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A STRUCTURE APPROACH FOR A PHOTOVOLTAIC STATION CONTROL BASED ON ADAPTIVE FUZZY AGENT

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The solar energy is directly converted into electrical energy by solar PV module. Each type of PV module has its own specific characteristic corresponding to the surrounding condition such as irradiation, and temperature and this makes the tracking of maximum power point (MPP) a complicated problem. To overcome this problem, many maximum power point tracking (MPPT) control algorithms have been presented. Fuzzy logic (FL) has been used for tracking the MPP of PV modules because it has the advantages of being robust, relatively simple to design and does not require the knowledge of an exact model where a mathematical model of the PV module, DC-DC converter, are used in the study of FL based MPPT algorithm. It is suggested to present this problem in the form of two-folds; first to identify the deviation of the power to maximum power point, and secondly, to control the voltage of the DC-DC converter corresponding to maximum power. In this paper, the first discussion approach will stress out the integration of model predictive control in maximum power point tracking MPPT and as progressing a second approach is identified as fuzzy logic controller FLC and perturb & Observe P&O algorithms are analyzed. All are interrelated to MPPT model for a photovoltaic module, PVM, to search for and generate the maximum power; in this case what's called P_{max}. As per the first technique the focus is on the optimal duty ratio, D, for a series of multi diverse types of converters and load matching. The design of the MPPT for a stand-alone photovoltaic power generation system is applied where the system will consist of a solar array with nonlinear time varying characteristics, and a converter with appropriate filters. The integration of model predictive control will be addressed first in this paper. The second fold will implement an MPPT system that use the FLC and compare it with a classicalMPPT P&O algorithm through the utilization of Simulink. The novel design in the FLC will be based on the use of asymmetrical membership functions to compensate for the asymmetrical P-V curve of solar panel.

Keywords: photovoltaic *station, maximum power point tracking (MPPT) control algorithms, fuzzy logic agent, model predictive control, optimal duty ratio.*

Introduction

It has been obvious that maximum power point tracking algorithm is currently playing a vital role to enhance the efficiency of the solar panel as less than 40% of energy incident is being converted into electrical energy. Due to the growing dependency and the increasing need in acquiring electricity, and due to the limitations in supply and the uprising prices of conventional sources (such as the continuous increase in electrical bills, generation, distribution, and maintenance of the electrical plants, fluctuating petroleum prices, etc.), photovoltaic (PV) energy vitality turns into a promising option as it is inescapable, openly accessible, environmentally promising, and has less operational and upkeep costs. Along these lines, the interest of PV era systems is by all accounts expanded for both standalone and grid-connected modes of PV systems. As a result, an efficient maximum power point tracking (MPPT) technique is vital for tracking the MPP at all environmental conditions and then push forward the PV system to functionally be operable at that MPP point. Undesirably, photovoltaic generation systems have two note-worthy issues: the conversion efficiency in electric power generation is somehow low (normally below 17 percent particularly under low irradiation conditions), and the amount of electric power generated by solar arrays changes persistently with climate conditions. Numerous MPPT methodologies have been recommended in the literature; the Perturb and Observe (P&O), the Incremental Conductance (IC), the Artificial Neural Network, and the Fuzzy Logic methods, etc. It has been noticed that the efficiency of the PV is influenced by the following two parameters: the panel's irradiance and temperature which are stochastic and unpredictable. In any PV module a DC/

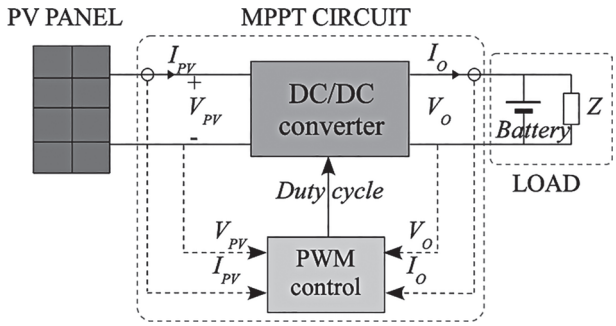

Fig. 1. MPPT module diagram

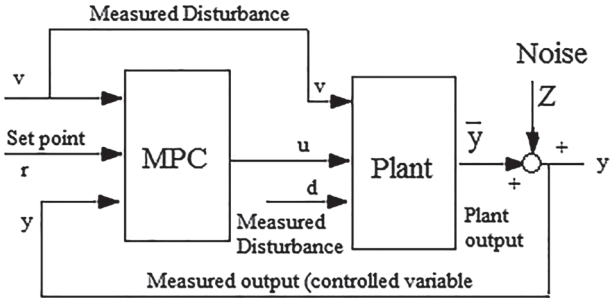

Fig. 2. Block diagram for MPC

DC converter is accountable for transferring maximum power to the load.

Unfortunately and since the MPP point must be sought, this can be achieved in either computation models or search algorithms. Figure 1 illustrates an MPPT module diagram.

We have to stress out that the voltage across the power-conditioning unit (DC-DC converter) is fed to get an isolated load. The input-output (I/P-O/P) voltage relationship for converter conduction mode is given by duty cycle. This paper will be expanded towards proposing an innovative fuzzy logic controller (FLC) for DC–DC converters that yield to an effective element of MPPT system so that it integrate itself into enhancing the photovoltaic modules to work under changeable operating conditions as well as dealing with the nonlinear properties of DC-DC power converters [1].

Overview of model predictive control

MPC is a model in view of line control approach with the following accompanying modules: a prediction horizon, a receding horizon procedure, and a regular update of the model and re-computation of the optimal control input [2, 3]. A block diagram of MPC system is shown in Figure 2. A process model is used to predict the current values of the output variables. The residuals, the differences between the actual and predicted outputs, serve as the feedback signal to a Prediction block. The predictions are utilized as a part of two types of MPC calculations that are performed at each sampling instant: the first is the set-point calculations and the second is the control calculations.

The set points for the control calculations, which are called targets, calculated from an economic optimization based on a steady-state model of the process, conventionally, a linear model. In MPC the set points are customarily computed each time the control calculations are conducted.

Nonlinear predictive control

The basic principle of model predictive control is shown in Figure 3. At a denoted time (t) certain measurements are provided, which will trigger the controller to predicts the future dynamic behavior of the system over a prediction horizon *Tp* and furthermore determine (over a control horizon $Tc \leq Tp$) the input under the condition a predefined open-loop performance objective is optimized.

When neither disturbances exist nor mismatching model plant presence is evident, and if the optimization problem could be solved for infinite horizons, then we can apply the input function found at time $t = 0$ to the system for all times $t \geq 0$. As a matter of fact, this is not feasible generally. Because of the factors of disturbances and

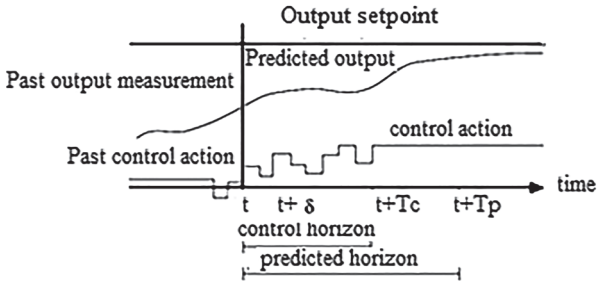

Fig. 3. Principle of model predictive control

the stressing model-plant mismatch, the real system behavior is going to differ from the predicted behavior. To integrate a feedback scheme, the open-loop manipulated input function acquired will be ready for implementation as the next measurement becomes available. The time difference between the recalculation/measurements can vary, however often it is assumed to be fixed, i. e. the measurement will take place every δ sampling time-unit. Using the new measurement at time $(t + \delta)$, then the whole process for the prediction and optimization is going to be repeated to find a new input function with the control and prediction horizons moving forward. Knowing that in Figure 3 the input is depicted as arbitrary function of time. For numerical solutions of the open-loop optimal control problem, it is often necessary to parameterize the input in an appropriate way. This is normally achieved by employing a finite number of basic functions; as an example, the input could be approximated as piecewise constant over the sampling time δ. The computation of the applied input (based on the predicted system behavior) permits the inclusion of constraints on states and inputs as well as the optimization of a given cost function. In general, the predicted system behavior will differ from the closed-loop one; and thus further cautionary should be taken into account to achieve closed-loop stability [1].

Adaptive Fuzzy logic Agent: Asymmetrical MFs

Asymmetric membership function and control rules, in which membership function and fuzzy rules are designed according to the nonlinear characteristic of PV module are introduced into fuzzy control to improve the control effect. Due to the asymmetrical characteristic of the solar cell P–V curve, asymmetrical MF is proposed to have a better performance. It can be observed from the

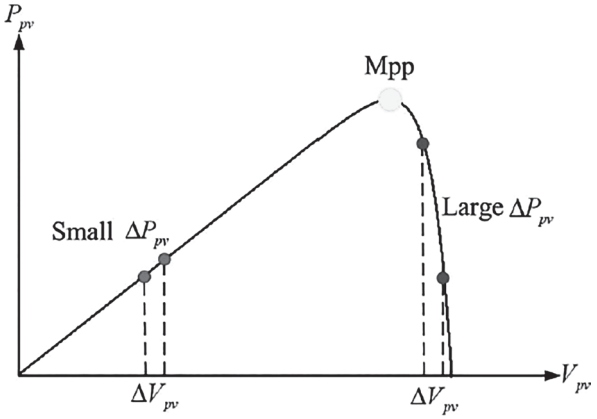

Fig. 4. Concept for designing MF setting values of novel adaptive

ΔP–ΔV curve that even the same voltage step $\Delta V_{pv}$is applied; the power variations on both left and right half planes of MPP are quite different where the ΔP_{pv} on the left is smaller than that on the right (where the right side is large) and this can be seen in fig. 4.

To improve the efficiency of PV system, membership functions are designed again according to nonlinear characteristic of PV module. Due to e(k) is nonlinear, membership function is designed in an asymmetric triangular from.

To implement easily the asymmetric fuzzy control and make the output of fuzzy controller stable, the membership of fuzzy controller output is designed as trapeze. The ΔD is the change of perturbation step.

The aim of fuzzy rules is to let the PV system to acquire a good dynamic and stable performances under different illuminations. So when the PV module operating point is away from MPP, the perturbation step should be large one to move the PV module to MPP quickly, when the PV module works near to MPP, the perturbation step should be small one to reduce the power oscillation around MPP.

Two dimensions fuzzy controller is designed in the proposed asymmetric fuzzy control. E(k) is one input (error) variable and another one is CE (change of error) according to working point. The output of fuzzy controller is the change of perturbation step.

The design based on both sides of the nonlinear characteristic of PV module which can make PV system response to illumination changing quickly and output stable power. The selected asymmetrical membership functions are shown in figures 5, 6, and 7.

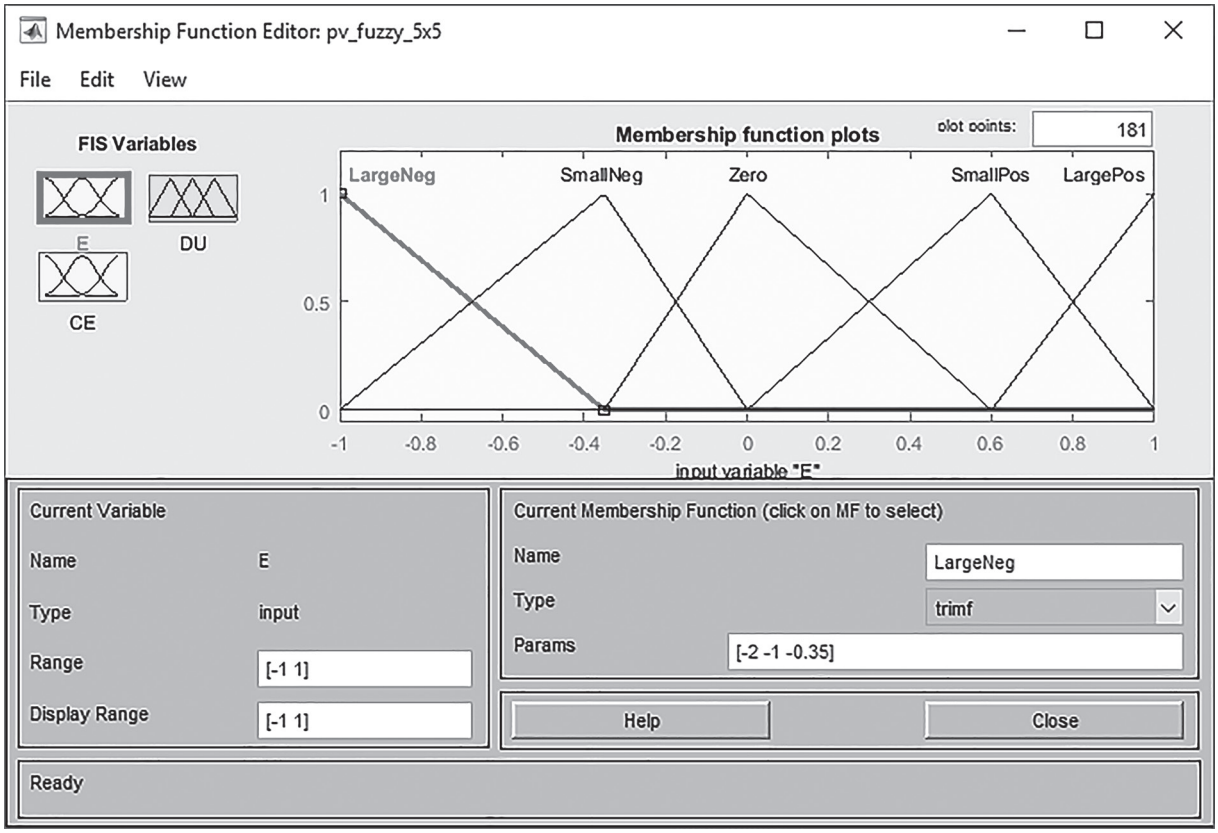

Fig. 5. Asymmetrical MF for E error

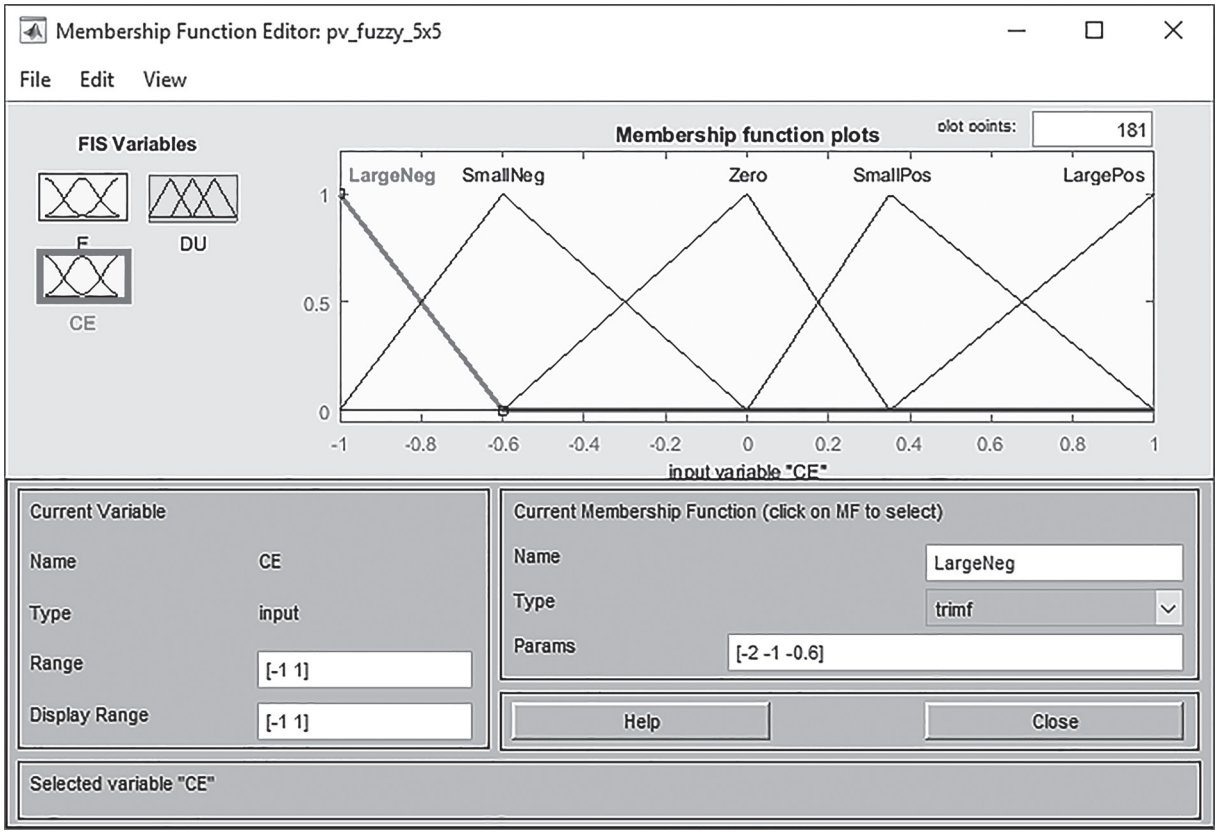

Fig. 6. Asymmetrical MF for CE change of error

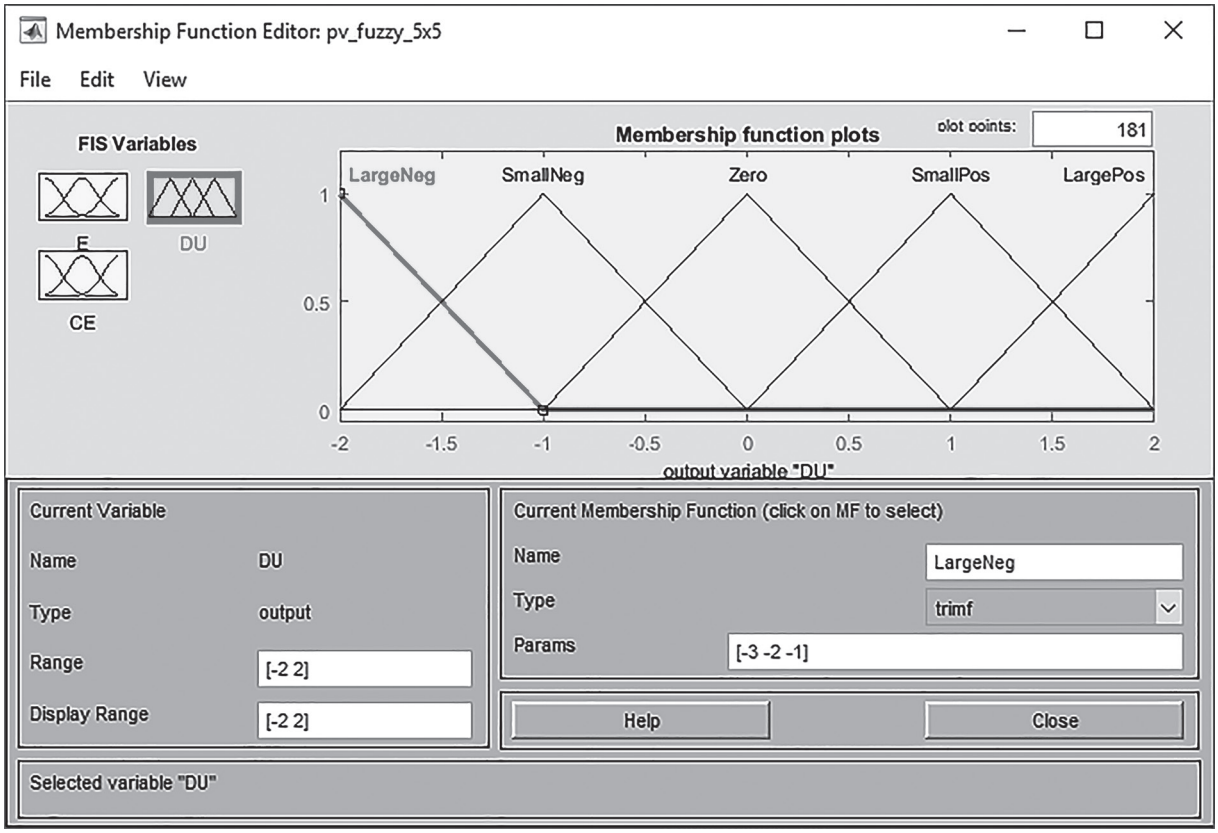

Fig.7. Membership functions for the change in duty cycle D

Simulations and results for FLC and P&O MPPT techniques

A new adaptation and simulation of a PV system using fuzzy logic controller that supports asymmetrical membership functions with an MPPT is addressed to overcome the asymmetrical nonlinear PV curve of a photovoltaic solar panels.

A sample of fuzzy rules are shown in table 1 and used to control the buck converter in a form to reach the maximum power point MPP of the photovoltaic PV generator, where the entries are a sort of fuzzy sets in the form of error (*E*), change of error (*CE*) and change of duty ratio (Δ*D*) to the converter.

Table 1. **Fuzzy rules**

E	CE				
	NB	NS	ZO	PS	PB
NB	ZO	ZO	NB	NB	NB
NS	ZO	ZO	NS	NS	NS
ZO	NS	ZO	ZO	ZO	PS
PS	PS	PS	PS	ZO	ZO
PB	PB	PB	PB	ZO	ZO

Figure 8 shows an approach for a main PV model structure composed of PV array, a DC-DC converter in the form of buck or step down converter along with MPPT controller which is connected to a load. This setup is manipulated inside the Matlab/simulink setting, which is shown in Figure 9.

Sunntech STb134.12/Tp represented the PV and its technical data is showing in table 2. Six PV modules connected in series formed the PV array which its total capacity is 810 W. The 105v DC input voltage was stepped down to 48v to fit the battery voltage level using a buck converter [11, 12].

In addition, and to implement the fuzzy logic controller FLC, FL toolbox in Matlab/Simulink will be selected and the simulation of fuzzy logic controller for MPPT to be conducted and as we progress an evaluation comparison with a Perturb & Observe (P&O) for MPPT controller was performed.

Table 2. **PV module specs**

Electrical specifications	Values
Open-circuit voltage	22.3 V
Short-circuit voltage	8.20A
Optimum operating voltage (V_{mpp})	17.5 V
Optimum operating current (I_{mpp})	7.71A
Maximum power at STC (P_{max})	135W
Current temperature coefficient of Isc	(0.055± 0.01)%K
Voltage temperature coefficient	–(75 ± 10) *mV/K*

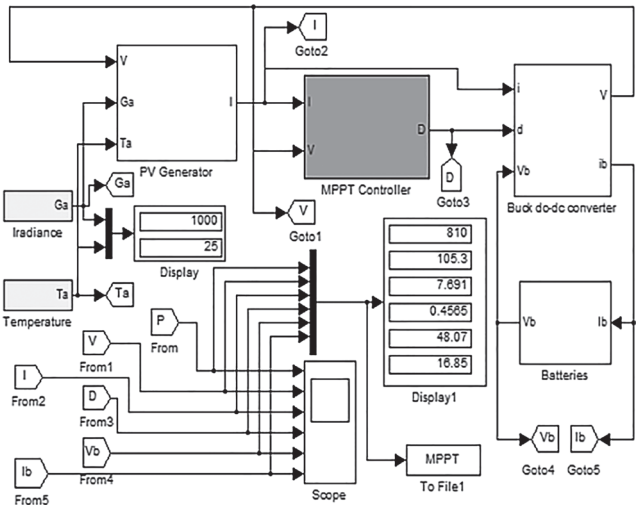

Fig. 8. Simulink implementation of the stand-alone PV system

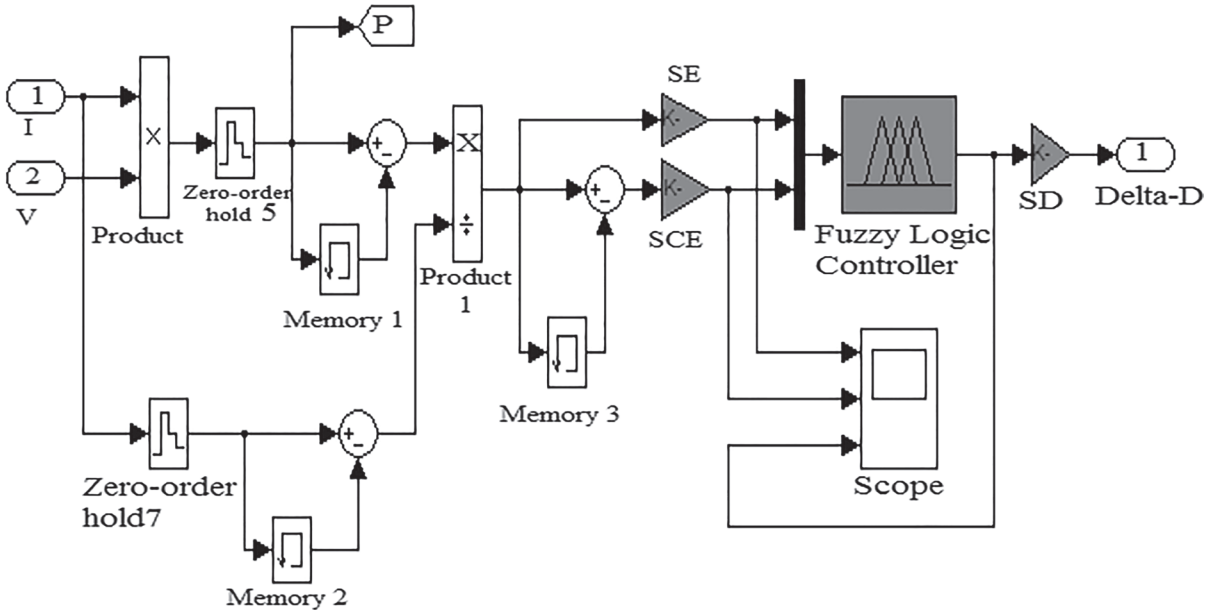

Fig. 9. FLC MPPT algorithm in MATLAB-Simulink

Figure 10 demonstrates the outcome of the simulation result of PV generator output power, operating current &voltage, and eventually the duty ratio «D» through the use of a buck converter and these results were obtained at a standard test conditions (STC) among the fuzzy logic controller «FLC» and the P&O based MPPT. To take the discussions a step forward obviously the outcome of the FLC MPPT had reduced clearly the response time of the PV system. On the other hand as we compare the above to P&O MPPT system, P&O showed an impact of energy losses. As we used the P&O technique there was an evidence of a continuous oscillation at the operation point and this was due to the incessant perturbation that took place at the operating voltage to reach the maximum power point «MPP». As compared to the FLC technique such oscillation wasn't existing in FL based MPPT technique, and was able to optimize the overall results, where the signals of the other parameters which were namely the power «P», voltage «V», current «I», and duty ratio «D» continued to stay constant, which would cause an impact on the reduction of power loss.

Figure 11 displays the simulation of the increase in irradiance from a 1000 w/m^2 to 1200 w/m^2. This fast increase was taking place at a «2 sec» time period, knowing that the temperature of the cell was staying at a constant temperature level of 25 °C. In accordance to those operational conditions, FLC technique was more reliable. More-

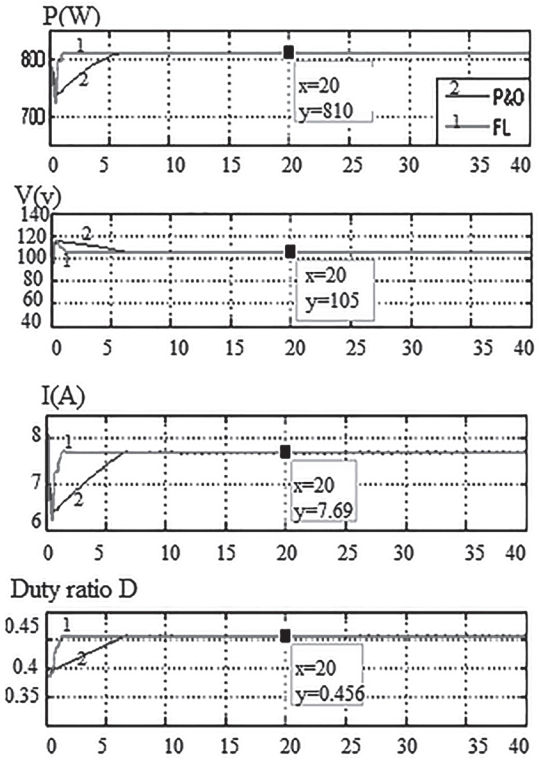

Fig. 10. Comparing P&O and FL signals

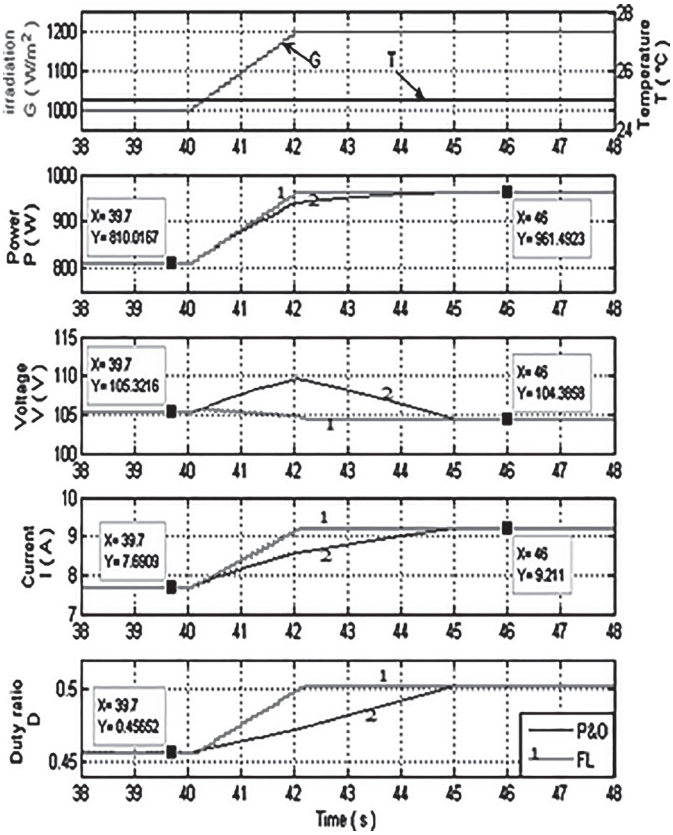

Fig. 11. FL and P&O methods at fast increasing irradiation

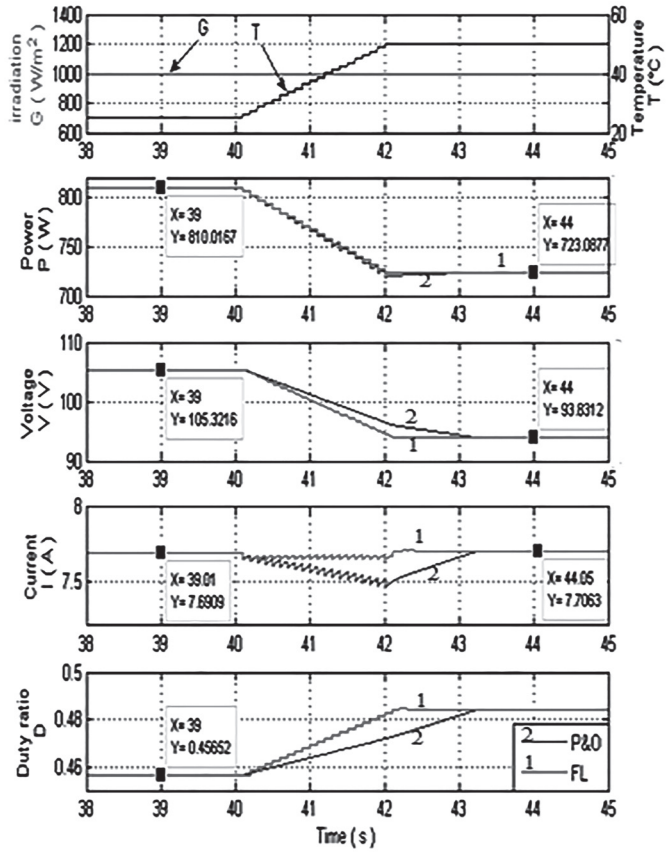

Fig. 12. FL and P&O methods at fast increasing temperature

over, linearity was increased at the output power of the FLC, where, the P&O technique deviated from the maximum power point «MPP».

Figure 12 displays the simulation of the increase in cell temperature from «25 °C» to «50 °C» which was taking place at a «2 sec» time period.

From the simulation results we can clearly see that irradiation stayed constant on a 1000 w/m^2 value. In nutshell, Figure 12 shows that the output power with a decreased linearity as we applied both MPPT algorithms namely the fuzzy logic and Perturb and Observe. At the same time P&O MPPT method resulted in low deviation from the maximum power point MPP.

Conclusion

The employment of MPPT for PV stations and their applications were addressed in the form of two schemes; a first scheme was an adaptation structure of a model predictive control (MPC) for a PV station that is considered to be a promising technique to maximize the efficiency of the power utili-

zation. The second scheme of the paper was focusing on the implementation and simulation of fuzzy logic controller (fuzzy logic agent) using asymmetrical membership functions for MPPT to seek the maximum power point and comparing it to P&O. From the simulation results, FLC provided a reliable response as compared to the P&O controller in regards to main performance of MPPT where FL was better in regards to the response time and oscillation.

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СТРУКТУРА УПРАВЛЕНИЯ ФОТОЭЛЕКТРИЧЕСКОЙ СТАНЦИЕЙ НА ОСНОВЕ АДАПТИВНОГО НЕЧЕТКОГО АГЕНТА

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Преобразование солнечной энергия непосредственно в электрическую осуществляется солнечными модулями в составе фотоэлектрической станции (ФЭС). Каждый модуль имеет свою характеристику зависимости генерируемой мощности от напряжения (P-V) при определенных условиях окружающей среды- интенсивности солнечного излучение и температуры. Характеристика P-V имеет уникальную точку максимальной выходной мощности (МВМ) и ее отслеживание является достаточно сложной проблемой. В мировой практике предложено большое разнообразие алгоритмов, обеспечивающих функционирование ФЭС при МВМ. Предложено рассматривать решение этой задачи в два этапа: 1 – выбор алгоритма идентификации отклонения и 2 – пректирование контроллера управления преобразователем постоянного тока, обеспечивающего величину напряжения, соответствующей точке МВМ. Наиболее совершенными характеристиками обладает предложенный адаптивный нечеткий агент, функции принадлежности (ФП) которого разработаны с учетом характерных уникальных свойств ФЭС-нелинейности характеристики P-V и ее несимметричности относительно точки МВМ. Приведен пример формирования ФП.

Эффективность предложенных решений подтверждается результатами проведенного численного эксперимента на разработанной имитационной модели в среде MATLAB-Simulink.

При этом адаптивный нечеткий агент обеспечивает сокращение времени выхода на заданную траекторию примерно вдвое.

Ключевые слова: *фотоэлектрическая станция, максимально выходная мощность алгоритм управления, агент нечеткой логики, упреждающее управление, оптимальный сигнал управления.*

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