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Performance Analysis of Photovoltaic System With Subpanel MPPT Converter

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Abstract

This paper presents Distributed Maximum Power Point Tracking (DMPPT) concept to improve the performance of photovoltaic system (PV) under mismatch conditions. The performance of PV system depends upon solar radiation and temperature. The performance of PV system is frequently affected by mismatch cases. Each PV cell string interfaced with its own MPPT converter called as subpanel MPPT converter (SPMC) is proposed to improve the performance of PV system. To reduce the cost and simplify the MPPT structure SPMC with unified output MPPT control structure is also proposed. The performance of proposed SPMC system is also compared with PV optimizer by using conventional MPPT and fuzzy based MPPT algorithms.

Keywords: Fuzzy logic controller, maximum power point tracking (MPPT), PV optimizer, subpanel MPPT converter(SPMC), unified output control.

Introduction

Photovoltaic PV power systems are one of today's fastest growing energy technologies**.** Solar cells which are the foundation of PV systems convert the energy in sunlight directly into electricity. Photovoltaic systems are usually composed of series and parallel arrangements of PV modules, each module consisting of a string of series connected PV cells. Moreover, the solar cell characteristic is nonlinear and varies with irradiation and temperature. There is a unique point on the I-V curve of the solar array called MPP, at which the entire PV system operates with maximum efficiency and produces its maximum output power. As the solar radiation varies throughout the day, the output power also varies. Mismatches due to manufacturing tolerances, partial shading, dirt, thermal gradient, or aging result in losses in PV system [1]. The mismatches have disproportional effects on the overall available power due to the reduction in current through the series connected cells. For the centralized or string level MPPT PV systems the mismatch cases degrade the performance of PV systems [2]. To harvest as much energy as possible to improve the systems efficiency and performance an efficient maximum power point tracker is required. MPPT control algorithm is usually applied in the DC-DC converter. Many different MPPT techniques have been developed to track the MPP [3]. The conventional MPPT methods such as perturb & observe, hill climbing, incremental conductance and ripple correlation control are effective under uniform solar irradiance. The nonlinearity of the PV system introduces multiple maximum points on the power-voltage characteristic under mismatch conditions [4]. The presence of local maxima reduces the effectiveness of the conventional MPPT methods. The conventional MPPT methods cannot be able to discriminate between real and local maximum points [5]. The fuzzy logic based MPPT algorithm can be able to track the global maximum power point during steady state and varying weather conditions [6].

Distributed Maximum Power Point Tracking (DMPPT) is one of the most promising solutions to overcome the drawback associated to mismatching phenomenon in photovoltaic applications. Many PV architectures based on distributed power electronics such as module level or sub module level MPP tracking have been investigated [7]. If each panel was connected to its own converter hence known as Module Integrated Converter (MIC) controller or PV optimizer, it would be possible to enhance the system efficiency. The panel level distributed MPPT solution eliminates the mismatch power loss among PV panels. But in a real world mismatch cases such as dust, and spot dirtiness such as leaves or bird droppings or damage of PV cells, partial PV panel cannot work as expected and result in disproportionate power loss in PV system. The performance of PV optimizer is less than satisfactory in such cases [8].

In this paper distributed MPPT architecture that connects each PV cell string with dedicated MPPT converter called Subpanel MPPT Converter (SPMC) is proposed to improve the performance of PV system in real mismatch cases. The SPMC system with unified output MPPT control structure is also proposed in order to reduce the cost and simplify the Distributed MPPT system. The performance of proposed SPMC system is compared with PV optimizer by using conventional hill climbing MPPT and Fuzzy based hill climbing MPPT algorithms

Modeling of Pv Module

Each solar cell is basically a p-n junction. The equivalent circuit of a PV cell is shown in Fig.1. The photovoltaic panel can be modeled mathematically [9] as given in equations.

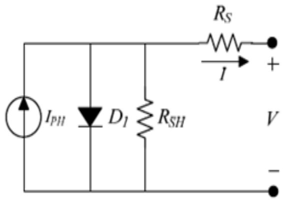


Figure 1: Equivalent circuit of PV cell

The current output of PV module is given by

$$I = I_{ph} - I_o\left\{e^{\left[\frac{q(V+IR_s)}{kAT_c}\right]-1}\right\} - \frac{V+}{R} \qquad (1)$$

where
I - Output current of PV module (A)
V - Output voltage of PV module (V)
I_{ph}-Light generated current or photocurrent (A)
I_o - Module saturation current (A)
q - Electron charge; 1.602×10^{-19} J/V
R_s - Series resistance (ohm)
R_{sh} - Shunt resistance (ohm)
k - Boltzman's constant; 1.38×10^{-23} J/K
A - Diode ideality factor
T_c - Cell temperature (K)
G - Insolation (W/m^2)

Solar insolation, temperature and output voltage of PV array are essential factors that affect the output characteristics of a PV cell. The characteristics curves of the solar cell are nonlinear. Generally the electrical characteristics of the PV system are represented by power versus voltage and by current versus voltage. Under partial shading conditions the PV characteristic gets more complex with multiple peak points. The specifications of PV module is shown in Table.I. The I-V and P-V characteristics of partially shaded PV module are shown in Fig.3 and Fig.4

Table 1: Specifications of PV Module

Rated Power	190W
Short circuit current I_{sc}	3.66A
Open circuit Voltage V_{oc}	43.2V
Current at P_{max} (I_{mp})	2.55A
Voltage at P_{max} (V_{mp})	36V
No of cells in series N_s	72

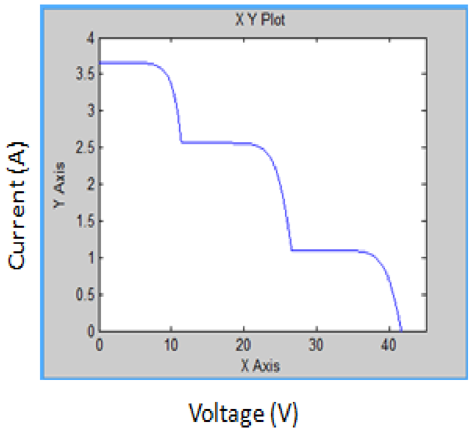


Figure 2: I-V characteristics of partially shaded PV module

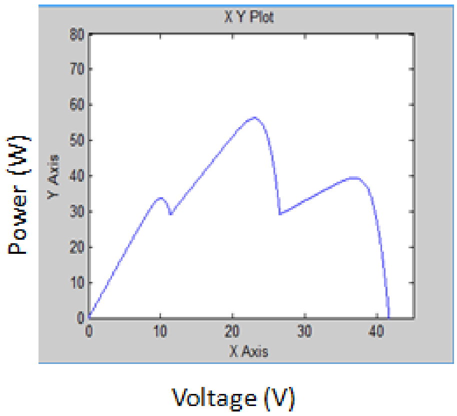


Figure 3: P-V characteristics of partially shaded PV module

Distributed Mppt Architecture

It has been recently demonstrated that performing MPPT on a per panel basis instead of using a single MPPT controller across the PV string can substantially increase the total harvested power, since each panel typically experiences unique light and temperature conditions. The second stage central MPPT converter is still required in the distributed MPPT converter based PV system. Traditional photovoltaic (PV) systems with multiple panels connected in series or parallel experience a substantial reduction in the harvested power when operating under mismatch cases and multiple maxima power points exist on power-voltage curve. Therefore performing maximum power point tracking (MPPT) on each PV panel is required to harvest total maximum power from the PV system. This technique is known as distributed MPPT (DMPPT). DMPPT architectures increase energy harvest by reducing the effects of panel mismatch and partial shading as MPPT is implemented for each PV module.

Distributed MPPT converter is usually implemented with a dc/dc power converter. Losses from the shading of a single panel are limited to that panel without affecting any other unshaded panel nearby.

A. PV Optimizer

In most mismatch conditions, such as module to module difference, different module orientations, and tilts etc., about 10%-30% of annual performance loss or more can be recovered by using the PV optimizers or PV MICs. If each panel was connected to its own converter hence known as PV optimizer (or) Module Integrated Converter (MIC), it would be possible to increase energy capture in PV system. The Fig.4 shows a standard PV panel consisting of PV cell strings connected in series, divided in three parts by corresponding bypass diode. Bypass diodes prevent the appearance of hotspots and protect the PV module from potentially destructive effects. The PV module is connecting with a MPPT converter which always operates the PV module at its maximum power point. Each converter can independently perform Maximum Power Point Tracking for its PV panel. The panel level Maximum Power Point Tracker (MPPT) control allows a huge reduction of the losses because of the mismatch between panels, which can be serious in partially shaded conditions. The MICs eliminates the panel-level hot spots thus improving the system reliability. Frequently the small scaled mismatch cases, such as dust, bird droppings, or damaged PV cells result in power loss in PV systems. In a real-world mismatch case, a shaded PV panel cannot be just exactly obstructed. So the performance of PV optimizer-based PV system is less under such cases.

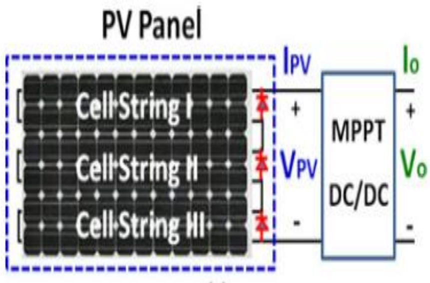


Figure 4: PV optimizer

B. Proposed Subpanel MPPT Converter (SPMC)

In order to increase the overall system energy capture, Subpanel MPPT Converter concept is proposed. Using this architecture mismatch between different submodules within the same panel can be eliminated which yields an increase in energy capture compared to panel level MPPTs. For the SPMC system the output terminals of all MPPT converters can be connected either in series or parallel. Since the panel is composed of several PV cell strings, we can divide the standard PV module into several parts and implement distributed MPPT solution into subpanel level.

The Fig.5 shows the SPMC system with three PV cell string level dc-dc converter that executes MPPT separately for sections of an individual PV module which provides a better solution to address the real world mismatch impact.

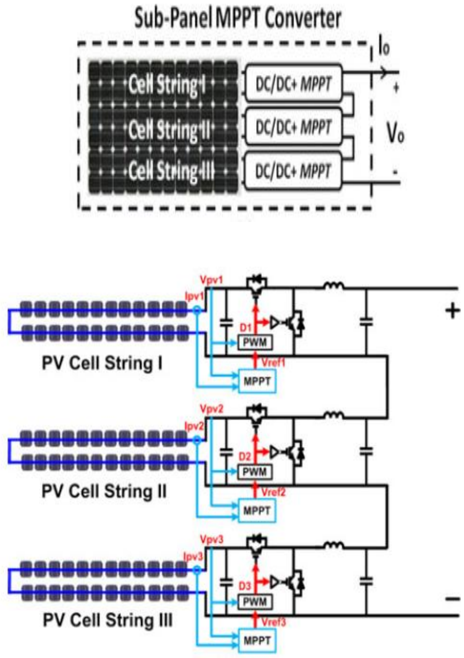


Figure 5: Diagram of SPMC with Distributed MPPT

For the SPMC system, the output terminals of all the MPPT converters can be connected either in series or parallel. Because of simple, high efficiency and suitability for the series connection, the Buck type converter is used as an implementation of SPMC. From the input side of each Buck converters, the converters are parallelly connected with each PV cell strings. From the output side of the MPPT converters, they are connected in series connection. In this SPMC system, the bypass diodes inside the junction box of a standard PV module should be retained in case of the malfunction of the MPPT converters.

The SPMC introduces an autonomous MPPT converter for each PV cell string in a standard PV panel. So the capability of performing the independent MPPT function on each PV cell string basis is hereby achieved and it regulates the duty cycle of the power stage separately in order to decouple a PV cell string from the others inside a PV panel. So a PV panel is divided into three independent parts and the mismatch case in one cell string cannot affect the others, and the power loss resulting from mismatch among PV cell strings, about 22% in this case, is thereby recovered. Although mismatch loss can be recovered through the SPMC with independent MPPT control, the implementation cost of the SPMC system is higher due to the increase in component count. A set of MPPT control IC, current sensor, voltage sensor, and corresponding A/D converters are needed for every PV cell string. In order to address the above issues, SPMC with unified output voltage control is proposed.

C. Proposed SPMC with Unified MPPT

In order to reduce the cost and simplify the independent MPPT control in SPMC structure, a unified output voltage control with single MPPT detection strategy is proposed as shown in Fig.6. In this structure:

1. a single MPPT unit is sensing the output power of the SPMC system with only one pair of voltage and current sensors.
2. three Buck MPPT converters share a common V_{ref} coming from the single MPPT unit
3. each Buck MPPT converter owns an independent control loop.

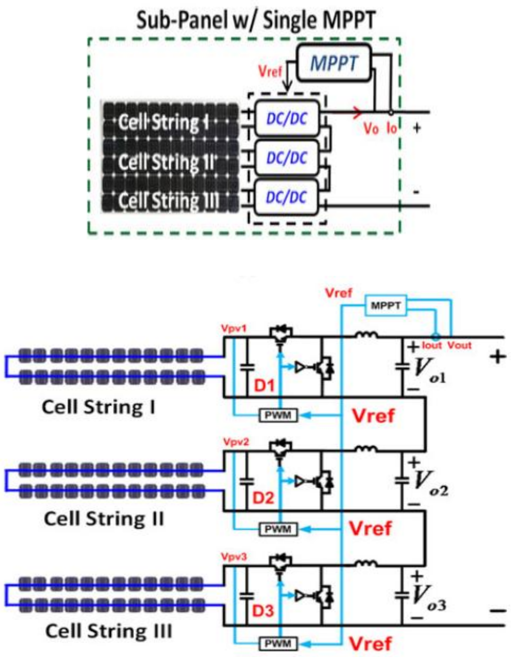


Figure 6: Diagram of SPMC with Unified MPPT

Therefore, the output voltage signal of the MPPT control unit is the common MPPT voltage reference for all the converters in a SPMC module, during the MPPT period. The PWM controller of each Buck converter in the SPMC system compares the sensed output voltage of each PV cell string and the common MPPT voltage reference to control their respective switch. When the common voltage reference is perturbed by the unified output MPPT controller, the input voltage of each Buck converter is regulated by an independent closed PWM control loop. Hence, the input voltage perturbation can be achieved. Because of their series connection, the Buck converters share a same output current. Therefore, the output voltage of each Buck converter will vary according to the extracted maximum power from its individual PV cell strings and proportionate to the maximum power. So the total output voltage of the SPMC is the sum of the output voltage of each MPPT converters.

$$Vout = \sum_{n=1}^{3} \text{V0\_n} \tag{1}$$

Although the PV cell string MPP voltage may change with irradiance case or temperature, it is assumed that such changes can be considered relatively small [10]. For the same V_{ref} signal is given to three independent control loops, so the output voltage of each PV cell string in steady state should be the same and equal to V_{ref}.

$$Vpv1 = Vpv2 = Vpv3 = Vr \tag{2}$$

The duty cycle of each MPPT converter is

$$\frac{V01}{Vpv1} = \text{D1}, \quad \frac{V02}{Vpv2} = \text{D2}, \quad \frac{V02}{Vpv2} = \text{D3}. \tag{3}$$

If no mismatch happens, the SPMC should be working with high conversion efficiency and all the maximum power points of the three PV cell strings are exactly the same. Therefore, the operating condition of each Buck converter in SPMC system is same as well. If mismatch case happens with part of a PV module, the power coming from the shaded PV cell string is decreased and the duty cycle of the corresponding MPPT converter is also decreased accordingly in order to save the power of shaded PV cell string and adjust the common output current limitation.

Maximum Power Point Tracking Techniques

The maximum power point tracking (MPPT) is usually an essential part of a photovoltaic (PV) power generation system, because of non linear characteristics of the PV array. The characteristics of PV are affected by irradiance and temperature variation. At a given temperature and insolation level PV cells supply maximum power at one particular operation point called maximum power point (MPP). The operation of MPP is to adjust photovoltaic interface so that the operating characteristic of the load and photovoltaic array at the maximum power point (MPP). Typically MPPT algorithms are integrated into power electronic converter systems where the duty cycle of the converter is controlled to deliver maximum available power to the load. Many algorithms have been proposed for MPP tracking, the mostly used ones are Hill Climbing (HC), perturb &observe (P&O) and incremental conductance algorithms.

A. Conventional Hill Climbing MPPT Technique

Hill climbing MPPT method is widely used because of its simplicity and reasonable accuracy. Hill climbing operates by perturbing the system by changing the converter duty cycle and observing its impact on the array output power. In HC-MPPT technique, the duty cycle is directly incremented or decremented in fixed steps depending on the panel voltage and power values until the maximum power point (MPP) is reached. The Fig.7 shows the flowchart of conventional Hill Climbing MPPT algorithm.

It is obvious that one of the most important parameters for hill climbing is the length of perturbation; small values will lead to a slow tracking performance while large values will increase the tracking speed but on the other hand will cause large oscillation at steady state. The oscillation around the MPP in steady state operation will cause energy loss and hence reduce the efficiency of the system. It has also been found that the conventional HC MPPT method can track in the wrong direction, away from the MPP, under rapidly increasing or decreasing irradiance levels.

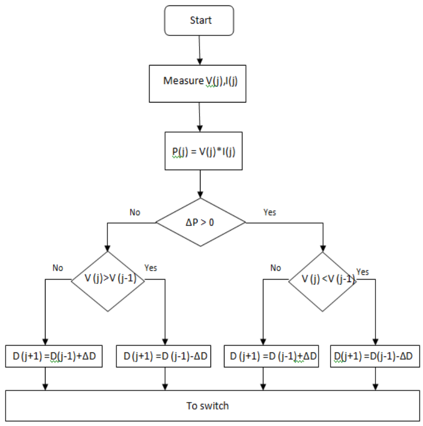


Figure 7: Flowchart of Hill Climbing algorithm

B. Fuzzy Logic Based Hill Climbing MPPT Technique

Fuzzy control has adaptive characteristic in nature, and can achieve robust response of a system with uncertainty, parameter variation and load disturbance. It has been broadly used to control ill-defined, non-linear (or) imprecise system. Fuzzy logic control generally consists of three stages: fuzzification, rule base lookup table, and defuzzification.

The PV system block diagram, along with the fuzzy logic controller, is shown in Fig.8.The fuzzy logic based MPPT controller has two inputs and one output. The change in power ΔP, change in current ΔI are given as inputs to the fuzzy logic controller and change in duty cycle ΔD is output which is given as a gate pulse to the converter. By changing the duty cycle of the buck converter maximum power point is tracked.

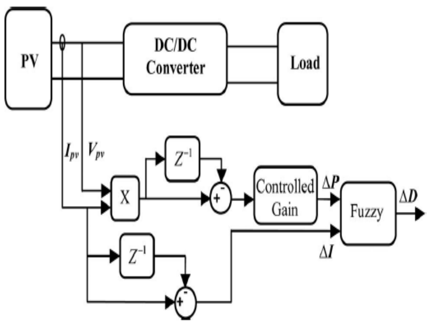


Figure 8: Block diagram of Fuzzy Logic Controller

The inputs of the FLC are

$$\Delta P = P(k) - P(k-1) \quad (6)$$

$$\Delta I = I(k) - I(k-1) \quad (7)$$

The output equation is

$\Delta D = D(k) - D(k-1)$ (8)

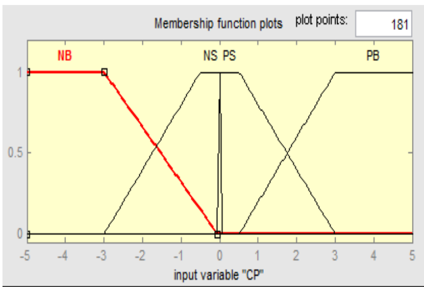
Where

ΔP is the PV array output power change,

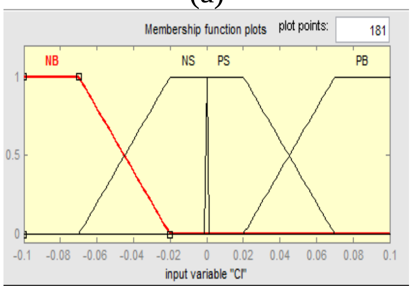
ΔI is the array output current change, and

ΔD is the buck converter duty cycle change.

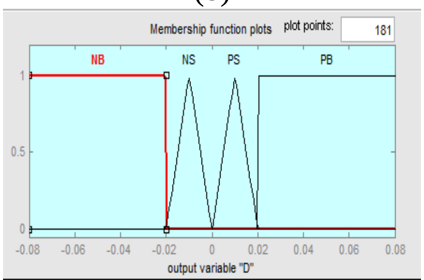
The Fig.9 shows the membership functions of input and output variable in which the variable inputs and output are divided into four fuzzy subsets: positive big (PB), positive small (PS), negative big (NB), and negative small (NS). Therefore, the fuzzy rules algorithm requires 16 fuzzy control rules; these rules are based on the regulation of hill-climbing algorithm. To operate the fuzzy combination, Mamdani's method with Max–Min is used. The fuzzy rules are shown in Table .II



(a)



(b)



(c)

Figure 9: Membership Functions for (a) Input ΔP (b) Input ΔI (c) Output ΔD

Table 2: Fuzzy Control Rules

ΔI / ΔP	**PB**	**PS**	**NB**	**NS**
PB	**PB**	**PB**	**NB**	**NB**
PS	**PS**	**PS**	**NS**	**NS**
NB	**NB**	**NB**	**PB**	**PB**
NS	**NS**	**NS**	**PS**	**PS**

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

$$\Delta D = \sum_{i}^{n} \mu(\mathrm{Di})\mathrm{Di} \Big/ \sum_{i}^{n} \mu(\mathrm{Di}) \tag{9}$$

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

Simulation Results and Discussion

The To evaluate the performance of the proposed method the simulations are done in Matlab/simulink software package. The buck converter specifications used in the simulation are shown in Table.III

Table 3: Buck Converter Specifications

Parameters	**Values**
Capacitor C1	250μF
Capacitor C2	2000μF
Inductor L	120μH
Resistor	1Ω
Switching frequency fs	20KHZ

Here the PV module is divided into three PV cell strings and each PV cell string is interfaced with its own synchronous buck MPPT converter.The first cell string receives radiation of 1000W/m^2 and second and third cell strings are partially shaded with radiation of 700W/m^2, 300W/m^2 respectively. The PV output power characteristic of PV optimizer and proposed SPMC with distributed MPPT and unified MPPT with conventional hill climbing MPPT technique and fuzzy based hill climbing MPPT technique are shown in Fig.10, Fig.11 and Fig.12 respectively.

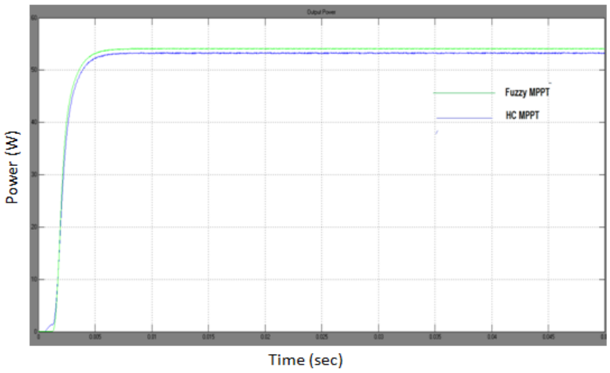


Figure 10: Output power characteristics of PV optimizer

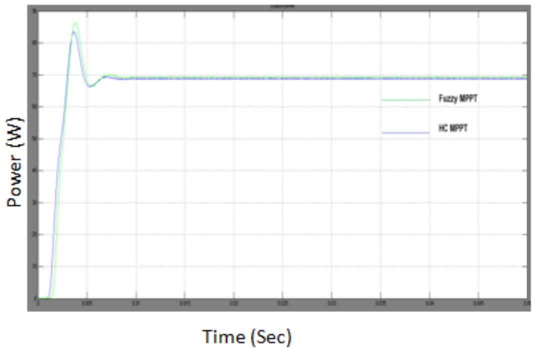


Figure 11: PV output power characteristics of Distributed SPMC

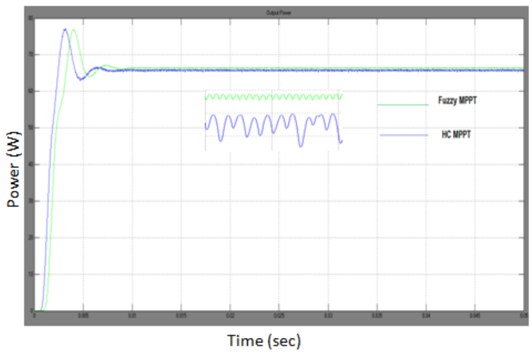


Figure 12: PV output power characteristics of Unified SPMC

Efficiency of SPMC with distributed MPPT = 91.7%
Efficiency of SPMC with unified MPPT = 93.1%

From the above simulation results the proposed SPMC with fuzzy based hill climbing MPPT can be able to track maximum power compared to conventional hill climbing MPPT. The conventional HC method has some oscillations around MPP. From the simulation results the performance of proposed SPMC is better than PV optimizer. Comparing the performance of unified SPMC with distributed SPMC, the efficiency of SPMC with unified MPPT is better than SPMC with distributed MPPT. The results can be summarized and Table.IV shows the comparison of performance of PV optimizer with proposed SPMC system.

Table 4: Comparison of Performance of Proposed SPMC with PV Optimizer

MPPT	**PV optimizer**		**Proposed SPMC with Distributed MPPT**		**Proposed SPMC with Unified MPPT**	
	(V)	**(W)**	**(V)**	**(W)**	**(V)**	**(W)**
Conventional	7.29	53.25	8.29	68.79	8.11	65.8
Fuzzy based	7.35	54.09	8.32	69.31	8.14	66.32

Conclusion

To improve the performance of photovoltaic system under common mismatch conditions SPMC system with distributed MPPT and unified MPPT is proposed. The proposed system was simulated in MATLAB/SIMULINK. The performanace of PV optimizer is compared with proposed SPMC system by using conventional hill climbing MPPT and fuzzy based hill climbing MPPT techniques.The fuzzy based MPPT technique can be able to track maximum power compared to conventional hill climbing MPPT technique.The coventional HC method has some oscillations around MPP.The SPMC system offers many advantages including better power harvest ability,independent control loop. The performance of proposed SPMC is better than PV optimizer under mismatch conditions.

Comparing the distributed MPPT with unified MPPT control structure,SPMC with unified MPPT has number of advantages such as ,it saves the number of A/D units,current sensors and MPPT controllers.So the cost is reduced and the structure is also simplified.Hence the performance of SPMC with unified output MPPT has good performance compared with distributed MPPT .

References

[1] S.M.MacAlpine, R.W.Erickson, and M. J. Brandemuehl, “Characterization of power optimizer potential to increase energy capture in photovoltaic systems operating under non uniform conditions,” *IEEE Trans.Power Electron.*, vol. 28, no. 6, pp. 2936–2945, June.2013.

[2] R. Alonso, E. Roman, A. Sanz,V. E.M. Santos, and P. Ibanez, “Analysis of inverter-voltage influence on distributed MPPT architecture performance,” *IEEE Trans. Ind. Electron.*, vol. 59, no. 10, pp. 3900–3907, Oct. 2012.

[3] M.G.Villava, J.R.Gazoli, and E.R.Filho, “Comprehensive approach to modeling and simulation of photovoltaic arrays,” IEEE Transactions on Power Electronics., vol.24, no-5, pp.99-107, February 1998.

[4] H.Patel and V.Agarwal, “Mat lab-based modeling to study the effects of partial shading on PV array characteristics”, IEEE Transactions on Power Electronics., vol.23, no.1, pp.302-310, March 2008.

[5] T.Esram and P.L.Chapman “Comparison of photovoltaic array maximum power point tracking techniques”, IEEE transaction in energy conversion.,vol.22, no.2, pp.439-449, July 2007.

[6] X. Weidong, N. Ozog, and W. G. Dunford, Jun. 2Bader N.Alajmi, Khaled H, Ahmed, Stephen J.Finney and Barry W.Williams, “A Maximum Power Point Tracking Technique for Partially shaded Photovoltaic systems in Micro grids”, IEEE Transactions on Industrial Electronics., vol.60,no.4,pp.1596-1606, April 2013.

[7] C. Olalla, D. Clement, M. Rodriguez, and D.Maksimovic, “Architectures and control of submodule integrated DC-DC converters for photovoltaic applications,” *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 2980–2997, June 2013.

[8] Feng Wang,Xinke Wu,fred C.Lee,Zijian Wang,Pengju Kong and Fang Zhuo, ,”Analysis of unified output MPPT control in Subpanel PV converter system” IEEE Transactions on Power Electronics., vol.29, no.3, pp.1275-1284. March 2014.

[9] N.Pandiarajan and R.Muthu, “Mathematical modeling of Photovoltaic module with simulink”, in Proceedings of the Ist International conference on Electrical Energy systems (ICEES 2011) pp.528-263, January 2011.

[10] C. Olalla, D. Clement, M. Rodriguez, and D.Maksimovic, “Architectures and control of submodule integrated DC-DC converters for photovoltaic applications,” *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 2980–2997, June 2013.