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Control and Analysis of MPPT Techniques for Maximizing Power Extraction and Eliminating Oscillations in PV System

S. Narendiran*, Sarat Kumar Sahoo*[1] and Raja Das[#]

Abstract – Maximum power point tracking (MPPT) is used in photovoltaic (PV) system to continuously maximize the available power from PV panel. The power output from the panel is non-linear due to atmospheric conditions. This paper explored the performance of different maximum power point tracking (MPPT) techniques under static and dynamic atmospheric conditions. For performance assessment perturb and observe (P&O), fuzzy logic control (FLC) and particle swarm optimization MPPT techniques are developed. The performance level of these MPPT methods varies in several prospects such as response time, oscillations around maximum power point (MPP), tracking efficiency, the percentage of energy reduced to attain steady state and hardware implementation. A PV array of 1.5KW and boost converter with P&O, FLC, and PSO MPPT techniques are pretend using MATLAB/Simulink environment and established through the experimental setup. For a hardware implementation, to generate duty cycle for a boost converter using different MPPT algorithms dSPACE DS1103 processor board is used. The methodologies followed for analysis in this work are as follows: to begin with, MATLAB based solar PV module is developed and verified, then different MPPT techniques are engaged in this PV module under static and dynamic atmospheric circumstances to study the success of MPPT through simulation and hardware setup.

Keywords – FLC, MPPT, photovoltaic, PSO, P&O.

1. INTRODUCTION

The Electric energy of a PV system is regarded as a usual energy that is more of use since it is at plentiful, dirt-free and spread over the globe which participates as a most important feature of all other appendages of energy creation on earth. A great advantage of a PV system is the reduction of carbon-dioxide (CO2) emission. According to expert, the energy obtains from PV system will become the most significant fill-in renewable energy source until 2040. Energy generation from the PV system is costly as compared to the active fossil fuel generated electricity from the grid. It is essential that the PV system is used to its maximum potential. In enjoin to accomplish that, the PV system has to operate at its MPP, which will be tracked by different MPPT techniques. Since MPP vary with irradiation and temperature, it is hard to maintain most favorable matching at all irradiation levels. A boost converter acts as the interface between the load and the PV system. By varying the duty cycle, the load impedance of the source is mottled and coordinated such that utmost power is harnessed from the PV system by maintaining the current-voltage relationship. In the recent past, numerous MPPT techniques have been advocated, developed and implemented. The usual MPPT techniques available are perturb and observe (P&O), incremental conductance (IC) algorithms. Conventional MPPT techniques are used widely but it has some drawbacks like slow tracking, steady state oscillations at MPP and deprived efficiency. To overcome these drawbacks artificial intelligence (AI) techniques like fuzzy logic control (FLC) and neural network (NN) are used, but those algorithms are periodically trained, it accesses more memory and it has a computational complexity which will be the major criteria's to concern while designing. The discussion based on MPPT techniques in this study is perturb and observe, fuzzy logic control and particle swarm optimization. The detailed overview of MPPT techniques in this study with its adverse features is as follows. Perturb and observe is the largely often used technique to track the MPP because of its features like, simple in configuration, high flexibility and less number of tuning parameters. This technique operates by regularly perturbing the PV module terminal voltage and compares the PV output power with that of the earlier perturbation cycle. A general difficulty with this technique is that the PV module cycle; therefore when the MPP is reached, the output power oscillates around the maximum, resulting in power loss in a PV system. The main features of P&O MPPT are simple, easy to implement, low cost, the operation does not rely on knowledge of PV characteristics. The main drawbacks of this approach include that it has moreover slowed convergence or large oscillations [1]-[5].

Fuzzy logic control is introduced to track the MPP. The main recompense of the FLC is its functioning with indefinite inputs, no need of an accurate mathematical model and handling non-linearity. Takagi-Sugeno fuzzy system is often used in predilection to Mamdani as it requires fewer rules and a coefficient can be implemented with less complexity. FLC MPPT approaches are restricted in their application as they rely on system specific parameters. If these parameters are not optimized approximately for the given system, the

*School of Electrical Engineering, VIT University, Vellore 632014, India.

[#] School of Advance sciences, VIT University, Vellore 632014, India.

[1]Corresponding author:
Tel: + 91 9840263009
E-mail: sksahoo@vit.ac.in

effectiveness of MPPT will be reduced. Application of FLC includes in control, complex system and engineering [6]-[9].

Particle swarm optimization is a metaheuristic optimization technique used to track MPP. The benefit of the proposed system [10] is the elimination of Proportional and integral (PI) control loops using direct duty cycle control method which outperforms the conventional method in terms of the act under different atmospheric conditions. Dormant PSO (DPSO) algorithm is activated to search the area of global peak and then the algorithm will be switched to conventional IC algorithm to track the maximum output power of the PV array [11]. During the iteration process of DPSO, if particles go on to search frequently or sway in a small region, they will be turned into DPSO state so as to decrease the convergence time and improve efficiency.

In [12] innovative algorithm combines the use of PSO for MPPT through the initial stages of tracking and then employs the traditional P&O method at the final stage. The result shows the faster convergence to the global MPP. The key features of PSO include the ability to track global peak power under varying atmospheric condition, faster dynamic response and easy implementation [13]. In [14] a modified PSO is proposed which assures zero steady state oscillation and faster convergence while tracking MPP. In [15] a hybrid P&O-PSO MPPT method is proposed. The advantage of using the proposed method is that the search space for the PSO [16] is abridged and hence the time that is necessary for convergence can be greatly improved [17]-[18].

This paper has been proposed as a comparison with the performance of conventional perturb and observe (P&O) MPPT technique, Soft computing based fuzzy logic control (FLC) MPPT technique and swarm intelligence based particle swarm optimization (PSO) MPPT technique. This paper is ordered as follows. System description in Section 2, which include MPPT control algorithms. Simulation and performance analysis in Section 3. Hardware setup in Section 4. Experimental results and discussion in Section 5. Finally, the conclusion is presented in Section 6.

2. SYSTEM DESCRIPTION

The block diagram of the MPPT technique controlled by PV system is shown in Figure 1.

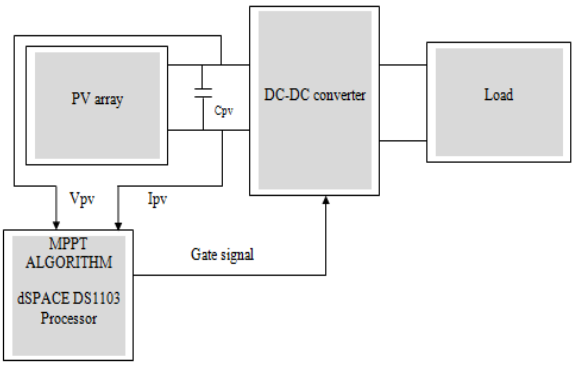

Fig. 1. MPPT controlled PV system.

2.1. Solar PV array

The 1.5 KW solar PV array model is developed in Simulink by means of the mathematical model, where six numbers of solar PV module, each with rated power of 250 W is connected in series (to increase panel output voltage) and parallel (to increase panel output current) combination to make 1.5 KW solar PV array. The PV array has the maximum power of 1500 W at V_{mpp} of 29.76 V for a panel. It is a polycrystalline silicon type that produces 250 W at 1000 W/m^2 and its parameters are shown in Table 1.

2.2. DC-DC Boost Converter

The boost converter is responsible for tracking maximum power available at the PV array. Thus the MPPT controller works effectively if the DC bus voltage remains constant. In boost converter, the output voltage is related to input voltage by the formula,

$$\frac{Vout}{Vin} = \frac{1}{1-D} \tag{1}$$

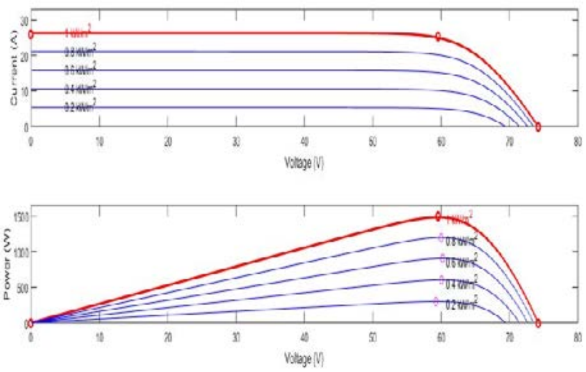

Fig. 2. Typical IV and PV characteristics of EMMVEE 250W PV panel at different irradiation levels.

The inductor used in boost converter can be calculated by,

$$L\min = \left[\frac{(1-D)^2 * D * R_{load}}{2f}\right] \tag{2}$$

The capacitor used in boost converter can be calculated by,

$$C\min = \left[\frac{Vout * D}{R_{load} * f * \Delta Vr}\right] \tag{3}$$

Where, V_{out} is the output voltage of the converter, V_{in} is the input voltage of the converter from PV, D is the duty cycle of the converter, R_{load} is the load used in the system, f is the switching frequency of the IGBT switch used in the converter, ΔV_r is voltage ripple of the converter. Boost converter can be worn as a switching-mode regulator to convert a DC voltage, normally unregulated to a regulated DC output voltage. The IV and PV characteristics of the panel are shown in Figure 2. The regulation is usually accomplished by pulse width modulation technique and the switching device is normally MOSFET or IGBT. The function of the boost converter is to step up DC voltage. Maximum power is reached when the MPPT algorithm changes and adjusts the PWM's duty cycle of the boost converter with switching frequency of 2 KHz. The value of the inductor is chosen as 0.507 mH and the value of the capacitor is around 307 μF. Resistive bank of capacity 16 Ω is chosen as the load.

2.3. MPPT Control Algorithm

MPPT algorithms are to adjust the duty cycle of the boost converter at the output of the PV array such that the load impedance visualized by the solar PV array which will formulate it to operate at the maximum power point for a given temperature and irradiation. Many methods for MPPT have been proposed. Two conventional algorithms are frequently used to accomplish the MPPT namely: perturb and observe (P&O) and the incremental conductance (IC) methods. On the other hand, AI-based techniques like FLC and blend techniques like artificial neural-fuzzy inference system (ANFIS) have received much attention from a number of researchers in the vicinity of power electronics. FLC is a bit easy controller to put into operation because it does not need an exact mathematical model. In evolutionary based swarm intelligence, optimization technique like particle swarm optimization (PSO) had gotten wide interest in the recent past due to its high adaptability and requires less number of tuning parameters for its efficient operation.

2.3.1. PV System with P&O MPPT Technique

P&O is the most generally used predictable technique to track the maximum power from the PV. The name itself imply that it is based on the perturbation of the system by increasing or decreasing V_{ref} or by acting directly on the duty cycle of the DC-DC converter and observing the effect on the output power of the panel.

Table 1. Electrical parameters of PV panel.

Parameter	Variable	Value
Maximum power	Pmax	250W
Voltage at MPP	Vmpp	29.76V
Current at MPP	Impp	8.40A
Open circuit voltage	Voc	37.62V
Short circuit current	Isc	8.76A
Total cells in series	Ns	60

The basic operation of P&O for generating a reference voltage and the duty cycle is shown in Table 2.

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

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

In the panel, if the present power value P(k) is higher than its previous power value P(k-1) then we keep the same tracking direction if not reverse the tracking direction to the previous cycle. The 1.5 KW PV system is pretended for fixed values of irradiation and temperature using perturb and observe maximum power point algorithm as shown in Figure 3. The value of irradiation is 1000 W/m^2 and the temperature is 25^{o}C. The voltage profile of P&O algorithm is shown in Figure 6. From voltage profile (blue color), the response time to achieve MPP is around 0.015s and oscillations persist for 15ms before attaining steady state condition in blue line as shown in Figure 6.

Table 2. Operation of P&O algorithm.

S.No	ΔPpv	ΔVpv	Vpv(ref)	Duty cycle
1	>0	>0	Increase	Decrease
2	>0	<0	Decrease	Increase
3	<0	>0	Decrease	Increase
4	<0	<0	Increase	Decrease

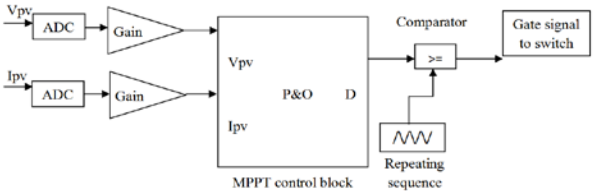

Fig. 3. P&O based MPPT control for boost converter.

2.3.2. PV System with FLC MPPT Technique

Fuzzy logic controller (FLC) works with imprecise inputs, it does not need an accurate mathematical model and it can handle nonlinearity well. FLC is more robust compared to the conventional nonlinear controller. The operation of FLC has 4 classifications namely, Fuzzification, rule base, inference engine and De-Fuzzification. The inputs of FLC are change in power (ΔP_{pv}), change in current (ΔI_{pv}) at sample time k from the solar cell are used while the output of FLC is ΔV_{pv}* or V_{pv} reference voltage to generate error signal E(k) which are defined by Equation 6 and change in error signal in Equation 7 from FLC.

$$E(K) = \frac{Ppv(k) - Ppv(k-1)}{Ipv(k) - Ipv(k-1)} \tag{6}$$

$$dE(k) = E(k) - E(k-1) \tag{7}$$

Where, $P_{pv(k)}$ and $I_{pv(k)}$ are the power and current from the PV module. The 1.5 KW system is pretended for a fixed value of irradiation and temperature using fuzzy logic control maximum power point tracking algorithm as shown in Figure 4. The value of irradiation is 1000 W/m^2 and the temperature is 25^{o}C. Large oscillation in the voltage profile from P&O is reduced in FLC MPPT method as shown in pink line in Figure 6. From power curve, the response time to achieve MPP is around 0.018s and oscillations persist for 18ms before attaining steady state condition as shown in Figure 6 which is high compared to the P&O MPPT technique.

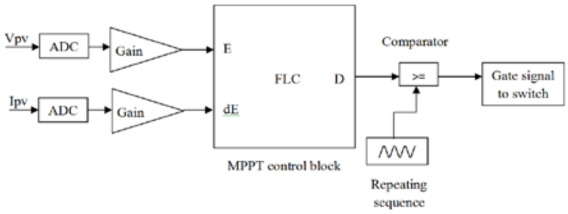

Fig. 4. FLC based MPPT control for boost converter.

2.3.3. PV System with PSO MPPT Technique

PSO algorithm is applied to DC-DC converter to generate gate pulses to the switch in a converter. These gate pulses or duty cycle signal is given to MOSFET switch in a converter. These gate pulses generated are given through real-time controller called dSPACE to deliver pulses to switch in the converter. Duty cycle of the PSO agents is grouped in a position vector as shown below,

$$d_{i,k} = [d_1 d_2 d_3 .....d_n] \quad (8)$$

i =1,2,3....n

where, i,k indicates the duty cycles of i^{th} agent at k^{th} iteration and d_n is the duty cycle of the n^{th} inverter for agent i and m is the total number of agents.

$$d_{i,k+1} = d_{i,k} + W_1 * (d_{t,k} - d_{i,k-1}) + W_2 * r_1 * (d_{tbest} - d_{t,k}) + W_3 * r_2 * (d_{gbest} - d_{t,k}) \quad (9)$$

where, d_{tbest} is the position vector corresponding to the maximum power achieved by the agent i and d_{gbest} is the position vector corresponding to the maximum power achieved by any agents. W_1,W_2,W_3 are weight constants and r_1,r_2 are random values (0-1). W_1 is the inertia coefficient of the agent. W_2 and W_3 are the factors that decide how fast the agent will move to the maximum point of agents. The agents maximum values are updated once the output power changes are larger than the allowed maximum power variation. The PSO algorithm is written in C++ and the updated duty cycles are used to calculate the power. The output power of converter is fed as input to C++ to form a closed loop control.

The 1.5 KW system is replicated for a fixed value of irradiation and temperature using particle swarm optimization, maximum power point tracking algorithm as shown in Figure 5. The value of irradiation is 1000 W/m^2 and the temperature is 25^{o}C. From power curve, the response time to achieve MPP is around 0.013s and oscillations persist for 13ms which are observed in Figure 7 is very less and fast compared to P&O and FLC MPPT techniques. The power produced from PSO based MPPT technique is around 1479 W (1500 W capacity) which is high compared to P&O and FLC techniques before attaining the steady state condition as shown in Figure 7.

3. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

The PV module of 1.5 KW was connected to boost converter to form a PV system. The PV modules of EMMVEE-250 W were selected which would be used in the hardware implementation afterward. It was accurately modeled in MATLAB/Simulink. By using this PV module, simulation works were carried out under static and dynamic conditions with P&O, FLC and PSO for performance evaluation and comparison are shown in Table 3.

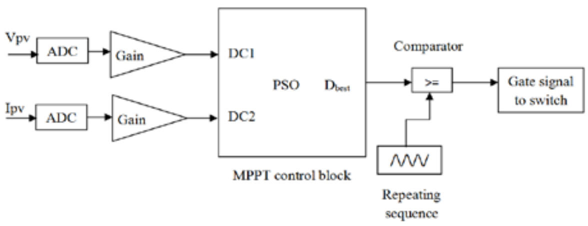

Fig. 5. PSO based MPPT control for boost converter.

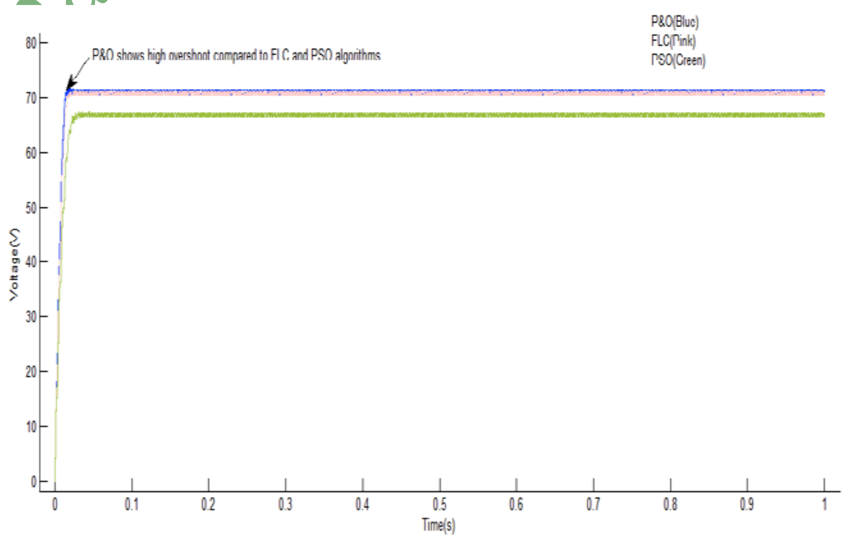

Fig. 6. DC output voltage and time response of P&O, FLC and PSO MPPT algorithms at static atmospheric condition.

3.1. Power Profile Variation at Static Atmospheric Conditions

To authenticate the performance of MPPT techniques, a competitive study is done between P&O, FLC, and PSO based on response time, oscillations around MPP, tracking speed, tracking efficiency, static efficiency, percentage energy reduction and hardware implementation.

The tracking efficiency of the PV system is given by

$$\%\eta_{pv} = \frac{P_{mppt}}{P_{\max}} * 100 \tag{10}$$

Where, P_{mppt} represents the output power of PV generator and P_{max} represents the output power of true MPPT.

The percentage energy reduction by different MPPT techniques while tracking the maximum power is given by:

$$\%E_{red} = \frac{E_{\max} - E}{E_{\max}} * 100 \tag{11}$$

Where, E_{max} represents maximum energy generate from PV, E represent the energy from PV system through simulation.

Table 3.Performance comparison of MPPT techniques.

MPPT algorithm	Response time,(s)	Oscillation, (ms)	Tracking efficiency (%)	Energy reduced (%)	Hardware implementation
P&O	0.015	15	72	28	Medium
FLC	0.018	18	74.4	25.6	Complex
PSO	0.013	13	95.2	4.7	Medium

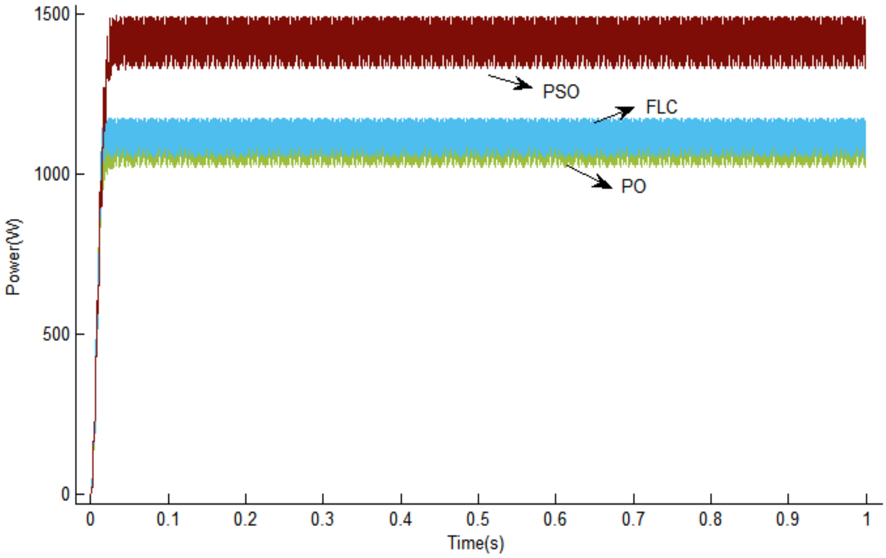

Fig. 7. Power extracted for the MPPT techniques at fixed irradiation and temperature.

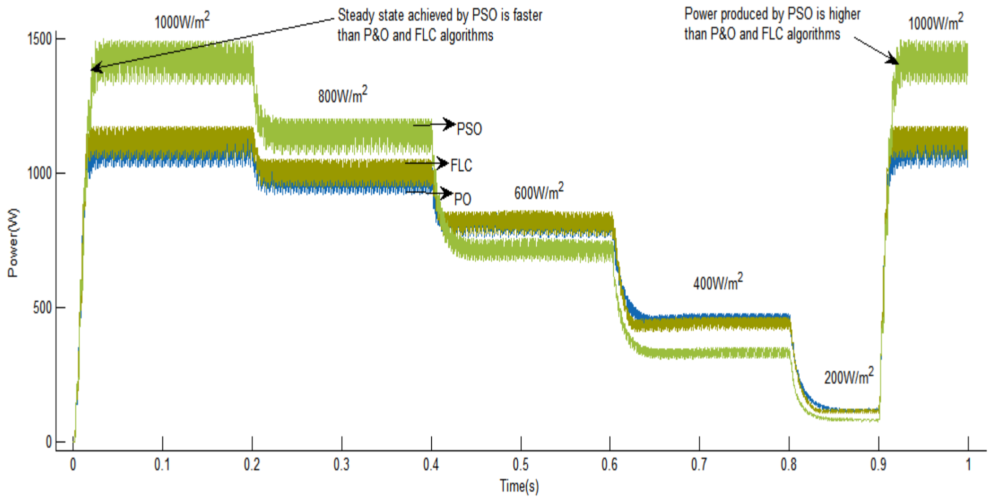

Fig. 8. Simulation results of dynamic performance of different MPPT techniques.

3.2. Power Profile Variation at Dynamic Atmospheric Conditions

Dynamic atmospheric conditions can be achieved with the use of signal builder in MATLAB/Simulink, different irradiation levels are stepping down as follows: initially from 1000 W/m^2 to 800 W/m^2 at 0.2s depicting cloudy weather, again irradiation level comes to 600 W/m^2 at 0.4s, 400 W/m^2 at 0.6s, 200 W/m^2 at 0.8s, again it step up to 1000 W/m^2 at 0.9s depicting clearing of the cloudy region.

For dynamic atmospheric condition, three test conditions were carried out, which covered low, medium and high irradiation levels. The low irradiation level is between 200-400 W/m^2, the medium irradiation level is between 400-800 W/m^2 and high irradiation level is between 800-1000 W/m^2. The performance of MPPT techniques under dynamic test conditions is shown in Figure 8 and Figure 9. At high irradiation, as shown in Figure 10 the waveforms clearly show that PSO performs better in terms of stability and power extraction from a PV panel. P&O and FLC show worse performance at the high irradiation level and good performance at low irradiation levels. P&O and FLC show high overshoot at each irradiation level compared to PSO. P&O and FLC have a low response time and not stable under dynamic test condition. PSO shows the best performance in terms of fast response time and reduced overshoot at the time of change in irradiation as shown in Figure 9. P&O and FLC relatively show equal performance in all three dynamic test conditions, FLC is much better as compared with P&O, but not as good as PSO in terms of reduced overshoot and high power extraction from a PV panel as shown in Figure 10.

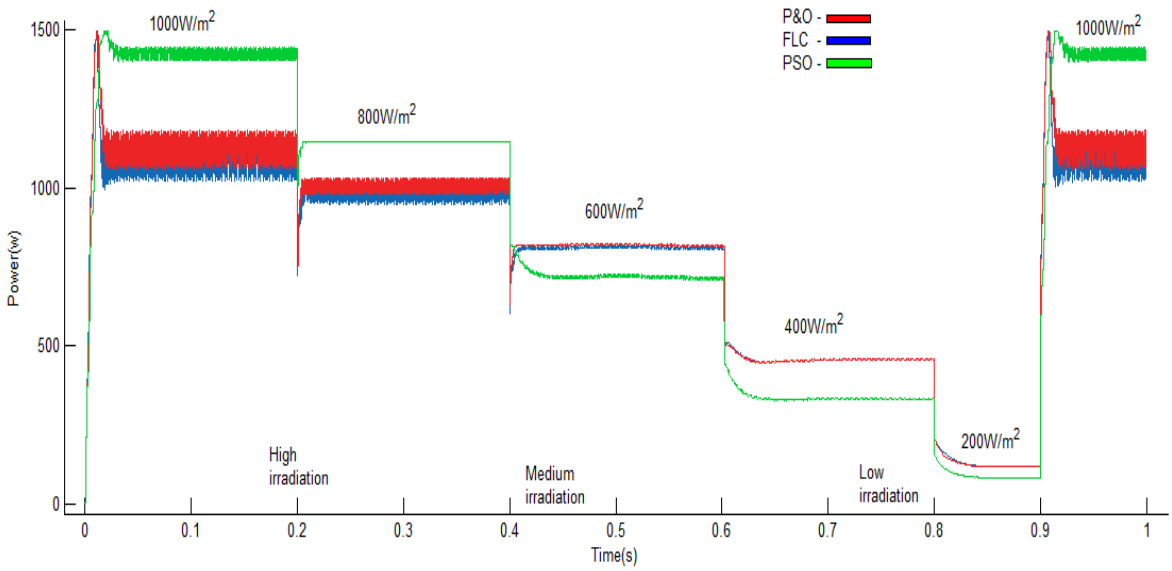

Fig. 9. Simulation results of different MPPT techniques at dynamic test conditions.

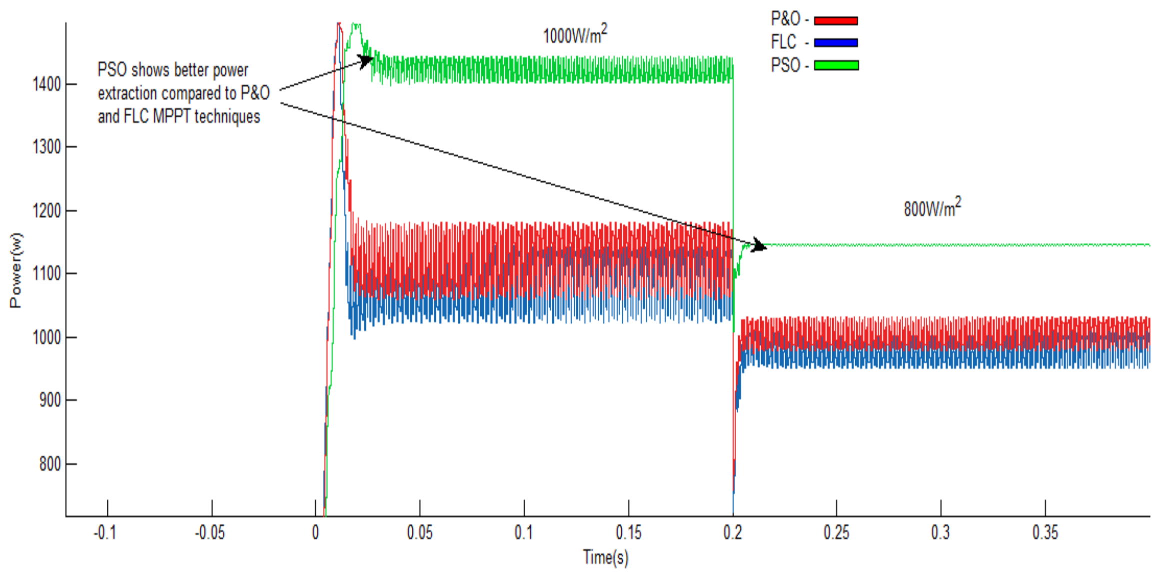

Fig. 10. Simulation results of different MPPT techniques at high irradiation level.

4. HARDWARE IMPLEMENTATION

The implemented hardware model arrangement is shown in Figure 11, being composed of solar panel supply inputs, the boost converter, voltage and current probes, voltage and current sensors, resistive load, dSPACE DS1103 and personal computer. The boost converter can operate with a switching frequency of 2 KHz. The inductor and capacitor values for simulation and hardware are 0.507 mH and 307 μF respectively, for a 16 Ω resistive load. The MPPT algorithms were digitally implemented in dSPACE DS1103 and personal computer. The boost converter can operate with a switching frequency of 2 KHz. The inductor and capacitor values for simulation and hardware are 0.507 mH and 307 μF respectively, for a 16 Ω resistive load. The MPPT algorithms were digitally implemented in dSPACE DS1103 platform the results are presented in this section. The solar PV array of 1.5 KW is constructed in building rooftop, from rooftop around .25km the panel supply lines are given in the laboratory supply box. From supply box for analysis and testing purpose, the PV generated supply is used. Due to the unavailability of power probe for real-time analysis, only the PV array voltage and current are shown in Figure 12. The simulation and hardware setup for evaluation are shown in Table 4. Since the current values are having the conflict in real time hardware setup when compared to simulation due to the perfect inductor, capacitor and load ratings for devices used in the hardware setup.

Table 4. Simulation and hardware results.

S.No	MPPT techniques	Simulation results		Hardware results	
		Voltage(V)	Current(A)	Voltage(V)	Current(A)
1	P&O	128.8	7.9	131	2
2	FLC	130.8	8.054	150	1
3	PSO	154.3	9.6	70	1

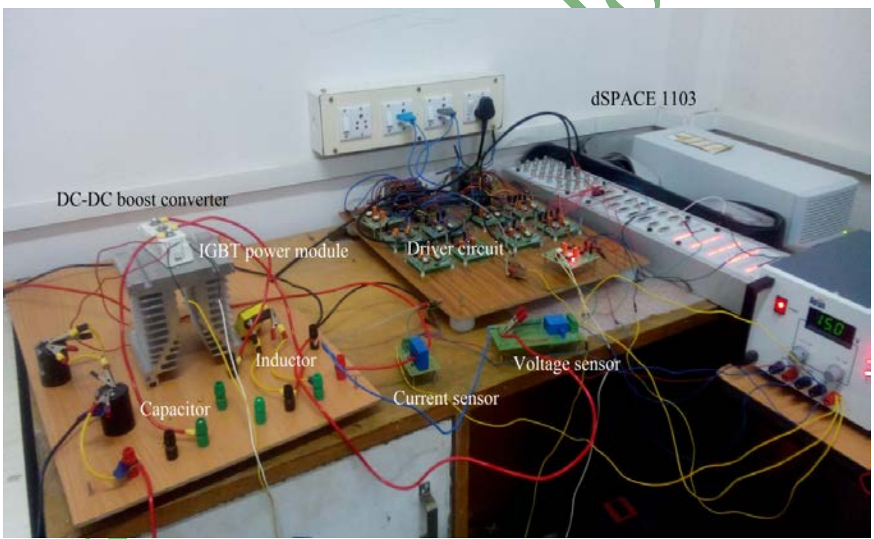

Fig.11. Experimental setup.

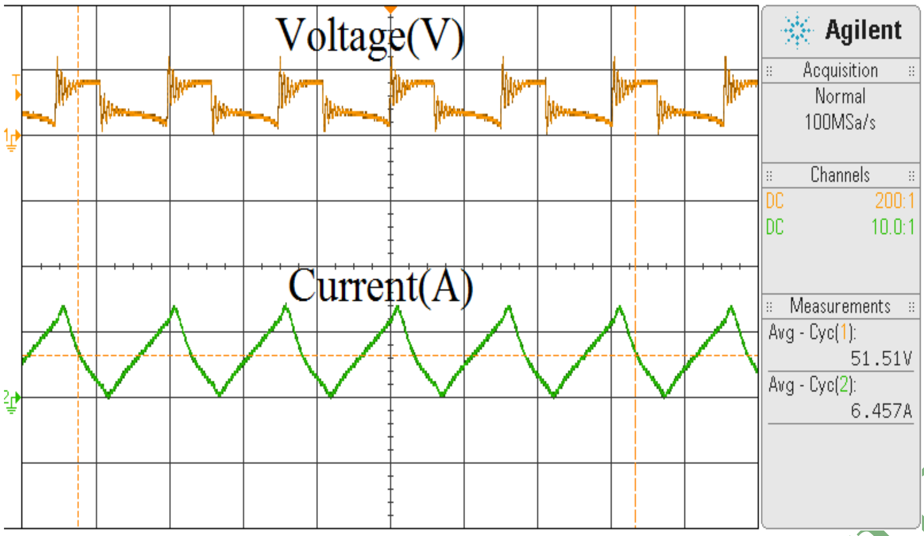

Fig.12. Panel output voltage and current.

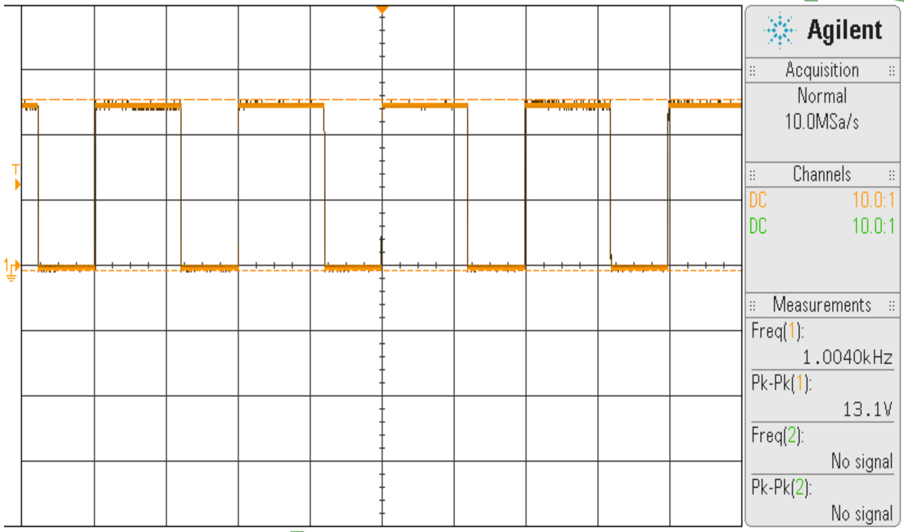

Fig. 13. Pulse generated using P&O MPPT for converter.

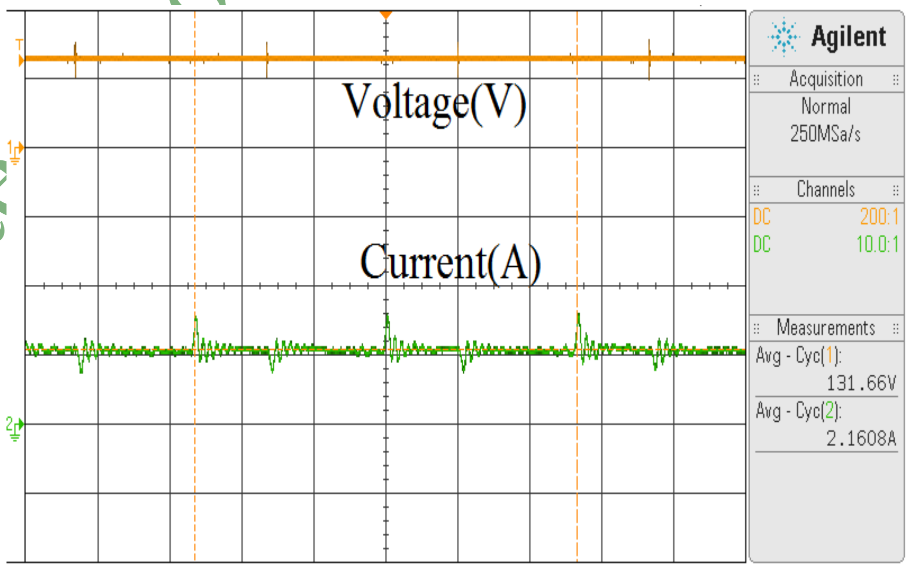

Fig. 14. Converter output voltage and current using P&O MPPT.

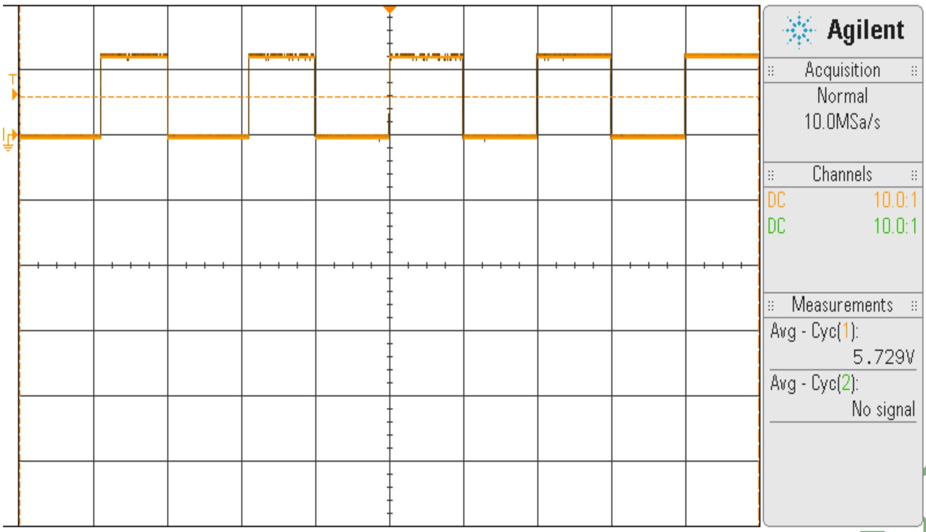

Fig. 15. Pulse generated using FLC MPPT for converter.

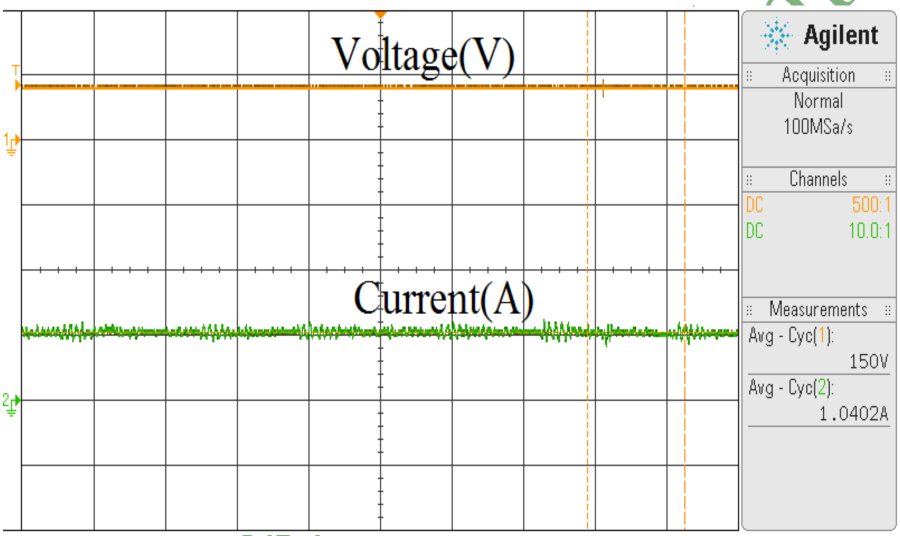

Fig. 16. Converter output voltage and current using FLC MPPT.

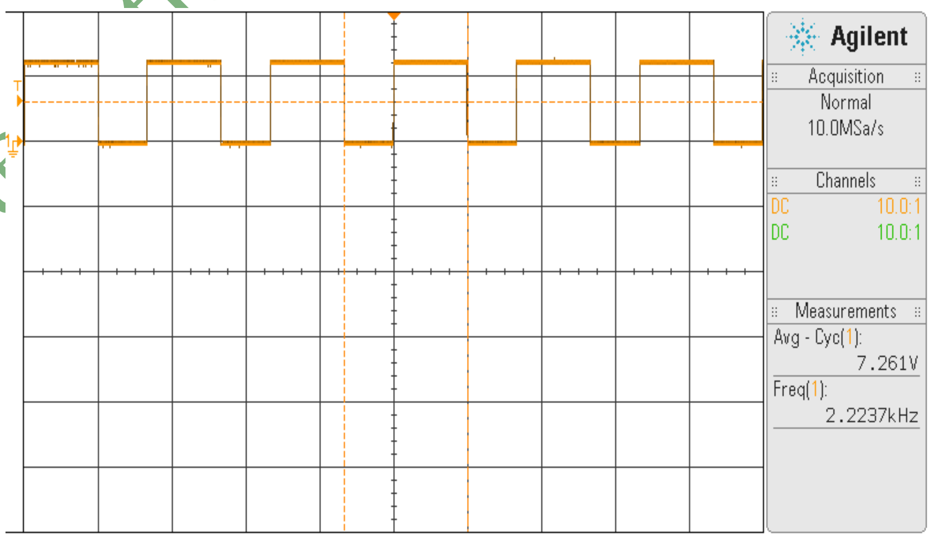

Fig. 17. Pulse generated using PSO MPPT for converter.

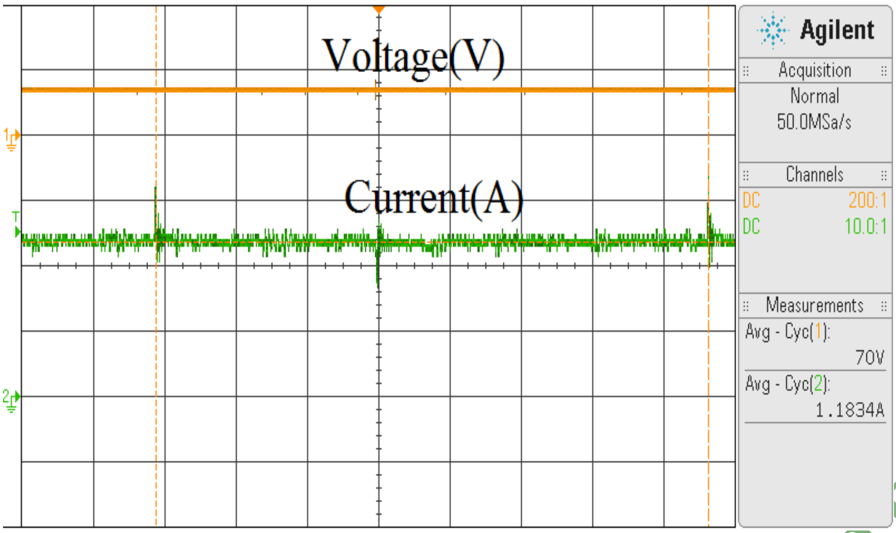

Fig. 18. Converter output voltage and current using PSO MPPT.

5. EXPERIMENTAL RESULTS

In the laboratory, prototype was developed to emulate the performance of different MPPT techniques. The boost converter was designed as per the simulation model. dSPACE DS1103 was used to generate gate pulses for IGBT in the boost converter. The pulse generated using P&O MPPT for the converter is shown in Figure 13. Using P&O MPPT the generated output voltage and current of the converter are shown in Figure 14. The pulse generated using FLC MPPT for the converter is shown in Figure 15. Using FLC MPPT the generated output voltage and current of the converter are shown in Figure 16. The pulse generated using PSO MPPT for the converter is shown in Figure 17. Using PSO MPPT the generated output voltage and current of the converter are shown in Figure 18. All these MPPT algorithms are tested in real time and the waveforms are shown only for an instant using DSO.

6. CONCLUSION

The performance of different MPPT techniques like P&O, FLC and PSO were used in 1.5KW solar PV system under static and dynamic weather conditions. The context of this paper provides the numerical simulations of PV system using MATLAB/Simulink and real-time interface using dSPACE DS1103. The performance is compared in terms of response time, oscillations around MPP, percentage tracking efficiency, percentage energy reduced and hardware implementation. The obtained simulation and hardware results under static and dynamic condition are promising, from the results it is observed that the PSO MPPT performance is better in terms of fast response time and reduced oscillations to acquire MPP than that of P&O and FLC MPPT techniques.

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