International Journal of Electrical and Electronics Engineering (IJEEE)
ISSN(P): 2278-9944; ISSN(E): 2278-9952
Vol. 3, Issue 1, Jan 2014, 49-60

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

FUZZY LOGIC BASED MAXIMUM POWER POINT TRACKING TECHNIQUE FOR PARTIALLY SHADED PHOTOVOLTAIC SYSTEM

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ABSTRACT

Current–voltage and power–voltage characteristics of large photovoltaic (PV) arrays under partially shaded conditions are characterized by multiple steps and peaks. This makes the tracking of the actual maximum power point (MPP) a difficult task. In addition, most of the existing schemes are unable to extract maximum power from the PV array under these conditions. This paper proposes a modified fuzzy-logic controller for maximum power point tracking is proposed to increase photovoltaic system performance during partially shades conditions. Instead of perturbing and observing the PV system MPP, the controller scans and stores the maximum power during the perturbing and observing procedures. The controller offers accurate convergence to the global maximum operating point under different partial shadowing conditions. A mathematical model of the PV system under partial shadowing conditions is derived. To validate the proposed modified fuzzy-logic-based controller, simulation results are provided.

KEYWORDS: Boost Converter, Fuzzy, Logic Controller (FLC), Maximum Power Point (MPP) Tracker (MPPT), Partial Shadowing and Photovoltaic (PV)

INTRODUCTION

THE ever-increasing demand for low-cost energy and growing concern about environmental issues has generated enormous interest in the utilization of nonconventional energy sources such as the solar energy. The freely and abundantly available solar energy can be easily converted into electrical energy using photovoltaic (PV) cells. A PV source has the advantage of low maintenance cost, absence of moving/rotating parts, and pollution-free energy conversion process.

However, PV systems suffer from a major drawback which is the nonlinearity between the output voltage and current particularly under partially shaded conditions [5]. During partially shaded conditions, the system *P–V* characteristic curve has multiple peaks. Therefore, a conventional maximum power point (MPP) tracker (MPPT) such as hill climbing, incremental conductance, and ripple correlation could miss the global maximum point [6]–[9]. In general, a PV source is operated in conjunction with a dc–dc power converter, whose duty cycle is modulated in order to track the instantaneous MPP of the PV source. Several tracking schemes have been proposed [2]–[12]. Among the popular tracking schemes are the perturb and observe (P&O) or hill climbing [4], [5], incremental conductance [8], short-circuit current [2], open-circuit voltage [7], and ripple correlation approaches [6]. Some modified techniques have also been proposed, with the objective of minimizing the hardware or improving the performance [7], [8]–[9].

A study of partial shadowing conditions in [2] shows that using a conventional MPPT during partial shadowing could result in significant losses of PV output power. Therefore, different researchers have investigated the limitation to improve tracking efficiency. Noguchi *et al.* [9] propose a short-circuit pulse-based MPPT with fast scan on the *P–V* curve to identify the proportional parameter which is commonly used in a current-based MPPT. The global maximum point is found; however, an additional switch in parallel with the PV source is required to compute the short-circuit current every few minutes. Therefore, such a method causes momentary power losses and requires additional cost.

To avoid using an extra switch, the authors in [3] propose a controller that swings the converter's duty cycle from zero to one to measure the open-circuit voltage and the short-circuit current and then computes the optimum voltage and current. From the computed values, the operating point is moved in one step to the optimal operating point.

Based on observation and investigation of the *P–V* characteristic, the authors in [4] claim that, on either side of the global maximum point, the local maxima consistently decrease. Therefore, an MPPT scheme for a PV system under partial shadowing conditions is proposed based on this observation. In [5], a simulation of a partially shaded PV system rejects the observation in [6], and an MPPT based on conventional hill climbing and a partial shadowing identifier has been proposed. Also, it is observed that the global maximum point of a PV system under non uniform conditions is always located to the left of maximum power at normal weather conditions. Therefore, a trajectory line of the PV system under different isolation levels is stored in a data-based memory to identify the partially shaded conditions. Such a technique could save the controller from having unnecessary global scan; however, the trajectory line is different between PV systems, and also, the PV parameters vary with time. A line search algorithm with Fibonacci sequence has been employed to track the global power point under partial shadowing conditions. However, this method can miss the global MPP in some partial shadowing conditions [6]. In a direct search algorithm is employed to search the Lipchitz function which describes the PV power and voltage relationship in an Interval In order for this method to ensure finding the global maximum power, the initial point must be carefully selected; otherwise, the controller may be trapped at a local MPP. Practical swarm optimization has been implied to track the maximum global operating point under abnormal weather conditions. A large time delay is required to allow agents to compute the global maximum point, resulting in a long computation time to reach the maximum operating point.

SYSTEM STRUCTURE

A PV system consists of a solar array which is a group of series-/parallel-connected modules, where the basic building block within the module is a solar cell. Commercially, the solar cell rated power varies between 1 and 2 W depending on the solar cell material and the surface area; therefore, to design a solar module, the solar cell's power is measured, and then, the modules are connected in series based on the desired output. Figure 1 shows a PV system.

Generally, the electrical characteristics of the PV system are represented by power versus voltage (current/duty cycle) and by current versus voltage. The characteristic curves of the solar cell are nonlinear because of operational physical phenomena. By using the equivalent circuit of the solar cell shown in Figure 2, the mathematical model of the generated current in a PV system is represented

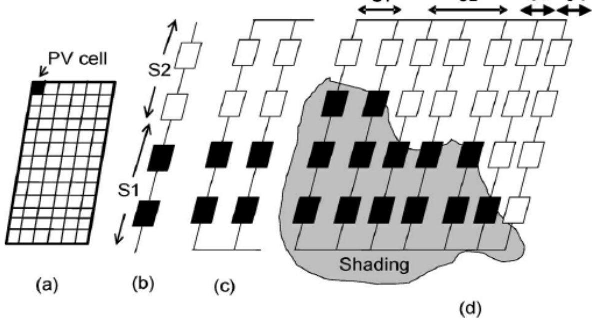

Figure 1: PV Array Terminologies (a) PV Module (b) Series-Assembly with Two Series-Connected Subassemblies S1 and S2 (c) Group (d) PV Array with Groups G1 to G4

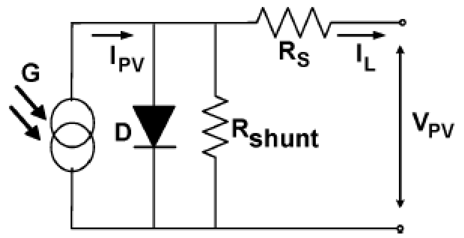

Figure 2: Equivalent Circuit of a PV Cell

$$I_{PV} = N_p - I_0\left[e^{\frac{q(V_{pv}+R_S I_{pv})}{AkTn_S}} - 1\right] - \frac{(V_{pv}+R_S I_{pv})}{n_S\,R_{sh}} \quad (1)$$

Where *V*pv and *I*pv represent the PV array output voltage and current, respectively. *Rs* and *R*sh are the solar cell series and shunt resistances, respectively. *q* is the electron charge (1.6 × 10−19 C), *I*ph is the light generated current, *Io* is the reverse saturation current, *A* is a dimensionless junction material factor, *k* is Boltzmann's constant (1.38 × 10−23 J/K), *T* is the temperature (in kelvins), and *np* and *ns* are the numbers of cells connected in parallel and series, respectively. The characteristic curves of the PV array system depend on the radiation and temperature of the PV system. For a given system, during normal conditions where the radiation is equally distributed among the PV modules, the power–duty cycle (*P*–*D*) characteristics under varying weather conditions are shown in Figure 3. However, when the radiation is not equally distributed, local and global maxima are introduced in the characteristic curves. In order to understand such phenomena, a PV array system with nine modules connected in series and parallel is considered, as shown in Figure 4. There are different possibilities for the radiation distribution among the PV modules; the following five cases are randomly considered.

Case 1: One module in each column is completely shaded (viz., modules 1, 4, and 7).

Case 2: One module in each column is partially shaded with equal radiation levels (viz., modules 2, 5, and 8).

Case 3: One module in each column is partially shaded with unequal radiation levels (viz., modules 3, 6, and 9).

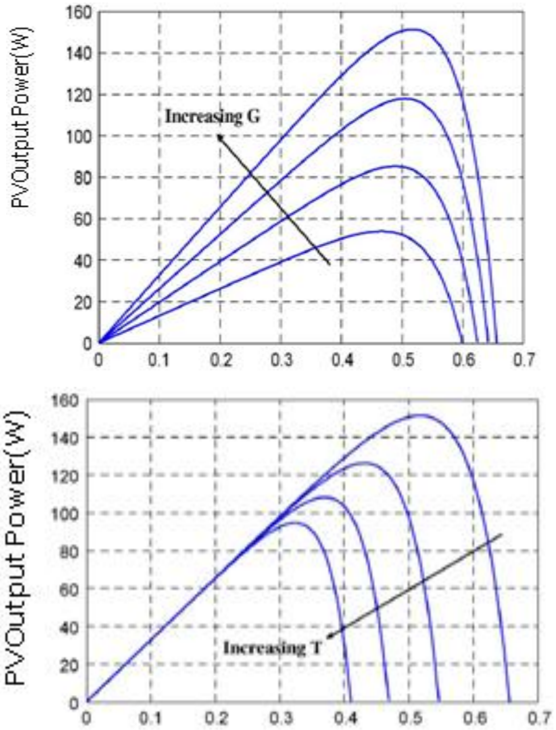

Figure 3: Influences of (a) Temperature (*T*) and (b) Solar Radiation (*G*) on the *P–D* Characteristics

Case 4: Two modules in the first column and one module in each other column are partially shaded with equal radiation levels (viz., modules 1, 2, 4, and

Case 5: All modules are partially shaded with different radiation levels.

Simulation results for the five cases indicate that a completely shaded module causes a reduction of the PV output power without creating local maxima. However, partially shaded modules result in a reduction of the PV output power, creating local maxima, where the number of local maxima increases as the variation of the radiation levels on each module increases. The PV output power characteristics for the five different cases are shown in Figure 5.

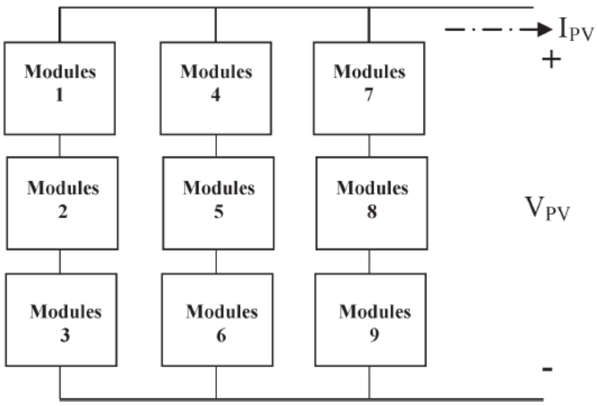

Figure 4: PV Array System with Nine Modules Connected in Series and Parallel

PV MODELING UNDER PARTIAL SHADING

During shadowing conditions, the PV system mathematical model in (1) is no longer valid because different radiation around the PV system. Therefore, a new mathematical model is required to represent the PV system under partial shadowing conditions. An extensive study has been undertaken for different PV module connections to derive a general PV mathematical model under shadowing conditions. For simplicity, three series-connected PV modules are considered.

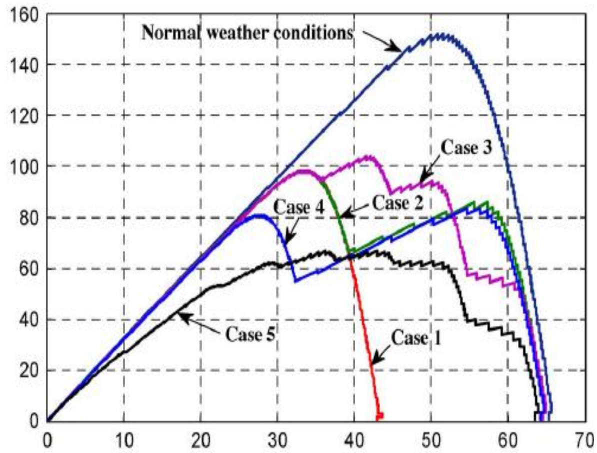

Figure 5: PV Output Power Characteristics under the Five Cases

Based on the data for the Shell SP150-PC, the short-circuit current and the open-circuit voltage for each PV module under rated radiation level are 4.4 A and 43.4 V, respectively. One PV module is partially shaded, and it receives a radiation of 500 W/m2, while the other two modules receive the rated radiation, which is 1000 W/m2. The three points are considered: point 1 where the current equals Isc and the voltage equals zero, point 2 where the current equals Istep and the voltage equals Vstep, and point 3 where the current equals zero and the voltage equals Voc. By inspection, the previous variables can be defined as follows.

- *I*sc is the short-circuit current of the un-shaded PV modules.
- *I*step is the short-circuit current of the shaded PV module.
- *V*step is the summation of the open-circuit voltages of the un-shaded modules.
- *V*oc is the summation of the open-circuit voltages of the shaded and un-shaded modules.

From these observations, the mathematical model of the given PV system is (2), shown at the bottom of the next page, where *nus s* and *nss* are the numbers of series un-shaded and shaded modules, respectively, and *λus* and *λs* are the radiation levels on the un-shaded and shaded modules, respectively. Equation (2) is valid for two radiation levels distributed around the series-connected PV modules. Therefore, (2) is extended to handle three radiation levels, as in (3). When the radiation distribution levels increase, the number of voltage/ current steps increases. Figure 7 shows the *I–V* characteristic of three series-connected PV modules with different shadowing levels. The PV system is tested under different partial shadowing conditions. Two PV modules are partially shaded and receive two different radiation levels, which are 500 and 300 W/m2, and the third module receives rated radiation, which is 1000 W/m2. Two more observations are added to the previous observations as follows.

- *I*step2 is the short-circuit current of the shaded PV modules with the highest radiation level.
- *V*step1 is the open-circuit voltage of the unshaved modules plus the summation of the shaded module open circuit voltages without the open-circuit voltage of the lowest radiation module.

Therefore, the mathematical model for three different radiation levels on three series-connected PV modules is (3), shown at the bottom of the page, where *ns*1 *s* is the number of partially shaded PV modules with the lowest radiation level and *ns*2 *s* is the number of partially shaded PV modules with the highest radiation level.[4] *λs*1 is the lowest radiation level, and *λs*2 is the highest radiation level. The general mathematical model of *n* series connected PV modules in a PV system is (4), shown at the bottom of the next page, where *nsN s* is the number of partially shaded PV modules with the highest radiation level and *λsN* is the highest radiation level. *N* is the number of distributed radiation levels. Usually, the PV system consists of parallel-/series-connected PV modules [2]. Therefore, to drive a mathematical model for the overall PV system, the previous three series-connected PV modules are connected in parallel with another three series connected PV modules, as for simplicity, the radiation levels are distributed as follows. In the first branch, modules 1 and 2 receive a radiation of 1000 W/m2, and the shaded module receives 500 W/m2

$$I_{pv\,Total} = I_{branch1} + I_{branch2} \tag{2}$$

From (2), the general mathematical model of *N* parallel connected PV modules in the PV system is

$$I_{pvTotal} = I_{branch1} + I_{branch2} + \cdots + I_{branchN} \tag{3}$$

PROPOSED METHOD

If the difference between the identified maximum power and the operated power is greater than the preset value, the duty cycle is increased; otherwise, fuzzy-logic-based MPPT is applied. In this the algorithm ensures that the MPPT is not trapped by local maxima and quickly recovers the new global maximum point during varying weather conditions. Unlike conventional scanning MPPT,[11] the essentiality of using a long time delay is not required because the controller scans the *P–V* curve while perturbation and observation are carried out[7]. Figure 6 shows the flowchart of the proposed method, where *V*pv and *I*pv are the PV output voltage and current, respectively, *D* is the duty cycle, *Pm* is the global MPP, and ΔPm is a constant that identifies the allowable difference between the global maximum point and the operating power point.

The second technique is to increase the duty cycle from a minimum to a maximum value with a fixed step. In this case, the *P–V* curve is scanned, and the global MPP is stored. The last technique is to apply a large initial perturbation step to make a wide search range on the PV power locus.

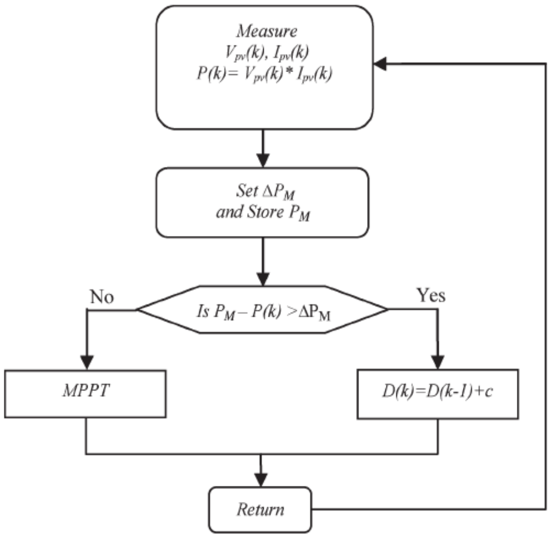

Figure 6: Proposed Method Flowchart

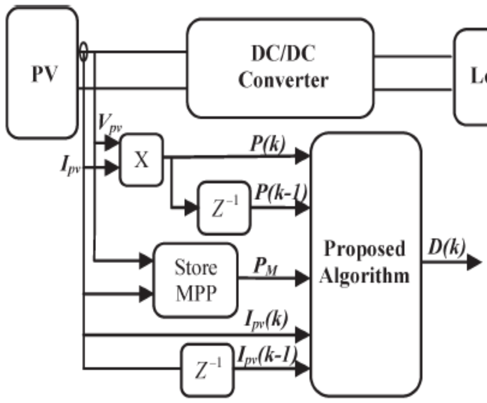

Figure 7: PV Array System Blocks Diagram and the Proposed MPPT Controller

FLC DESIGN

Modification to the fuzzy-logic-based MPPT algorithm, using the scanning and storing procedures, is proposed to quickly locate the global MPP. Fuzzification of the flowchart in Figure 7 is considered in the proposed MPPT design[7]. The inputs to the fuzzy-logic controller (FLC) are

$$\Delta P = P(k) - P(k-1) \tag{4}$$

$$\Delta I = I(k) - I(k-1) \tag{5}$$

$$\Delta P_M = P_m(k) - P(k) \tag{6}$$

And the output equation is

$$\Delta D = D(k) - D(k-1) \tag{7}$$

Where ΔP and ΔI are the PV array output power change and current change, respectively, ΔPM is the difference between the stored global maximum power (PM) and the current power, and ΔD is the boost converter duty cycle change [12]. To ensure that the PV global maximum power is stored during the scanning procedure, a fast initial tracking speed is used. The variable inputs ΔP and ΔI are divided into four fuzzy subsets: positive big (PB), positive small (PS), negative big (NB), and negative small (NS). The variable input ΔPM is divided into two fuzzy subsets: PB and PS. The output variable ΔD is divided into six fuzzy subsets: PB, positive medium (PM), PS, NB, negative medium (NM), and NS. Therefore, the fuzzy algorithm requires 32 fuzzy control rules;

Table 1: Fuzzy-Logic Rules

ΔP \ ΔI	NB	NS	PS	PB	ΔP$_M$
NB	PM	PM	NM	NM	PS
NS	PS	PS	NS	NS	
PS	NS	NS	PS	PS	
PB	NM	NM	PM	PM	
NB	PB	PB	PB	PB	PB
NS	PB	PB	PB	PB	
PS	PB	PB	PB	PB	
PB	PB	PB	PB	PB	

The shapes and fuzzy subset attritions of the membership function in both of the inputs and output are shown in Figure 8.

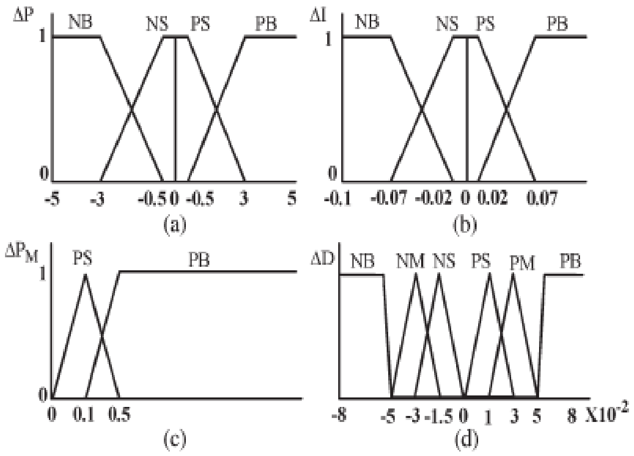

Figure 8: Membership Functions: (a) Input ΔP, (b) Input ΔI, (c) Input ΔPM, and (d) Output ΔD

The last fuzzy controller stage is defuzzification where the center-of-the-area algorithm is used to convert the fuzzy subset duty cycle changes to real numbers

$$\Delta D = \frac{\sum_i^n \mu(D_i) D_i}{\sum_i^n \mu(D_i)} \tag{8}$$

Where ΔD is the fuzzy controller output and Di is the center of the max–min composition at the output membership function.

The surface view of the fuzzy logic controller is as show in the figure 9 as show in the figure below

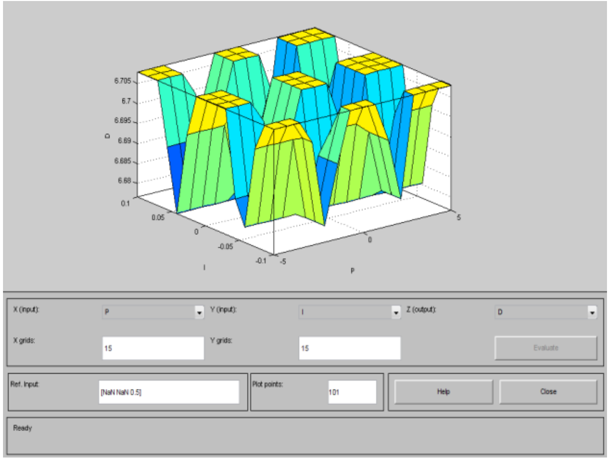

Figure 9: Surface View of the FLC

SIMULATION RESULTS

The simulation circuit as shown in the figure below with temperature 20^{Oc} and the irradiance is the$400^{W/cm}$ and simulation results is all so show in the figure

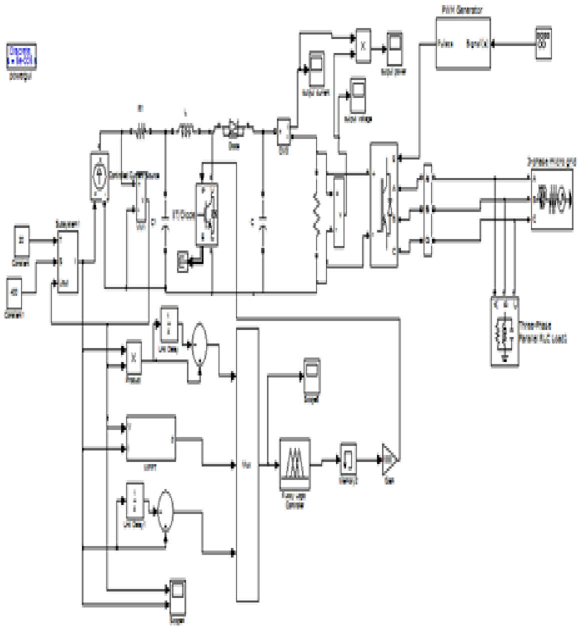

Figure 10: Simulation Circuit Diagram

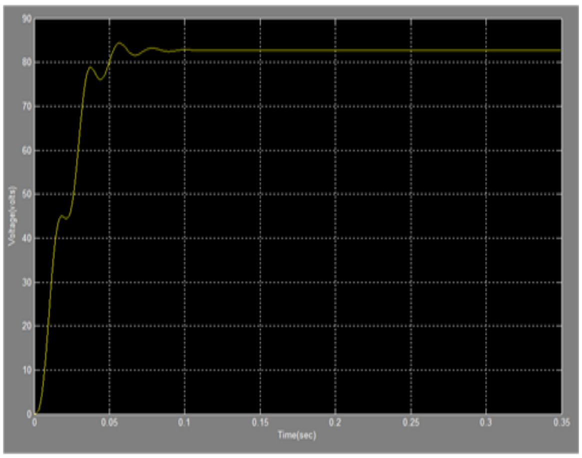

Figure 11: Output Voltage with Fuzzy Logic Controller

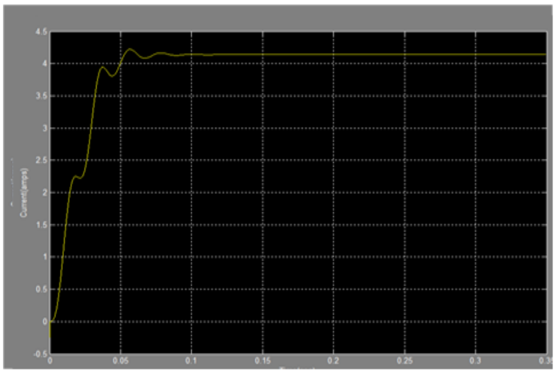

Figure 12: Output Current with Fuzzy Logic Controller

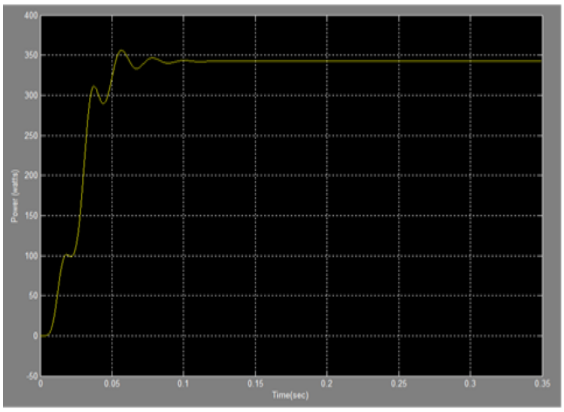

Figure 13: Output Power with Fuzzy Logic Controller

CONCLUSIONS

In this paper, a fuzzy-logic-based MPPT has been proposed to extract the global MPP under partially shaded PV system conditions. The proposed MPPT has been implemented by combining fuzzy-logic-based MPPT with a scanning and storing system. Three scanning techniques have been proposed to scan the PV power characteristic curve and store the

Maximum power value, during initial and varying weather conditions. A new mathematical model has been proposed to represent the behavior of the *P*–*V* characteristic under partial shadowing conditions. Mat lab/Simulink simulations and practical Experiments of a partially shaded PV system have Been carried out to validate the proposed MPPT. The results show that the proposed MPPT is able to reach the global MPP under any partial shading conditions. Moreover, the controller exhibits a fast converging speed, with small oscillation around the MPP during steady state.

REFERENCES

1. J. M. Guerrero, J. C. Vasquez, J. Matas, M. Castilla, and L. G. de Vicuna, “Control strategy for flexible micro grid based on parallel line-interactive UPS systems,” IEEE Trans. Ind. Electron., vol. 56, no. 3, pp. 726–736, Mar. 2009.
2. J. T. Bialasiewicz, “Renewable energy systems with photovoltaic power generators: Operation and modeling,” IEEE Trans. Ind. Electron., vol. 55,no. 7, pp. 2752–2758, Jul. 2008.
3. C. Rodriguez and J. D. K. Bishop, “Organic architecture for small to large-scale photovoltaic power stations,” IEEE Trans. Ind. Electron., vol. 56, no. 11, pp. 4332–4343, Nov. 2009.
4. L. Wuhua and H. Xiangning, “Review of nonisolated high-step-up DC/DC converters in photovoltaic grid-connected applications,” IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1239–1250, Apr. 2011.

5. G. Lijun, R. A. Dougal, L. Shengyi, and A. P. Iotova, “Parallel-connected solar PV system to address partial and rapidly fluctuating shadow conditions,” IEEE Trans. Ind. Electron., vol. 56, no. 5, pp. 1548–1556, May 2009.
6. T. Esram and P. L. Chapman, “Comparison of photovoltaic array maximum power point tracking techniques,” IEEE Trans. Energy Convers., vol. 22, no. 2, pp. 439–449, Jul. 2007.
7. A. Safari and S. Mekhilef, “Simulation and hardware implementation of incremental conductance MPPT with direct control method using Cuk converter,” IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1154–1161, Apr. 2011.
8. L. Fangrui, K. Yong, Z. Yu, and D. Shanxu, “Comparison of P&O and hill climbing MPPT methods for grid-connected PV converter,” in Proc. 3rd ICIEA, 2008, pp. 804–807.
9. J.W. Kimball and P. T. Krein, “Discrete-time ripple correlation control for maximum power point tracking,” IEEE Trans. Power Electron., vol. 23,no. 5, pp. 2353–2362, Sep. 2008.
10. H. Patel and V. Agarwal, “Matlab-based modeling to study the effects of partial shading on PV array characteristics,” *IEEE Trans. Energy* Converse. vol. 23, no. 1, pp. 302–310, Mar. 2008.
11. T. Noguchi, S. Togashi, and R. Nakamoto, “Short-current pulse-based maximum-power-point tracking method for multiple photovoltaic candconverter Module system,” *IEEE Trans. Ind. Electron.*, vol. 49, no. 1,pp. 217–223, Feb. 2002.
12. T. L. Kottas, Y. S. Boutalis, and A. D. Karlis, “New maximum power point tracker for PV arrays using fuzzy controller in close cooperation with fuzzy cognitive net-work,” IEEE Trans. Energy Conv., Vol. 21, pp

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