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Research paper

An Intelligent Maximum Power Point Tracking Algorithm for Photovoltaic System

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Abstract

This work comprehensively demonstrates the performance analysis of Fuzzy Logic Controller (FLC) with Particle Swarm Optimization (PSO) Maximum Power Point Tracker (MPPT) algorithm on a stand-alone Photovoltaic (PV) applications systems. A PV panel, DC-DC Boost converter and resistive load was utilized as PV system. Three different MPPT algorithms were implemented in the converter. The result obtained from the converter was analyzed and compared to find the best algorithm to be used to identify the point in which maximum power can be achieve in a PV system. The objective is to reduce the time taken for the tracking of maximum power point of PV application system and minimize output power oscillation. The simulation was done by using MATLAB/Simulink with DC-DC Boost converter. The result shows that FLC method with PSO has achieved the fastest response time to track MPP and provide minimum oscillation compared to conventional P&O and FLC techniques.

Keywords: *DC-DC Boost Converter, Maximum Power Point Tracking, Photovoltaic.*

1. Introduction

Greenhouse gases emission, global warming and environmental issues due to increasing electrical power generation have attracted the attention of researchers to explore extensively on renewable energy. Photovoltaic (PV) has a big potential in power generation system that can potentially overcome the issues. PV panels has been widely used in power system application tends to be distributed generation (DG) unit as they can operate independently from larger grid. This DG unit has been developed widely in many countries such as Japan, Germany, Spain and USA [1]. Generally, PV system are divided into grid-connected, stand-alone and hybrid as discussed in [2]. However, a factor such as loads impedance, solar irradiance intensity and temperature gives significant impact to the PV output power and leads to less effective of power generation. In addition, when output voltage increase, the power increase first then drop, thus there are exist voltage corresponding to maximum power output. Hence, power electronic such as Buck, Boost or Buck-Boost converter are widely implemented in between PV panels and loads which able to control the seeking of maximum power point (MPP) and drawn maximum output power of PV panel which can be found and maintain the voltage exist. This converter known as Maximum PowerPoint Trackers (MPPTs) which can dominate the duty cycle of the the power electronic interfaces by an algorithm [3]. The MPPTs are vital technique in PV application because they can track the maximum power of PV output [2]. This will recovered an efficiency of PV output power generation as their power losses reduced. It is vital to track the MPP of PV output generation because of their intermittency production due to stochastic behaviour. PV plant's efficiency is affected by the efficiency of power electronics interfaces and MPPT algorithm. The power electronics interfaced not improve their efficiency because they depends on availability of hardware technology, but tracking the MPP with new improved algorithm is easier, fast and reliable and leads to efficienct to the PV power generation [4]. At MPP, the PV arrays generated maximum power with retain of controller to avoid any power losses [4].

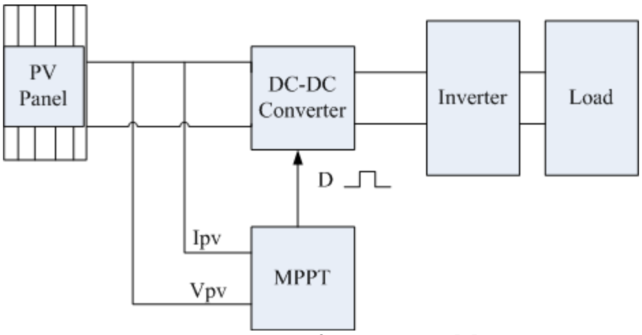

Fig.1: Concept of MPPT system [4]

Fig.1 explained the concept of MPPT technique in PV system. A DC/DC converter is implemented in the system to matching the condition. The MPPT algorithm adjust the duty cycle (D) until the best D value is detected at matching condition and transferring power to the load [5][6]. In order for PV output power to reach MPP, the PV system is required to operate at a specific levels of voltage and current, as shown in Fig.2. The MPP is depends on temperature and irradiance variations of solar radiation. Hence, the MPP tracking system is essential for this system in order to keep close and track to MPP. There are several modern and traditional MPPT algorithms which were reported to achieve the MPP output in order to maximize the efficiency of PV system [2][6][7].

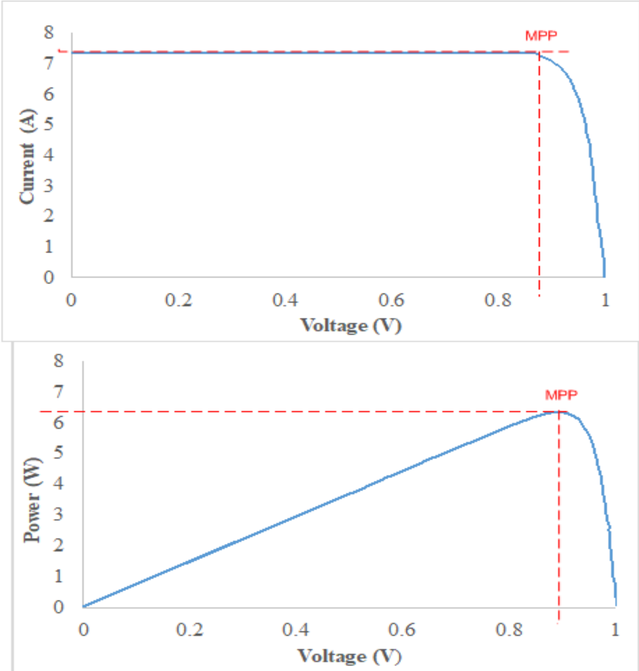

Fig.2: P-V and I-V characteristic of PV arrays [4]

An advantage of using MPPT algorithm for PV applications is discussed in this paper. Furthermore, the simulation work has demonstrated the result of most common algorithm used in MPPT techniques, which are FLC and Perturb & Observe. The boundaries input and output of membership functions of FLC were optimized by using Particle Swarm Optimization (PSO) and compared for evaluation.

2. Theoretical Background

2.1. Solar Panel

Solar cell is the main component in solar panel which to convert light energy to an electrical current by moving a charged particle in silicon. A PV module is made up by connecting many series and parallel of solar cell. Fig.3 shown a single model of solar cells which connected to a diode and two resistor.

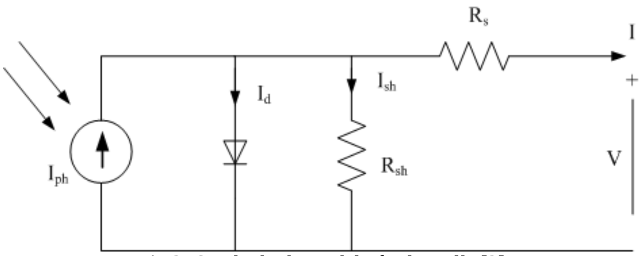

Fig.3: Single diode model of solar cells [3]

The characteristic equation for single solar cells is given by equation (1).

$$I = I_L - I_0\left[e^{\frac{q(V-I_{RS})}{AkT}}\right] - \frac{V - I_{RS}}{R_{SH}} \quad (1)$$

Where I and V are the output current and voltage respective. I_{ph} is photocurrent, q and T are the electron charge with a value of $1.6\text{x}10^{-19}$ (C) and the absolute temperature in degree Celsius, respectively. Boltzmann constant, $k = 1.38\text{x}10^{-19}$ (J/k), R_s and R_{sh} are the series and shunt resistances, respectively. To characterize the properties of solar cells, it is important to indicate the Power-Voltage and Current-Voltage curves. Fig.4 shows the effect of solar irradiation variation (1kW/m^2) on the Power-Voltage and Current-Voltage curves in this project. As shown in Fig.4, the change of current brings a significant effect than the voltage. As such, the higher solar irradiation, the higher would be solar input to solar cells and leads to increasing power magnitude [3][8].

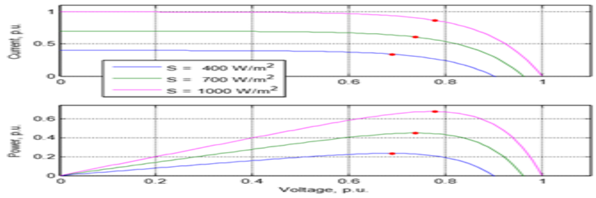

Fig.4: V-I and V-P

The temperature has given significant effect to the voltage. As shown in equation (2), the open circuit voltage is proportional to the temperature.

$$V_{OC}(T) = V_{OC}^{STC} + \frac{K_{V,\%}}{100}(T - 273.15) \quad (2)$$

Fig.5 shows the Power-Voltage and Current-Voltage changes with the temperature. As changing of irradiance and temperature, solar panel's internal resistance accordingly changes. From the curve obtained, it is clear that, as increasing in irradiance level, the net output power increase while increase in ambient temperature, it non-linearly decreased [6][9].

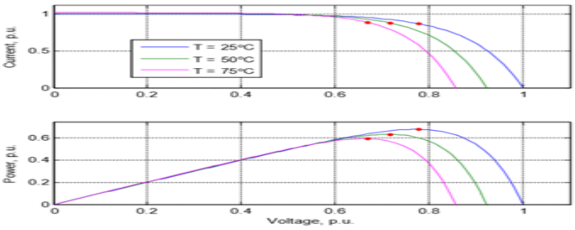

Fig.5: The change in output characteristics of PV with variation in temperature

Maximum output power can be obtained when the solar panel's output resistance is equal to its internal resistance. Hence, tracking a maximum power in any conditions is essential to verify the MPP is obtained from PV board. The temperature and irradiance are not constant due to fluctuation behaviour of weather. This behaviour makes MPP inconstantly tracking the maximum output power of PV generation and leads to unstable power generation. Hence, the process is commonly performed by an advance MPPT algorithm that have been developed previously [10].

2.2. MPPT with Perturb & Observe

To increase the efficiency of solar cell, the method called MPPT is undertaken to match the sources and load properly. Hence, Perturb & Observe (P&O) are popular methods to implement the MPPT [3][4][10]. It perturbs the operating voltage of PV arrays, and observe the effect of this changes on PV generated power.

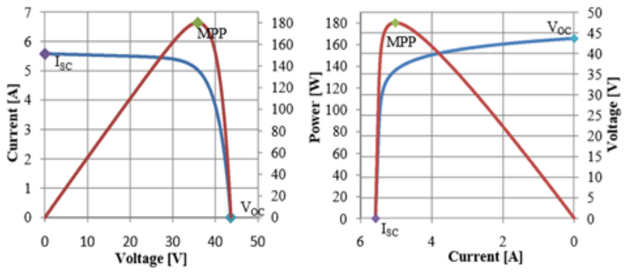

Fig.6: Curve characteristic of PV panel

As shown in Fig.6, once the power production increases, the perturbation direction kept remain at the same as before. And, it should be in the other direction to achieve the MPP once power decrease [11]. This repeated process is done until the MPP output is achieved. Fig. 7 demonstrated the flow chart of P&O method.

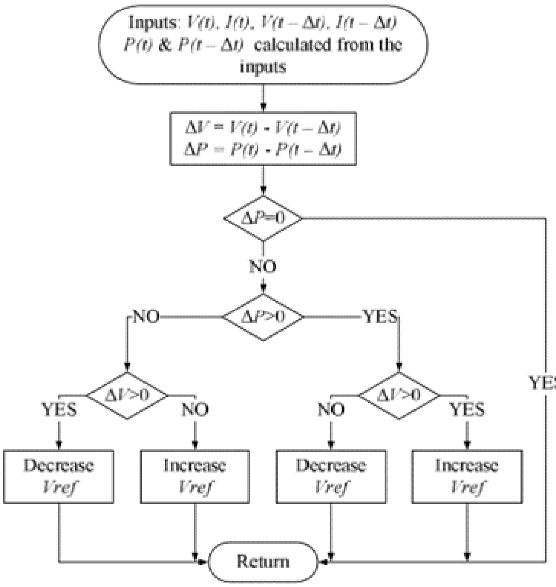

Fig.7. Perturb & Observe method [3][6]

2.3. MPPT with Fuzzy Logic Controller (FLC)

This method has capability to track MPP of PV system as their ability to solve non-linear behavior, robust and easy to implement with imprecise and incomplete data [7][10][12]. The proposed FLC for MPPT in PV system is shown in Fig. 8. Generally, FLC consist of three stages which are fuzzification, ruled based table lockup and defuzzifications [7].

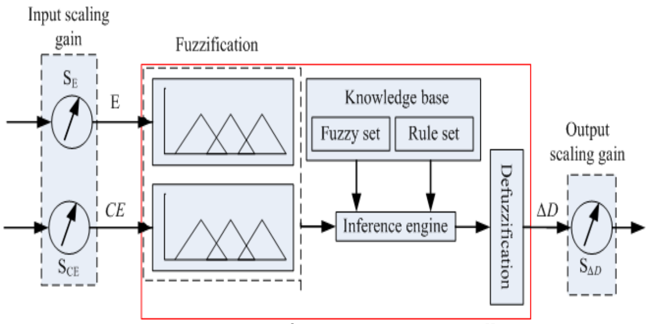

Fig.8: Structure of a Fuzzy Logic Controller

During fuzzification, crisp value is transformed into grade of membership function for linguistic term of fuzzy sets. This called decomposing system input into one or more fuzzy sets. In this case, five levels of are addressed which are NB (negative big), NS (negative small), Z0 (zero), PS (positive small), PB (positive big). The input of FLC was set as error (*E*) and change of error (*ΔE*), which were derived from actual signal (*E, ΔE*) from Fig. 8. After multiplication of actual signal with scale gain (S_E, S_{CE}), the input then convert into fuzzy levels.
ΔE and *E* are the input of MPPT FLC. The *E* and Δ*E* can be chosen by the user using an approximation based on equations (3) and (4) [13].

$$E(k) = \frac{P(k) - P(k-1)}{I(k) - I(k-1)} \quad (3)$$

And

$$\Delta E(k) = E(k) - E(k-1) \quad (4)$$

Where *P(k)* and *I(k)* are the power and the current, respectively. *E(k)* shows the location of the operating point inside the MPP at the instant *k*, according to the P-*I* graph. The direction of the operating point is indicated by the input *ΔE(k)*. The controller provides output on the change in converter's duty ratio (*ΔD*) [14].

Table 1: Fuzzy Membership Function Rules

E	ΔE				
	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

After calculating and converting the *E* and *ΔE* into linguistic variables, the *ΔD* of FLC output of converter can be searched and obtained in Fuzzy membership function rules, as shown in Table I. In this paper, Table I is developed based on the boost converter that was used in this research because the assignment of the linguistic variable to *ΔD* is different and dependent on power converter used. As an example, operating point is avoided towards left of MPP as in Fig.2, then *E* is PB and *ΔE* is Z0, so that *ΔD* must be Positive Big to achieve maximum power point. In defuzification stages, the linguistic variable converted into numerical variable given fuzzy sets and corresponding membership degrees [7]. This will map the fuzzy sets into crisp set to provide decision or signal to a power converter.

2.3. MPPT with Particle Swarm Optimization (PSO)

PSO is an advance method and considered powerful optimization that have ability to solve complex optimization problem as developed by [15]. The performance of the algorithm is evaluated and achieved by considering the efficient and intelligent movement of particles and the collaboration of the swarm [16]. Generally, the system initialized the population randomly and search the optima by updating generation. The general flowchart of PSO algorithm shown in Fig. 10. In this research, PSO was utilized to find an optimal adjustment of scaling factor for fuzzy-MPPT controller. In this work, PSO was used to perform satisfactorily in steady state condition and it was aimed at improving the transient performance if the system yields a condition that is oscillating or abnormal. In addition, an improvement of fuzzy control performance is made by optimize the membership function to heuristically define the optimum membership function of fuzzy logic controller [17]. The proposed diagram of PSO algorithm is shows in Fig.9.

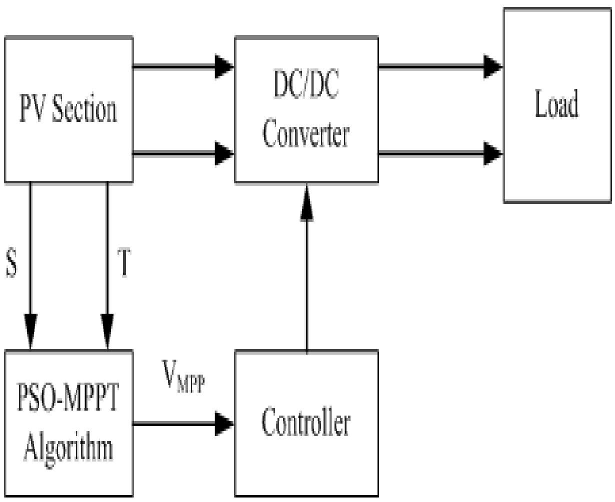

Fig.9: Block diagram of proposed PSO algorithm

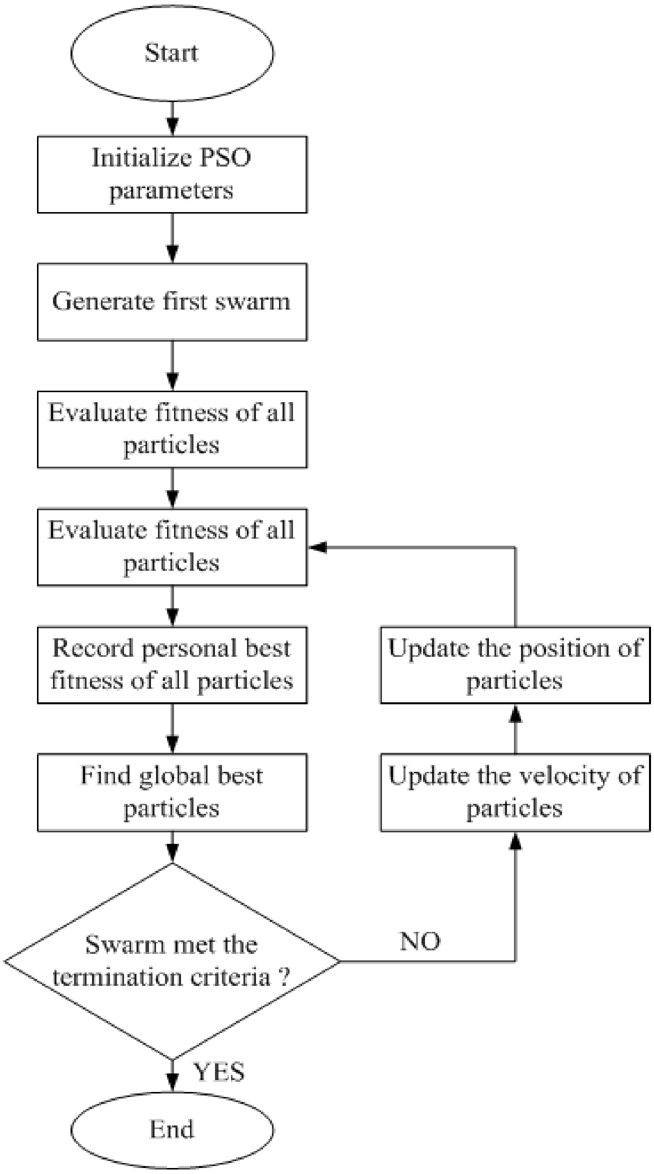

Fig.10: Flowchart of PSO algorithm

3. Methodology

The method in this research is done by MATLAB/Simulink for PV array, boost converter P&O algorithm and FLC with PSO optimization. The operation and simulation of each algorithm was performed under standard conditions with an irradiance power density of 1000 W/m^2 and at a temperature of 25^{o}C). The extract result has compared and evaluated for each of algorithm.

3.1. System Configuration

The simulation has developed and done by using MATLAB/Simulink. Fig.11 shows completed model of system consist of PV module, boost converter circuit and MPPT controller.

The PV module considered in this simulation STP135-12/Tb is made of serially-connected 35 multicrystalline silicon solar cells with a nominal rated power at 150 W. Two PV arrays that were used with similar power output produced and compare the MPPTs with the same input at standard operating conditions. The DC-DC Boost converter consist of inductor, diode and IGBT are depicted in Fig. 12. The Fig.13 shown the block diagram of MPPT controller developed using MATLAB/Simulink.

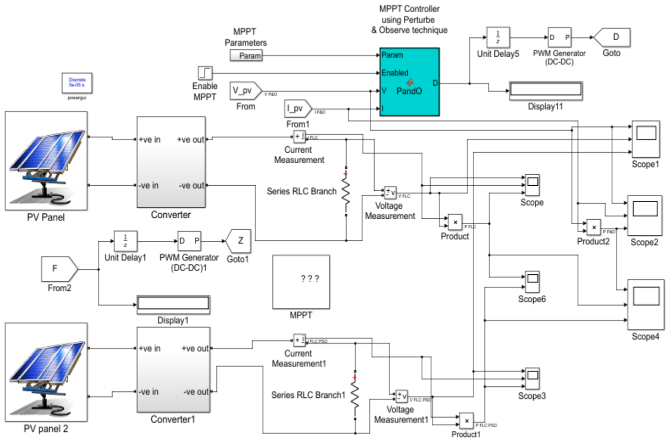

Fig.11: Model of the PV system, Boost converter and MPPT controller in MATLAB/Simulink

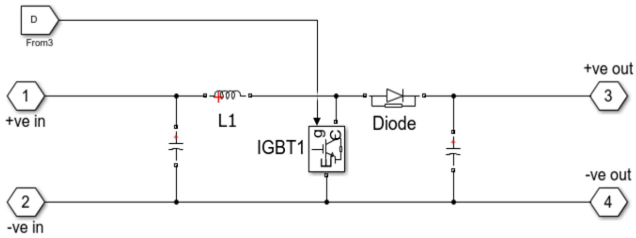

Fig.12: DC-DC Boost Converter diagram

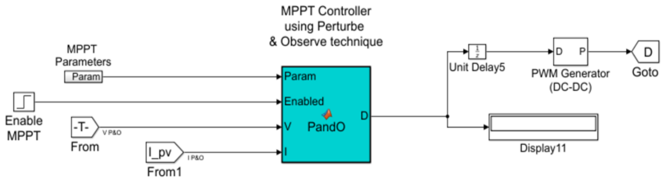

Fig.13: MPPT controller model

3.2. Fuzzy Rule Algorithm

The association of the output of fuzzy to the input was derived based on the investigation and analysis of the system behavior. Fig.14 shown diagram of fuzzy MPPT algorithm.

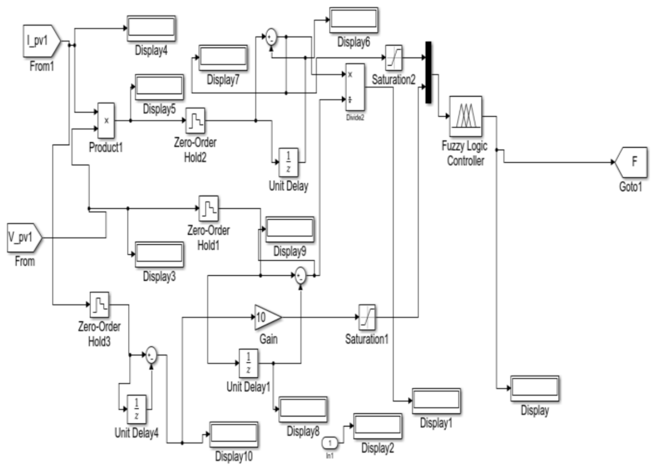

Fig.14: Diagram of fuzzy MPPT algorithm

The inputs of voltage and current will change to *E* and *ΔE* before execute by fuzzy inference system. A few conditions were included by designing the fuzzy rules and they are listed below.

- Change in membership function of input and output to keep in direction by adjusting *ΔD* of the converter.

- Shifting to optimum point due to fluctuation of temperature and sunlight level to the characteristic curves.
- At a peak power point, the point of operation is stabilized by providing the system with a set of rules.

With considering on this points, the membership function of fuzzy sets is defined as shown in Fig.15.

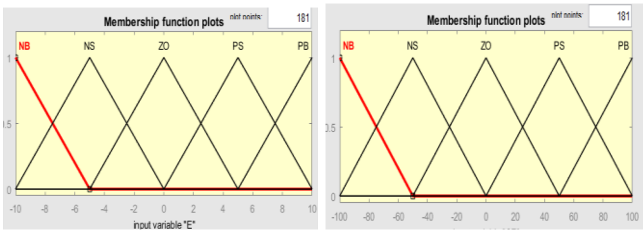

Fig.15: Membership function of *E* and *ΔE*

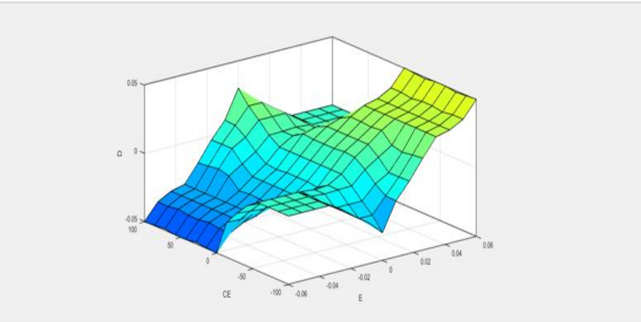

Fig.16: Three-axis model of the MPPT fuzzy surface

Mamdani's method was used in combination with the maximum-minimum fuzzy combination law. Fig. 16 shows a fuzzy inferences surface method resulted as Mamdani's pattern.

3.2. Optimal Fuzzy Logic Controller

Although the ability of FLC can deals with non-linear behaviour, choosing the boundaries of input and output of membership functions was a major disadvantages of FLC method. Hence, the optimization method applied to obtain an optimal membership function of fuzzy logic controller. The purpose is to obtain an optimum boundaries for the membership function's input/output. The important elements that involved are input formation, limitations of optimization and fitness-function. Every elements is operated toward an enhancement and categorization/classification to produce the optimum membership functions. The optimization searches for the best possible solution by reducing the fitness-function to a minimum value even though the inputs and constraints selection in each iteration is manipulated. Fig.17 shows a developed diagram of optimization technique applied to adjust the membership function in order to obtain the best boundaries solution for membership functions through PSO technique.

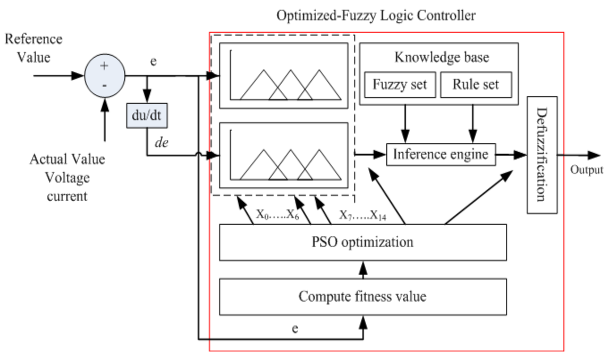

Fig.17: Block diagram of optimized FLC membership function

4. Result & Discussion

The result and discussion section includes comparison of MPPT controller using P&O method, FLC method and FLC with PSO in terms of its power tracking features at a standard operating condition, under the irradiation 1000W/m^2 and ambient temperature of 25^{o}C. The main highlight of obtained result are the ability of PV system response time to generate output power of MPP. Also ability of corresponding algorithm to simultaneously enhance the dynamic performance and steady state performance of the PV system. Fig. 18 shows a result of output power generated by MPPT algorithm.

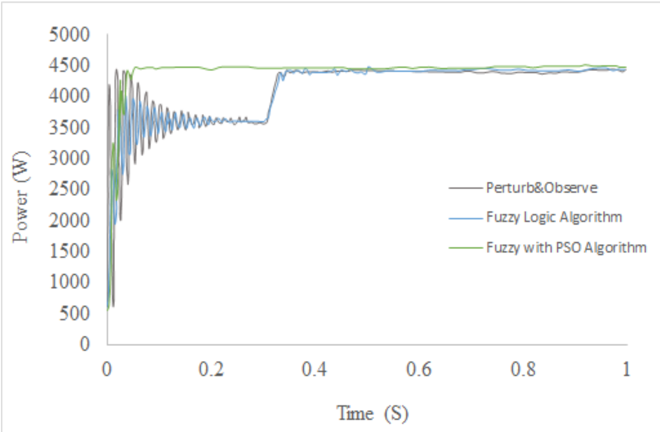

Fig.18: Comparison of MPP output power generation

From result, it observed that, the output power generated by FLC with PSO reached 4840 W of MPP and hence improve steady state performance and response time to reach MPP than conventional P&O and FLC algorithm. This shows that the steady state behaviour of PV system using FLC with PSO algorithm are more stable and provide smaller oscillation. Fig.19 shows a comparison output voltage obtained by the corresponding algorithm.

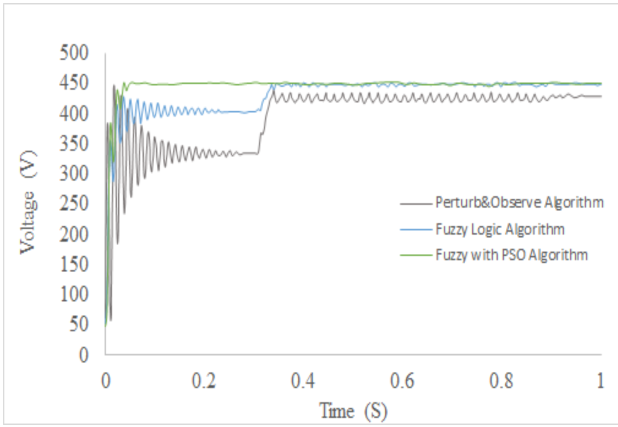

Fig.19: Comparison of MPP output voltage generation

From Fig.19, the performance of output voltage for three MPPT algorithm was observed and the FLC with PSO had given maximum voltage at 420V with short times response. This is to indicate that the time taken for FLC with PSO to reach maximum voltage are faster than P&O and FLC algorithm.

5. Conclusion

Simulation was carried out by using MATLAB/Simulink with PV module of STP135-12/Tb to generate a 150W PV generation. The simulation of each algorithm was performed under standard operating condition of irradiance 1000W/m^2 and temperature of 25ºC. Simulation results have shown that the proposed MPPT using FLC with PSO algorithm provides a more stable tracking of maximum power at a faster rate, as compared to MPPT using P&O method and FLC method.

Acknowledgement

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