008.

[7] Chu, C., Chen, C., "Robust maximum power point tracking method for photovoltaic cells", a sliding mode control approach. Solar Energy 83 (8), 1370-1378, 2009.

[8] Mellit, A., Mekki, H., Messai, A., Salhi, H., "FPGA-based implementation of an intelligent simulator for stand-alone photovoltaic system", Expert Systems with Applications 37, 6036-6051, 2010.

[9] Khaehintung, N., Sirisuk, P., "Implementation of maximum power point tracking using fuzzy logic controller for solar-powered lightflasher applications", The 47th IEEE International Midwest symposium on Circuits and Systems, Hiroshima, July 25-28, pp. 171-174, 2004.

[10] Weidong Xiao, Magnus G. J. Lind, William G. Dunford, Antoine Capel, "Real-Time Identification of Optimal Operating Points in Photovoltaic Power Systems", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 53, NO. 4, AUGUST 2006.

[11] Y. Pankow, "Étude de l'intégration de la production décentraliséedansun-réseaubasse tension Application aux générateursphotovoltaïques", Thèse de doctorat Centre national de recherché technologique de Lille 2005.

[12] F.Bouchafaa, I.Hamzaoui and A.Hadjammar, "Fuzzy Logic Control for the tracking of maximum power point of a PV system", Energy Procedia (Elsevier), vol. 6, pp. 633-642, 2011.

[13] Emil Jimenez-Brea, Andres Salazar-Llinasy, Eduardo Ortiz-Riveraz, Jesus Gonzalez-LlorenteX," A Maximum Power Point Tracker Implementation for Photovoltaic Cells Using Dynamic Optimal Voltage Tracking", Applied Power Electronics Conference and Exposition (APEC), PP. 2161 - 2165, 2010.

[14] Kida, J., Tokuda, K., Ishihara, Y., Todaka, T., "Analysis of DC-DC converter for the maximum power point control of photovoltaic", In: INTELEC'91, IEEE Proceedings, pp. 291-295, 1991.

[15] Bader N. Alajmi, Khaled H. Ahmed, Stephen J. Finney, Barry W. Williams, "Fuzzy-Logic-Control Approach of a Modified Hill-Climbing Method for Maximum Power Point in Microgrid Standalone Photovoltaic System" , IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 26, NO. 4, APRIL 2011.

[16] Chokri Ben Salah, Mohamed Ouali, "Comparison of fuzzy logic and neural network in maximum power point tracker for PV systems", ELSEVIER Electric Power Systems Research 81 (2011) 43-50.

[17] Kalantari, A., et al., A Faster Maximum Power Point Tracker Using Peak Current Control, IEEE Symposium on Industrial Electronics and Applications, 2009.

[18] C. Larbes, S.M. Cheikh, T. Obeidi, A. Zerguerras, "Genetic algorithms optimized fuzzy logic control for the maximum power point tracking in photovoltaic system", Elsevier Ltd, renewable energy 34, pp. 2093-2100, 2009.

[19] Biology of genetic algorithm. Retrieved from website http://www.cs.drexel.edu/~shartley/geneticAlgorithms.html

[20] D.T pham, D. Karaboga, " Optimum Design of Fuzzy Logic Controllers Using Genetic Algorithm", Journal of Systems Engineering, pp. 114-118, 1991.

[21] BP SX150 - 150 watt multi crystalline photovoltaic module datasheet, 2001, (http://www.southwestpv.com/download.html)