iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 Issue: XI Month of publication: November 2019

DOI: http://doi.org/10.22214/ijraset.2019.11035

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue XI, Nov 2019- Available at www.ijraset.com

Comparative Analysis of MPPT Techniques for Solar PV System using P&O and Fuzzy PSO

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Abstract: In this paper, it has been done on MPPT based solar system performance enhancement by use of fuzzy logic controller's designs optimized by particle swarm optimization (PSO). We have described about different latest A.I. techniques that has been hybrid with fuzzy logic for improving PV array based solar plants performance in recent time. The artificial intelligence technique applied in this work is the Particle Swarm Optimization (PSO) algorithm and is used to optimize the membership functions for maximum power point tracking rule set of the FLC. The PSO algorithm is used for the optimization of the FLC, which is the able to maximize the energy being absorbed by the system loads while ensuring a higher stability and speed as compared to P&O based MPPT algorithm.

Keyword: Fuzzy Logic Controller, PSO, Artificial Intelligence.

I. INTRODUCTION

Renewable energy is the most common energy that utilize without generating any pollution. Solar energy is converted into electrical energy using photovoltaic panels. The photovoltaic term is made up of two Greek words i.e. photo and voltaic .Photo means light and voltaic means electric and the conversion of solar radiation into electrical energy is called solar energy conversion and which can be used in the electrical grid system.

Photovoltaic cells directly converts solar energy into electrical energy. Photo-Voltaic commercially categories into two types: Crystalline silicon and thin films. The photovoltaic pane is made up of crystalline silicon which can be categorized such as mono-crystalline and multi-crystalline PV cells. This is most efficient technologies till known. This efficiency good in electric generation and PV system is created from semiconductor materials. Mono-crystalline are more efficient than multi-crystalline cells, but are more expensive in manufacturing photovoltaic devices.

II. SYSTEM CONFIGURATION

In this paper, project has categories into three different part primary part is solar panel PV system, Secondary part is controller for optimized maximum power of the input supply and last is load. Buck-Boost converter commonly used in the PV system and in which, P&O most commonly used algorithm, MPPT technique used to maximize power of the system. And hybrid system can apply on PV system and it provide the more stable system as compare to P&O and PSO.

A. PV Panel

Each unit of Solar PV cell is connected in the series to make a solar PV module/panel. These pv panel are connected in series and parallel to form Arrays. PV cell module has been connected with single type of the diode in order to control the flow of the current. The simple and basic equation figure drawn below with series and parallel connection. In this circuit basic equation can defined as generated value of the current and many other parameters can be deducted with this equation. As shown in Figure 1 this is non-ideal solar cell circuit which is used to convert solar energy into electrical energy and this effect is called photovoltaic effect. Solar cells generate near about 0.5 to 0.6 volt varying with the respect of the temperature and independent of irradiance and both are dependent with sun light and temperature. The mathematical equation of the PV cell is shown in Fig-1.

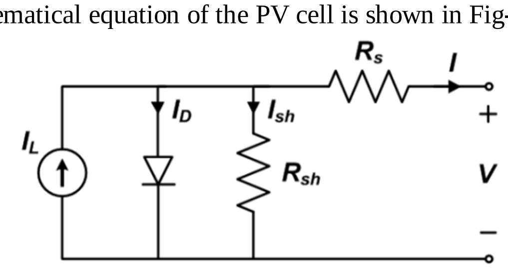

Fig.1. Equivalent model of Photovoltaic Module

Its mathematical equation

$$I = I_L - I_0\left[\exp^{\left(\frac{V+I R_s}{aV_{th}}\right)} - 1\right] - \frac{V + IR_s}{R_{sh}} \quad (1)$$

where PV output voltage is shown as V (Volt); Photon generated is shown as I_L current (Amps); the electron charge is shows as q (1.6* 10^{-19}C); V_{th} is the thermal voltage. I_0 is the reverse saturation current; R_s and R_{sh} are the series and shunt resistance of a PV cell respectively.

B. Particle Swarm Optimization (PSO)

PSO works on principle similar to biological manouvre followed by flocks of birds and shoals of fish. PSO is a computational technique with good efficiency. PSO is also known artificial technique for fast searching and accurate results. It is simple and easy to find the result. It carries the iteration directly in order to communicate from one element to another and delivers the best results.the step is repeated in searching point starting from the new base point. So that every swarm has ability to generate its base point. The speed and place of every molecule is balanced by the accompanying formula:

$$Vid = WXVid + c_1rand()(Pid-Xid) \quad +C_2Rand()(Pad-X_{id}) \quad (2)$$

$$X_{id} = X_{id} + V_{id} \quad (3)$$

where c_1 are the cognitive and c_2 are the social learning. These are the element can store its relative importance memory whose store. The variable rand() and Rand() are two random functions. These are the variable can change the iteration(swarm) and it is providing the equally in distributed the range [0,1] i.e. shown with (X iteration) Xi = (Xi1, Xi2, Xi3,.,XiD) represents the series of the i^{th} iteration and optimize the iteration. Pi = (Pi1, Pi2, Pi3,.,PiD) represents the history of the previous complete position and store it new element with i^{th} particle. Best value is represented in the 'g' and it has store best position of the iteration. Vi=(Vi1,Vi2,Vi3,.,ViD) represent the velocity of the i^{th} particle.The general process of PSO is as follow:

Calculate fitness of particle

Update P_{best} if the current fitness position is better than previous position. and choose the particle with the best fitness values of all the neighbours as the nbest. For every particle Calculate the particle velocity according to (2.). Update particle position according to (3). While maximum iterations or minimum criteria is not attained.

C. Dynamic and Adjustable PSO:

In this section, we propose two improved algorithms called Dynamic and Adjustable Particle Swarm Optimization 1 (DAPSO1) and DAPSO2. In DAPSOs, in order to adjust the velocity of each & every particles, all particles are calculated the distance from itself to the global best position by the following function.

$$\Delta x_{di} = |(x_{di} - xg_{best})| \quad (4)$$

$$FDd = Max(\Delta x_{di}) \quad (5)$$

Where x_{di} is the position of the i^{th} particle, xg_{best} is the position of g_{best}. FDd is at the farthest distance from the particle to g_{best}. In DAPSO1, the velocity and position of each particle is modified by the following formula:

$$V_{id} = WX_{Vid} + c_1rand()X(P_{id}-X_{id}) + C_2X_{Rand}()X(P_{ad}-X_{id}) \quad (6)$$

$$ac = rand()*0.5 \quad (7)$$

$$V_{new} = \begin{cases} V_{id} * \left(1 + ac_d * \frac{Gene-Iter}{Gene}\right) & \frac{\Delta x_{di}}{FD_d} > 0.5 + ac_d \\ V_{id} * \left(1 - ac_d * \frac{Gene-Iter}{Gene}\right) & \frac{\Delta x_{di}}{FD_d} < 0.5 - ac_d \\ V_{id} & 0.5 - ac_d <= \frac{\Delta x_{di}}{FD_d} <= 0.5 + ac_d \end{cases} \quad (8)$$

$$X_{id} = X_{id} + V_{new} \quad (9)$$

Where X_{id} is updated by velocity which is adjusted by the distance of the particles from the global best and is the adjustment coefficient. DAPSO1 and DAPSO2 differ from the adjusting method. In DAPSO2, the velocity and position of each particle is adjusted by the following formula:

$$V_{id} = WXV_{id} + c_1rand()(P_{id}-X_{id}) + C_2 Rand()(P_{ad}-X_{id}) \quad (10)$$

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$$\text{Vid}=\begin{cases} V_{id} * \left(1 + \frac{\text{rand ()}}{4} * \frac{\text{Gene}-\text{Iter}}{\text{Gene}}\right) & \frac{\Delta x_{di}}{FD_d} > 0.5 + ac_d \\ V_{id} * \left(1 - \frac{\text{rand ()}}{4} * \frac{\text{Gene}-\text{Iter}}{\text{Gene}}\right) & \frac{\Delta x_{di}}{FD_d} < 0.5 - ac_d \\ V_{id} & 0.5 - ac_d <= \frac{\Delta x_{di}}{FD_d} <= 0.5 + ac_d \end{cases} \tag{11}$$

$$X_{id} = X_{id} + V_{id} \tag{12}$$

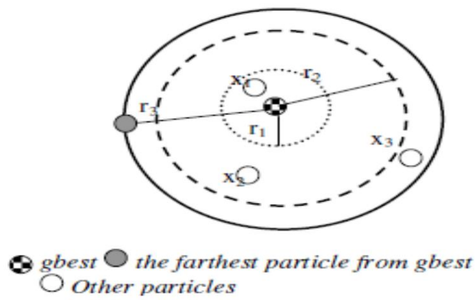

Fig. 2: Three radius of (0.5- ac)* FDd, (0.5+ ac)* FDd, and FDd .

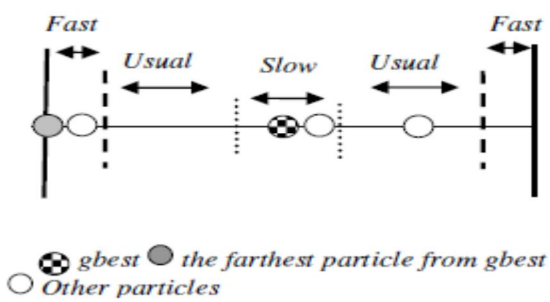

Fig. 3: Adjust the velocity according to the distance from the particle to gbest

D. *Perturb and Observe Algorithm*

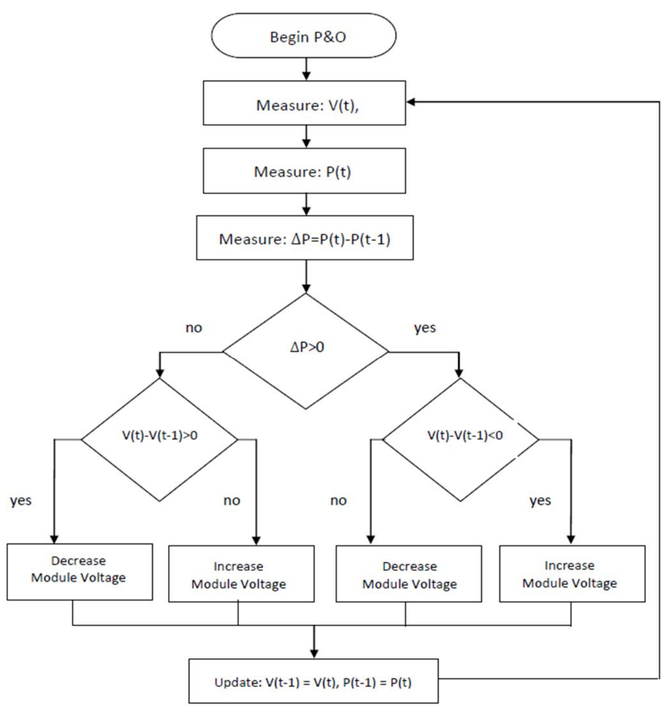

Figure 4. P&O Algorithm.

P&O is one of the simplest and less calculation intensive algorithm for the MPPT control. This algorithm uses minimal measurement for the recalibrating the MPPT point according the changing conditions. In this approach, The DC-DC converter is used for the MPPT operation. The converter is controlled by the duty cycle which is periodically perturbed and the corresponding change in the output power is calculated by comparing the present and the previous states of the power for the given perturbation.
The V and I are the PV array output voltage and current which are passed through LPF V filter and I filter to remove then ripples then using the hold circuit voltage and current samples V(n) and I(n) are sampled to the memory to access V(n-1) and I(n-1) delayed samples. These values are used to provide P(n),P(n-1) for checking the delP and delP values. As per the delP and delV the converter voltage module are increased by increasing or decreasing duty cycle in a PWM manner by comparing the duty cycle with triangular wave repeating sequence.

E. Fuzzy logic Controller

Fuzzy logic controller has controller that provide the result on basis of the change in error and error. And it categories into three main part: fuzzification process, inference engine, and defuzzification process. fuzzy logic controller below shown in figure and all three-part shown. All of the main components are discussed below.

1) *Fuzzification Process:* The Member function can be categories number of the input and its categories into many parts as required. Below figure 5 as shown, membership function of fuzzy logic and this is comparison two type of input first error and second is change in error. This value is usually designated by the symbol μ.

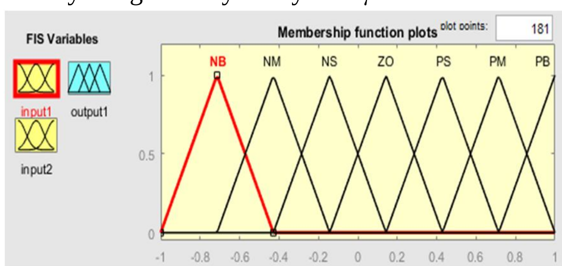

Figure 5. membership function of fuzzy logic

2) *Inference Engine:* In the Fuzzy logic membership function can generate by input who's presented to the inference engine. Typical type fuzzy logic make a number of membership function and it can categories as we want in the fuzzy logic membership function we create lots of input (NB, NM, NS, ZO, PS, PM, PB). in which input signal categories into seven membership function and it is generate output signal on basis into error and change in error in the input signal. As take a example if a NB signal is large, NM signal is larger than NB signal and same vary to the other signal then what effects on the output of the system then it is generate the maximum power of the system except 0. In the past either this rule (or any other congregation these criteria) has been unveiled, as known the effect of the input signal (error and change in error) based on output improved.
3) *Defuzzification:* When the degree of the membership function then it is generate output membership and it is attain by the diffusion engine. Diffusion process convert signal into required signal i.e. dispatch signal. Dispatch signal is normally change all in individual signal i.e. called defuzzification process. Signal generate response and it is directly affected to the system. The average of the all signal generate the output signal.
4) *Optimized Fuzzy Logic Controller:* PSO is optimized the fuzzy logic signal controller and PSO is the one of the best algorithms for optimizing of the signal and it can ability to control the membership function in the fuzzification process. PSO is an iterative algorithm and search one by one. It is biological based algorithm and every iteration has ability to control the velocity and position. P_{best} has to ability can store the previous value of the position. PSO has lot of ability to improve the signal in the all direction. So that it is very useful for optimize the system. And when one of the all position (P_{bast}) i.e. called $g_{best.}$ The best equation can find utilize utilize of the below equation. In each, i^{th} iteration utilize of the number of the particles.

$$\text{Velocity}(i) = 0.1 * \text{rand} * \text{Velocity}(i) + 2 * \text{rand} * (\text{pbest}(i) - \text{Position}(i)) + 2 * \text{raud}(\text{gbest} - \text{Position}(i))$$

$$\text{Position}(i) = \text{position}(i) + \text{Velocity}(i)$$

The quality of solution for each particle is measured by the fitness function when evaluated at the particle's current position.

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III. RESULT & DISCUSSION

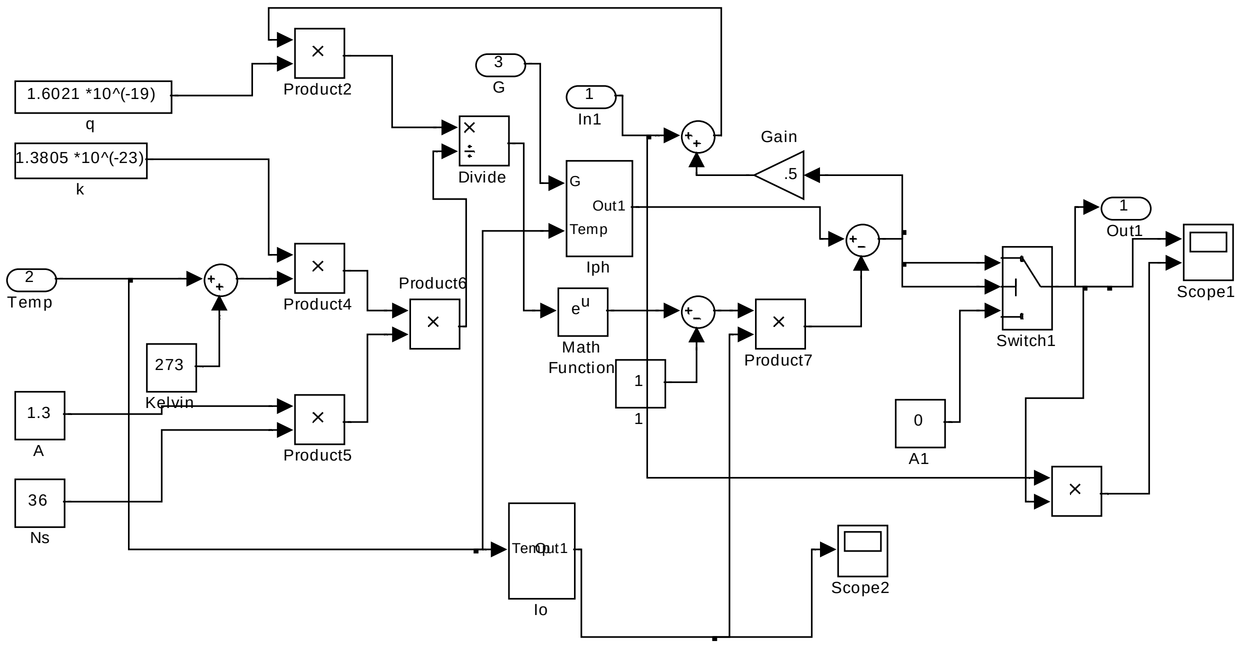

Figure 6: Internal Model of PV array subsystem.

Figure 6 shows the complete model design after assembling the PV array with fuzzy controller to the buck converter. The current model is operated at irradiance 700 W/m2 at temperature 35 C. The power, current and voltage output of PV array is shown in scope and output of converter is shown at scope in figure 7. As we can see the in fig 7 topmost plot is for pin i.e. power input to buck from the fuzzy controlled PV array. Similarly, I_{in} and vin are the PV array current and voltage output given to the input of DC-DC converter. The fuzzy controller varies the duty cycle of gate pulse as per the value of voltage and current change i.e Vin and Pin such that after iterative changes in voltage the converter input condition achieves the state of maximum power point. Due to this we can observe fluctuation in Vin, Iin and Pin in starting moments of plot of figure 7. After some time as the max. power point is achieved the perturbation becomes very small just to maintain the duty cycle at a voltage desired Vin. We can see that at steady state Vin is at 60V and Pin is 1100W (approx.).

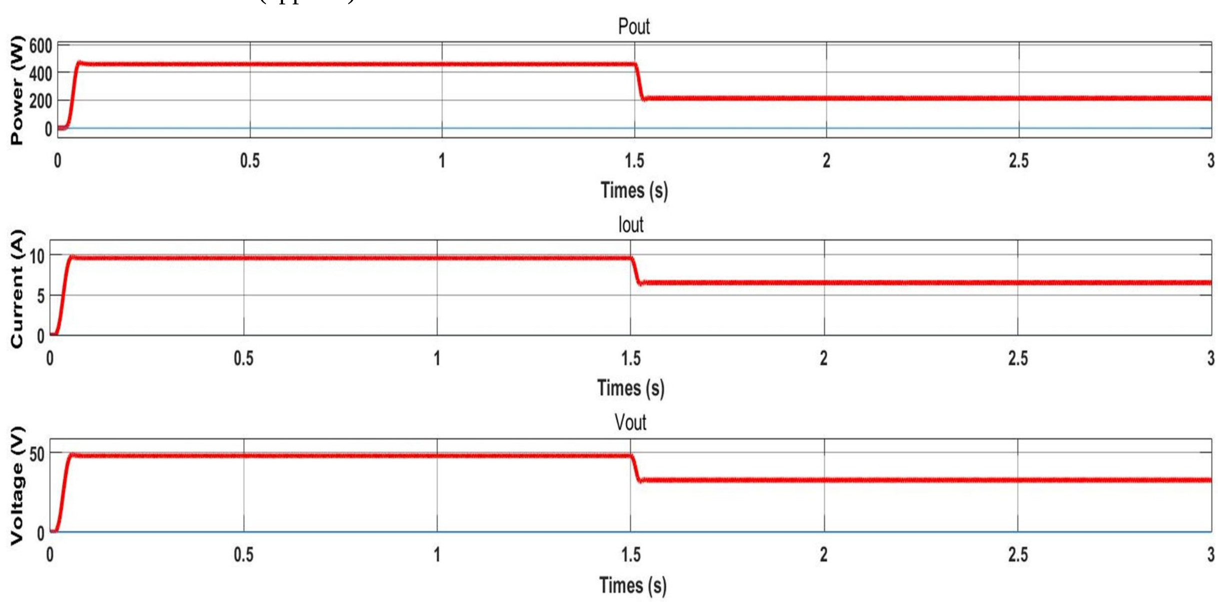

Figure 7: PV array with MPPT controller and Buck converter ouput power, current and voltage

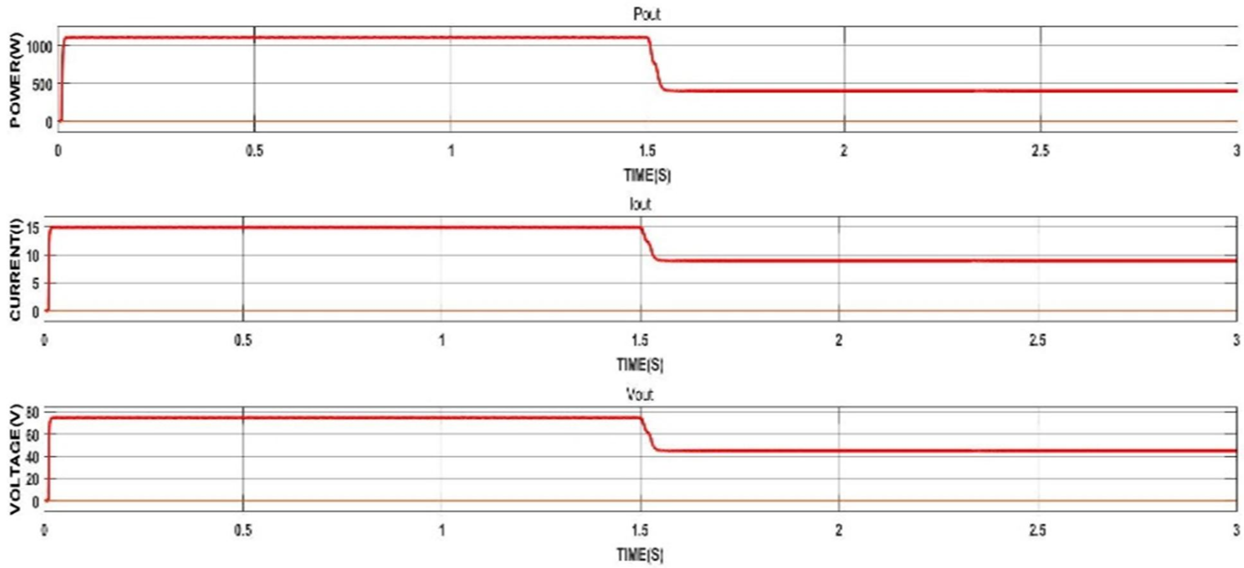

Figure 8 PV array with fuzzy controller and Buck converter output power, current and voltage.

A. *PV array with PSO tuned Fuzzy controller and Buck Converter*

In this section we will demonstrate the result for FIS rule application that is optimized for achieving MPPT control. The PSO algorithm is designed to generate a fuzzy membership function for input values of error and change in error. It has been observed that at different choice of membership function range of E and Ec the output power varies and it is very typical to search the Emin ,Emax, Ecmin and Ecmax values at which designed MF can give highest output power by achieving the duty cycle at an optimum value of near about 0.8.

We have selected a particle swarm of size n=10 and the algorithm is run several times for maximum number of iterations value of birdstep=20.

The PSO generates the n particles in terms of randomly initialize value of Emin ,Emax in between -30 to 30 and Ecmin , Ecmax in between -50 to 150. Hence each particle represent a dimension space of 4 parameter [Emin, Emax, Ecmin, Ecmax].

Hence initially a 4xn matrix of n particles is generated for in a limited range with an equal dimension size of velocity associated with each parameter. The main PSO algorithm calls the fitness function named as 'tracslq.m' to design the FIS structure for given particle parameters by adding fuzzy input vectors membership functions by equally partitioning the error in range Emin to Emax and change in error by Ecmin to Ecmax, after generating the MF for each particle in name of linguistic variable given as NB, NS, Z, PS and PB as shown in figure 4.10.

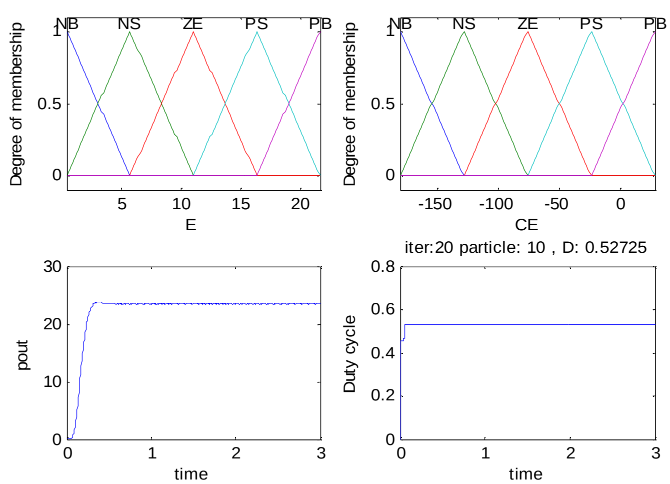

Figure 9: MF function plot for an arbitrary PSO generated particle parameters of [Emin, Emax, Ecmin, Ecmax].

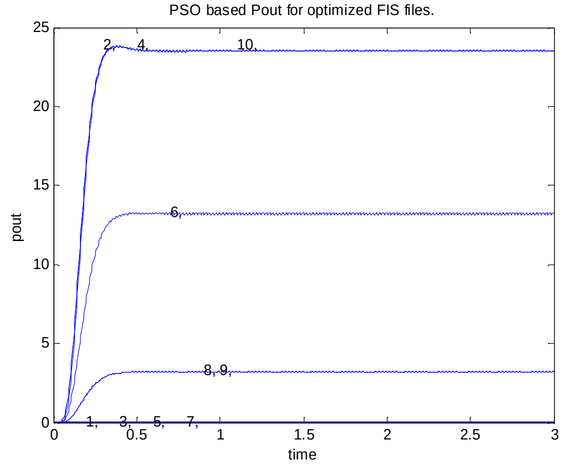

Figure 10: Collective results of output power (pout) for all finally optimized particle fuzzy MF.

The particle parameters are updated by the velocity value to generate a new particle population to find the updated performance. In the figure 10 the optimized parameter of final membership functions is shown for running of our PSO Fuzzy membership optimization algorithm for n=10 particles and for number of iterations of iter=20.

In figure 10 we can see that particle 2,4,8 can give maximum power output in the range of 24Watt (approx.) and particle 1.3,5,7 has insignificant pout while 8,9 has very low pout and 6 has pout at value of 6watt (approx.).

The MF of each optimized particle whose pot performance are collectively shown in figure 11 is separately shown from figure 10. In figure 10. top left subplot is MF value of particle 1 at 20th(last) iteration showing input MF plot of error varying from -1x109 to 1x109.The subplot in top right position is showing input MF plot of change in error varying from -99.23 to 44.37.The subplot in bottom left position is showing Pout at given MF value of error and change in error MF. The pout is varying from 0 to 0.04. The subplot in bottom right position is showing duty cycle variations at given MF value of error and change in error MF. The duty cycle is varying from 0 to -0.2 at average value of -0.007.

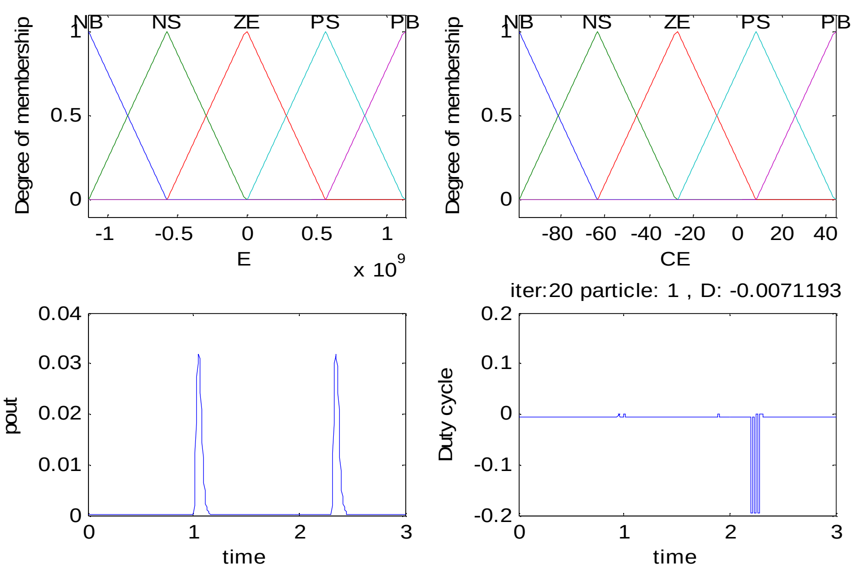

Figure 11: Plots for optimized particle no. 1 parameters-based MF and the pout and duty cycle performance for PSO Fuzzy MPPT approach result.

The figure 11 shows the MF plots of both the fuzzy inputs for determining the duty cycle the values of all the MF range are given below obtained at final iteration of the PSO solutions:

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Volume 7 Issue XI, Nov 2019- Available at www.ijraset.com

Table 1: Optimized MF range

Id	E min	E max	Ec min	Ec max	Avg Duty Cycle
1	-1.14x109	1.12x109	-99.23	44.37	-0.0071193
2	10.146	16.975	-106.43	20.284	0.53279
3	-1.73x1011	1.69x1011	-74.246	14.368	-0.075052
4	10.448	16.481	-70.657	0.25122	0.54807
5	0.54807	1926.8	-138.64	-1.1961	-0.13072
6	-5966.4	24494	-85.511	27.18	0.32855
7	-4.8 x1010	4.5 x1010	-78.105	-11.432	-0.17995
8	15.628	17.688	-180.38	2.4604	0.54638
9	-613.59	1825.7	-82.077	36.544	0.21738
10	-0.48983	21.292	-138.32	4.5537	0.54169

Out of n=10 particle position the algorithm select the best particle which have highest on average duty cycle value hence from above average duty cycle values the particle at id 4 has average duty cycle of 0.54807. Thus, the algorithm selects the best Particle id as 4 having best particle parameters of values:

Emin	Emax	Ecmin	Ecmax
10.448	16.481	-70.657	0.25122

The algorithm finally shows the plot of MF parameters, pout values and respective duty cycles at different time instants.

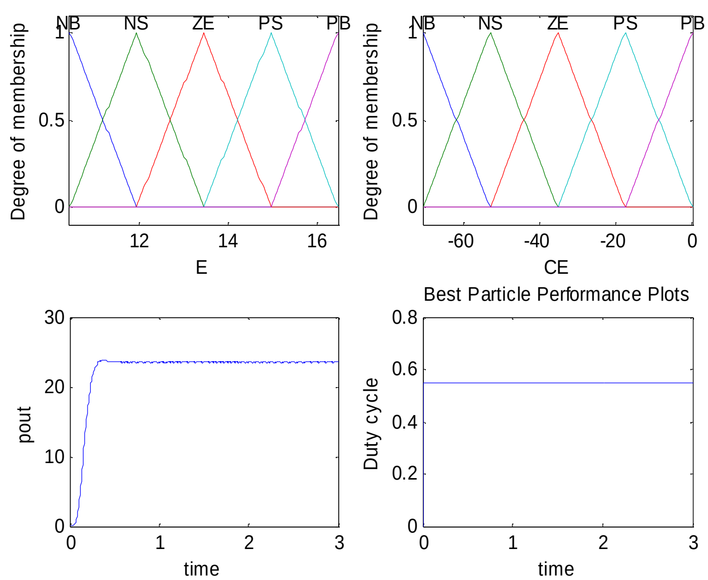

Figure 12: Plots for best particle parameters-based MF and the pout and duty cycle performance for PSO Fuzzy MPPT approach result.

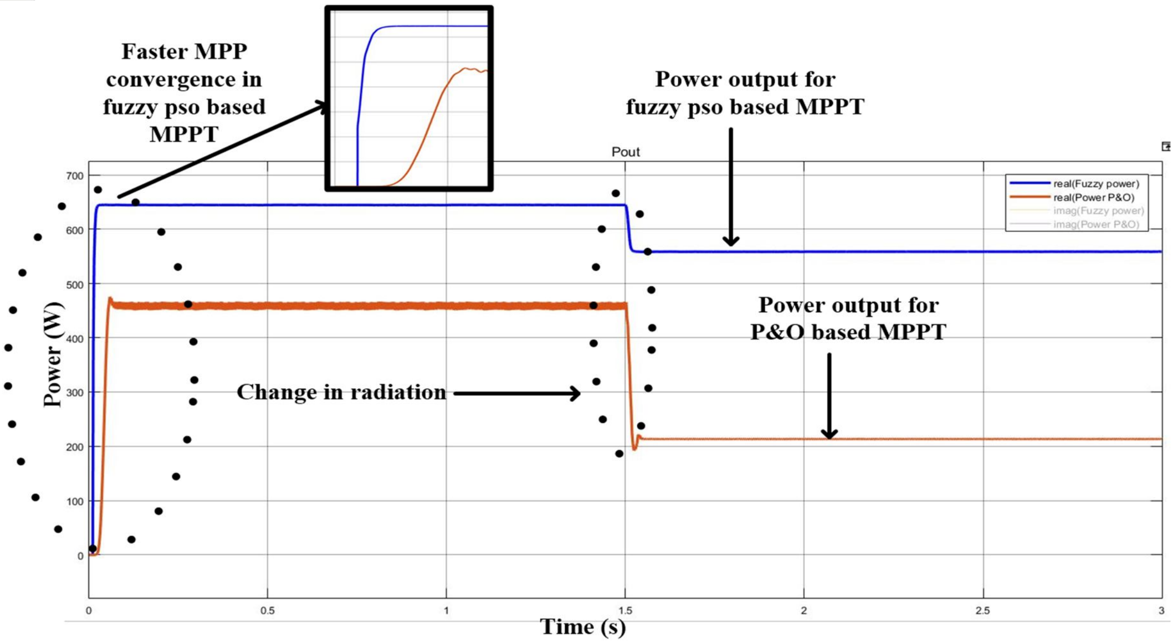

Figure 13: Comparative plot for output power for P&O MPPT and PSO optimized fuzzy MPPT.

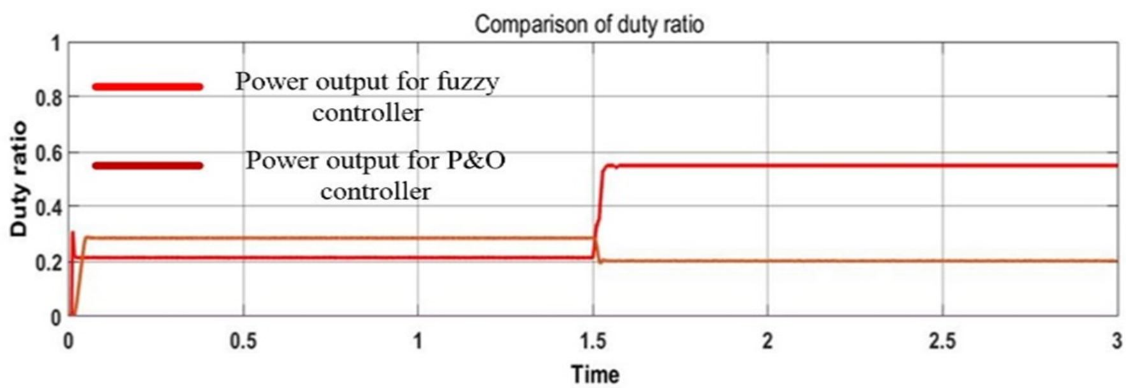

Figure 14: Comparative plot for duty cycle range obtained for P&O MPPT and PSO optimized fuzzy MPPT.

Figure 13 demonstrates the plot of all the power output of different MPPT approach for the solar cell array. The Simulink models runs for three sec. one by one and their output powers along with the duty cycle values are transferred at MATLAB workspace to generate the multivariable plots. The copper red line is the pout (top) of P& O based MPPT model having maximum power of 500 watt approx. reaches it peak at time 0.3 seconds approx. But the pout fluctuates multiple time and takes long time to stabilize even at small dip in the duty cycle as we see the duty cycle in bottom figure (copper red line).The P& O MPPT has duty cycle of 0.3 at most of the time there are two small value dips in duty cycle but it creates large amount of oscillations that stays for long time in Pout. The second plot is for PSO optimized input MF of fuzzy controller input for the finally selected best particle having highest average duty cycle (see figure 4.18).The Pout (top subplot, red line) has Pout of 1100 Watt higher than the P& O MPPT hence the best particle MF values gives highest out power for solar array. The oscillations in this case are negligible hence the Pout performance are ripple free hence shows reduction in harmonics it has been also observed that there is no peak overshoot in PSO optimized fuzzy MF output power plot.

The last advantage that can be observed in the pout plot is that the fastest performance (i.e least rise time) is in the Pout of PSO optimized fuzzy MPPT and through the plot of duty ratio we can see that the duty ratio is higher in case of fuzzy PSO than P&O. hence the output voltage has a relatively smaller dip as compared to P&O. From the fig. during 0 to 1.5 duty cycle of fuzzy settles at 0.2 and when irradiance falls to 500w/m^2 the duty cycle changes to 0.6.

During lower radiations, fall in output voltage is lesser in fuzzy.

Table 2: Comparative analysis of power output at different irradiance

N_S	N_p	PS0		P&O	
		1000 W/m²	800 W/m²	1000 W/m²	800 W/m²
2	2	850	680	645	580
3	2	945	875	680	640
4	2	995	940	710	670
5	2	1020	975	725	690

In table 2, The table shows the power output for the P&O and the Fuzzy PSO based MPPT under various series parallel combination of solar cell. Where Ns is number of series cells in pv array and Np is number of parallel cells in pv array Here we analyzed the result in two different irradiance level, one is 1000W/m2 and other one is 800W/m2 where we see that in case of PSO controller output power is more in comparison to P&O controller. Hence, we can conclude that Fuzzy PSO controller is better than P&O controller while tracking optimum power.

IV. CONCLUSION

The output power of a solar photo voltaic cells depends on the sunlight exposure, irradiation intensity and the environmental temperature. This paper considers the case of obtaining maximum power from photovoltaic cells-based array for power system usage. The objective is consideration of a design of power system that fulfils the requirement of stable and fast maximum power point tracking (MPPT) controller. Perturb and Observe (P&O) method is utilize to the compare with PSO and fuzzy logic controller. PSO and fuzzy logic controller are very stable system. And in this paper, controller is more capable to converge to maximum power point tracking faster than Perturb and Observe (P&O) method. It almost provides zero fluctuation at steady state, so that controller can save much amount of energy, regardless the power loss when initiated.

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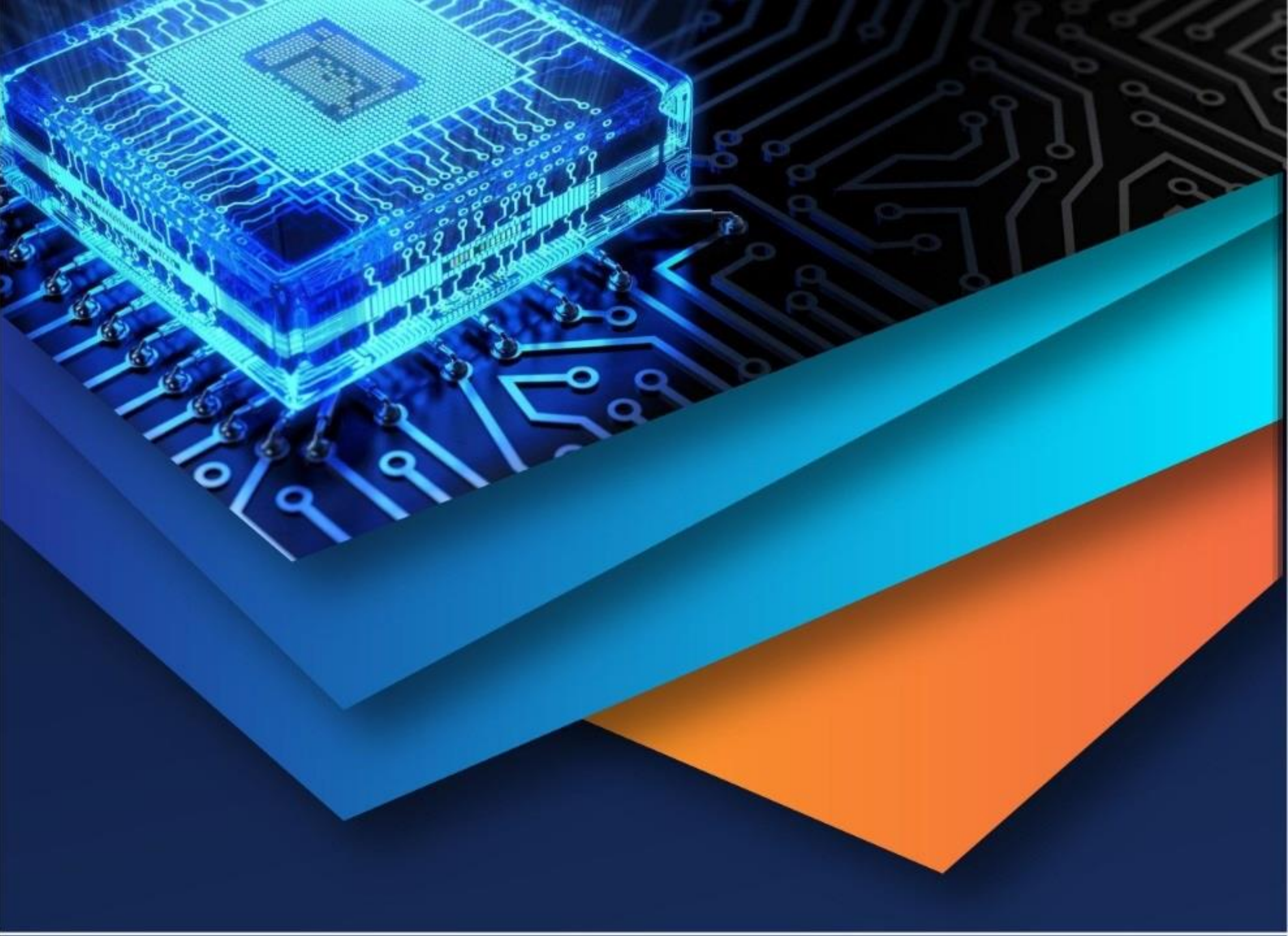

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