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A Novel Hybrid Maximum Power Point Tracking Technique with Zero Oscillation Based on P&O Algorithm

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Abstract- Maximum Power Point Tracking (MPPT) is meant for the maximum utilisation of the available power of Solar Photovoltaic (SPV) modules under both rapidly varying atmospheric conditions and partially shaded conditions and is an important concern in the efficiency improvement of SPV systems. This paper presents a novel hybrid Zero Oscillation MPPT algorithm for a standalone SPV system with boost converter inorder to mitigate fluctuations in output power owing to variations in operating voltage and current of the PV module which are caused by fast changes in irradiation and temperature. The proposed algorithm is composed of two techniques ie Variable Step Size(VSS) Zero Oscillation (ZO) Perturb & Observe MPPT (P&O) and Look Up Table (LUT) MPPT algorithms. To assess the performance of the proposed system, a PV system is modeled and simulated in Matlab/Simulink for different atmospheric conditions. The influence of the proposed MPPT on the performance of the system is studied. The simulation results are compared with an intelligent MPPT, VSS Fuzzy and a classical MPPT, VSS P&O for uniformly/non uniformly varying as well as Partial Shading condition (PSC). Ripple analysis is also done to ensure the effectiveness of the proposed system. It is inferred that the hybrid MPPT shows improvement in tracking performance, output power ripple, input current ripple and power conversion efficiency. Also the implementation of the proposed MPPT is easier and cheaper when compared to other MPPT methods.

Keywords: Fuzzy Logic Controller; Look-Up Table; Maximum Power Point Tracking; Solar Photovoltaic; Variable Step Size Perturb & Observe; Zero Oscillation

1. Introduction

Among nonconventional energy sources, SPV source draws very much attention because of its least negative environmental impact and the reduction in cost of implementation and maintenance. But the power conversion efficiency of the SPV system is greatly affected by the atmospheric conditions [1]. The power generated by the PV modules is of low level and hence a power conditioning unit is necessary to uplift the power level [2]. The role of MPPT controller is used to harness the maximum optimised PV power by adjusting the duty ratio of the power conditioning unit. The variations in the atmospheric conditions may alter the position of Maximum Power Point (MPP) on the P-V curve [3]. These variations should be considered while designing the MPPT controller. The most important atmospheric factors that influence the system are fast variation of solar irradiation (G), variation of temperature (T) around the PV module and Partial Shading Conditions (PSC) [4]. Various accurate MPPT methods based on numerical and analytical approaches have been proposed to maximise the PV power. MPPT algorithms are broadly categorised as classical and intelligent types. The classical MPPTs are again categorised as direct or online and indirect or offline algorithms. The attractive features of classical and/or intelligent methods are combined and classified as hybrid MPPT method [5].

Classical MPPT techniques comprises of Short Circuit Current (SCC), Open circuit Voltage (OCV), Look up Table (LUT) , Perturb & Observe (P&O), Hill Climbing (HC), Incremental Conductance (InC), Modified P&O, Modified InC, Constant Voltage (CV) etc. These methods are very simple and easy to implement but perform better for uniform variation in atmospheric conditions. Above methods experience oscillations at MPP, which results in power loss. More over when partial shading occurs, these methods fail to track the actual Global Maximum Power Point (GMPP) [4]. OCV MPPT method is commonly used for low power applications, in which physical/offline parameter Open Circuit Voltage (V_{oc}) is measured and the value of maximum voltage (V_{mp}) is estimated. A modified OCV method is proposed in [6] which works good for PSC. SCC method continuously measures the value of short circuit current (I_{sc}) and the value of maximum current (I_{mp}) is approximated [7]. Both methods require continuous measurement of physical parameters which results in unnecessary power loss for the complete system. LUT MPPT requires G and T as inputs and all the associated data are stored prior. During execution, these data are fetched directly which reduces the execution time and avoids the searching process as in the case of perturbation. For higher precision, more storage data are needed, which increases the memory requirement [8]. Online methods like P&O and InC are based on perturbation by continuous measurement of PV voltage (V_{pv}) and PV current (I_{pv}) until the MPP reaches [4]. As already mentioned, fast changes in atmospheric conditions result in shifting of PV power, and these classical MPPT methods fail to track this value. The oscillations at MPP can be adjusted by varying the step size, but it has a negative impact on the tracking speed [9]. HC method requires duty ratio, D as the measuring variable. No sensor is required for this method but the major limitations include the inability of this method to differentiate the cause of power change as well as the presence of oscillations at MPP [10]. Modified P&O and InC MPPT reduce the oscillation Size and improve the tracking speed. Modified P&O method suitable for PSC is proposed in [11]. Many adaptive P&O and InC methods are proposed to extract maximum power with negligible oscillations [12]. CV MPPT method is applicable only for uniform irradiation and slightly varying temperature conditions. This method requires only one voltage sensor, which senses V_{pv} continuously and compares with a reference voltage. The method is very simple and easy to implement but not accurate [13].

Intelligent techniques are proposed for accurate tracking under fast varying atmospheric conditions. But the circuits are complex and are difficult to implement. Moreover, trained data and expert knowledge are required for proper execution of these techniques [4]. The tracking efficiency for these methods is very high and hence they are emerging at a faster rate. The method includes Fuzzy Logic Control (FLC), Artificial Neural Networks (ANN), various optimization methods like Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Cuckoo search MPPT, Firefly Algorithm (FA) and Grey Wolf Optimization (GWO). In [14], FLC MPPT is proposed which improves tracking efficiency of the system. The main advantage of FLC MPPT is that it doesn't need an exact mathematical model of the PV system. In [15], ANN MPPT is applied for PSC, and the MPP is tracked within fraction of seconds. An improved ANN technique is proposed in [16], which is suitable for locating GMPP. PSO is a bio-inspired MPPT technique based on a search process and hence locating GMPP is very easy. Many papers propose PSO as an efficient MPPT algorithm for PSC [17]. In [18], ACO MPPT is implemented for shading conditions and is compared with conventional topologies. ACO based systems extract more power from PV arrays and hence perform superior than other techniques. In [19], tracking speed and efficiency of the system with ABC MPPT are compared with PSO and P&O techniques and it is inferred that ABC performs superior than others. Modified InC, hybrid PSO and cuckoo search MPPT are compared in [20]. The latter performs better in the context of tracking speed and efficiency. In [21], stability analysis of a grid connected PV system is analysed with FA and Modified PSO MPPT and the performance of FA is found to be superior. A broad comparison is made with GWO, P&O and Modified P&O in [22] and the performance of the former one is well studied.

In hybrid MPPTs, classical methods are utilized for locating the position of MPP, and by using the intelligent methods steady state performance is improved. P&O method is used in most of the hybrid algorithms because of its simplicity [23]. The method includes Artificial Neuro Fuzzy Inference System (ANFIS), Fuzzy PSO (FPSO), GWO-P&O, PSO- P&O, FLC- P&O, ACO-P&O, Fractional Open Circuit Voltage – P&O (FOCV- P&O), Fractional Short Circuit Current – P&O (FSCC- P&O), Support Vector Machine (SVM-P&O), Learning Automata- P&O and ANN-P&O . In [24], the actual location of GMPP is effectively tracked by ANFIS MPPT with high speed. Fuzzy and PSO combination is used in [25] to track GMPP for grid tied PV systems. GWO-P&O hybrid MPPT is well implemented in [22], which reduces the computational complexity of GWO. In this, the performance of GWO-P&O MPPT is analysed and confirmed that the hybrid one shows superior performance in tracking speed and the results are verified experimentally. Ref [26] gives a modified GWO which quickly tracks GMPP. In [27], PSO- P&O MPPT is well utilized for PSC and a tracking efficiency of more than 97% is obtained. By combining P&O with PSO, mathematical computation burden is very much reduced. Ref [28] gives the performance analysis of an PV system with PSO and Neuro Fuzzy MPPT. In this, the location of GMPP is identified using Neuro Fuzzy with small error and short time. In [29], fast and efficient tracking performance is obtained by combining local and global search capacity of P&O and ACO algorithms. A fair convergence speed with lesser power ripple is obtained in [30] using FOCV-P&O MPPT. In this V_{oc} is measured intelligently without using an additional sensor. Rapid tracking under varying atmospheric conditions, less power ripples and more average power output are obtained with FSCC- P&O MPPT . The method avoids the usage of irradiation sensor by intelligently measuring the value of I_{sc} [31]. A hardware implementation with dSPACE DS1104 is also done and the results are validated. In [32], a novel idea of using SVM to compromise the performance and implementation cost of the MPPT method is proposed. Based on historical irradiance data, the perturbation step size of P&O for a particular location is determined using SVM. A novel hybrid algorithm consists of a combination of P&O and Learning Automata to search the MPP which reduces steady state oscillations than modified P&O MPPT is proposed in [33]. The performance of ANN-P&O hybrid MPPT technique to track the GMPP is analysed in [34]. The method accurately tracks the global point and increases the output power level for various shading cases.

Based on the review conducted, a qualitative comparison among different MPPT techniques is presented in Table 1.

Table 1. Qualitative comparison of different MPPT techniques

Performance Parameters	Classical MPPT	Intelligent MPPT	Hybrid MPPT
Tracking time	High	Low	Low
Tracking accuracy	Low	High	High
Power conversion efficiency	High for uniform variations. Low for PSC	High	High
Oscillations at MPP	High	Negligible	Negligible
Circuit complexity	Low	Medium	High
Response to PSC	Low, can't distinguish LMPP and GMPP	High	Very high

From the Table 1, we can arrive at a conclusion that the performance of any parameter like tracking speed, circuit complexity, implementation cost, power conversion efficiency, steady state oscillation etc. can be improved by compromising the other one.

The main features of the proposed system are listed below.

- The technique is a combination of VSS P & O and LUT MPPT
- The system is capable of handling uniform/non-uniform variations in atmospheric conditions and partial shading conditions with improved power conversion efficiency and tracking time
- Exhibits negligible oscillations at MPP that results in reduced ripple levels
- Senses V_{pv} and I_{pv} as input variables instead of *G* and *T*, hence no need of irradiation and temperature sensor
- Since the proposed MPPT is a combination of two very basic techniques, the system is less complex and can be implemented with reduced cost
- The superiority of the proposed technique is verified by comparing simulation results with VSS Fuzzy and VSS P&O MPPT techniques

The paper is systematized as follows. Section 2 explains the proposed MPPT, Section 3 describes mathematical modeling of the PV module and Boost converter, Section 4 consists of simulation setup and results and Section 5 explains the performance analysis and Section 6 concludes the work.

2. Proposed hybrid VSS ZOPO - LUT MPPT

LUT alone needs a lot of memory to store data and if the input is beyond the range of LUT, the tracking may not be accurate. If VSS P&O MPPT uses alone, oscillations exhibit at the maximum power point. A hybrid MPPT scheme is developed to solve the aforesaid drawbacks of LUT and VSS P&O algorithms. The flowchart of the scheme is illustrated in Fig.1.

In the proposed hybrid VSS ZOPO-LUT MPPT algorithm, two step values, ΔD_1= 0.025 and ΔD_2= 0.005 are selected, where ΔD_1 and ΔD_2 are calculated by trial and error which makes the oscillations negligibly small. The scheme uses PV voltage and current as LUT inputs, called as breakpoint data and employs basic MPPT techniques, so that no such trained data and skilled knowledge is needed for the implementation. The algorithm continuously uses the duty ratio values of LUT for every change in atmospheric condition. The step value is selected according to the value of $\frac{dP}{dV}$. If $\frac{dP}{dV}$ > error value *e*, the step size ΔD_1will be chosen otherwise it will be ΔD_2. Thus the algorithm quickly reaches near the MPP using duty ratio values of LUT and reaches the MPP using ΔD_1 and maintains the position with zero oscillation using ΔD_2. That means for every rapid change in the irradiation pattern, LUT within the hybrid system responds immediately. Thus the proposed hybrid MPPT algorithm acts quickly and thereby improves the tracking with negligible oscillations.

Partial shading detection is possible by introducing a new value, $\Delta = \Delta P_{pv} * \Delta V_{pv}$ [35]. Using this, the MPPT compares two power inputs, the power at any time (In_1) and the power at the previous time (In_2). If the power at any instant is higher than the previous power with a positive increment in voltage, it means that the system is operating at the left of MPP but can't identify MPP as a local or global point. The system remains operating in the same direction till reaching an MPP of higher power, then the controller treats this power as MPP_1 and continues to operate in the similar path. The controller stores the power as MPP_2 when the value of $\frac{\Delta P_{pv}}{\Delta V_{pv}}$ reverses. By this way the controller detects the global and local MPPs and finally identifies the global point. The developed Simulink model of proposed MPPT is represented in Fig.2.

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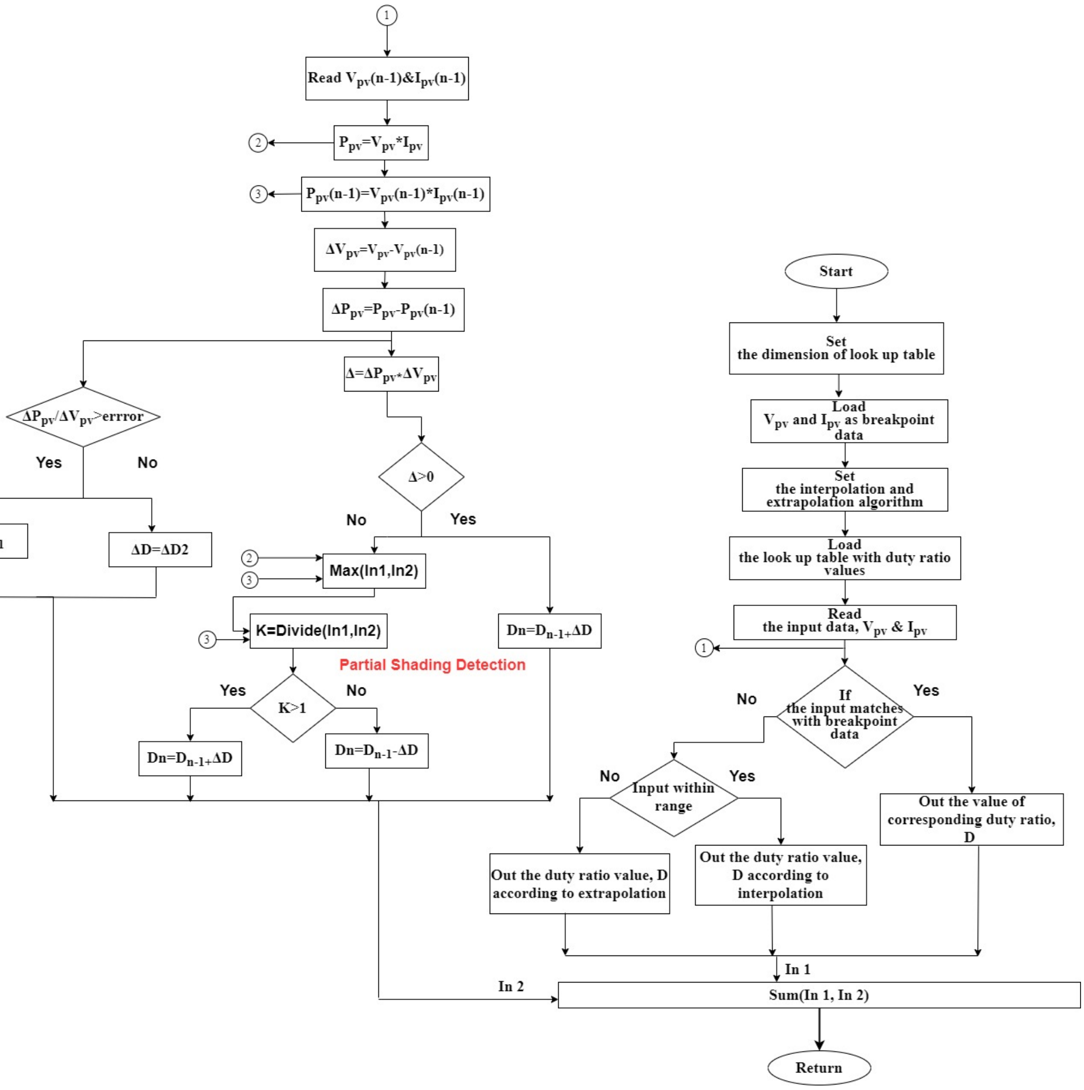

Fig.1. Flow chart of the proposed hybrid MPPT

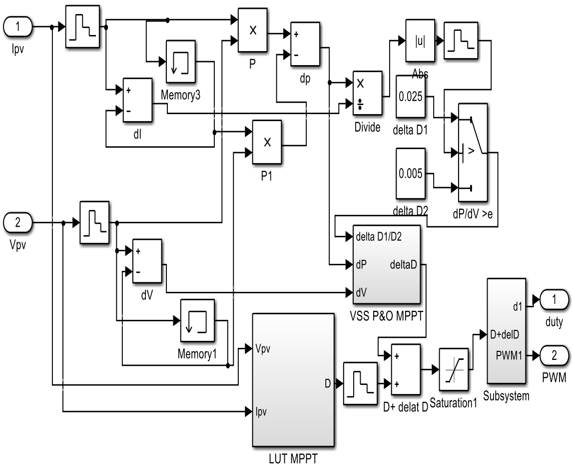

Fig. 2. Simulink model of the proposed hybrid MPPT

3. Modeling of Standalone SPV System

The diagrammatic representation of the proposed system is given in Fig. 3.

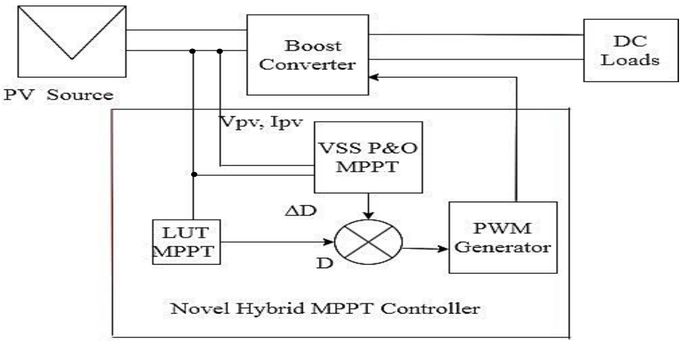

Fig.3. Block diagram of the proposed system

The system comprises a SPV source, an interfacing Boost converter and an MPPT Controller. Mathematical modeling of the system is also described in this section.

3.1 Mathematical Modeling of PV Cell

Figure 4 represents the electrical circuit representation of a PV cell [36].

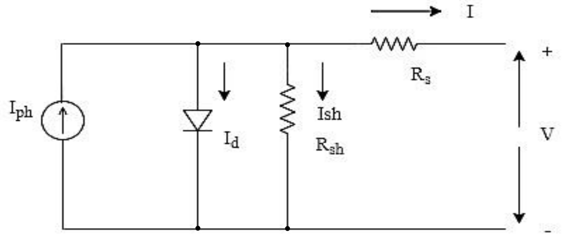

Fig. 4. Equivalent circuit of a PV cell

where ; D – diode, I_{ph} - photo current (A), R_s - series resistance (Ω), R_{sh} - parallel resistance (Ω), I_d - diode current (A), I_{sh} - shunt current (A), *V* - PV output voltage (V), *I* - PV output current (A)

The expression for photo current I_{ph} is given in Eq. (1)

$$I_{ph} = \left[I_{sc} + k_i\left(T - T_{ref}\right)\right]\frac{S}{S_n} \tag{1}$$

where; S_n - irradiance at Standard Test Condition (STC) (W/m^2), T- operating temperature (K), T_{ref}- reference temperature at STC (K), S - irradiance (W/m^2), I_{sc} - short circuit current (A) and k_i-short circuit current coefficient, obtained from the datasheet of PV module[14].

PV module reverse saturation current I_{rs} can be expressed as in Eq. (2)

$$I_{rs} = \frac{I_{sc}}{\left[exp\left(\frac{qV_{oc}}{T_{ref}nkN_s}\right)-1\right]} \tag{2}$$

where; q - charge of electron, V_{oc}- open circuit voltage (V), N_s - number of series connected cells, k - Boltzmann's constant equal to 1.38 x 10^{-23} JK^{-1} [14] and n – diode ideality factor

PV saturation current,I_0 is expressed in Eq. (3).

$$I_0 = I_{rs}\left[\frac{T}{T_{ref}}\right]^3 exp\left[\frac{qE_{g0}}{nk}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \tag{3}$$

where; E_{g0} - energy band gap of semiconductor (0.67eV for Germanium and 1.14eV for Silicon) [14].

PV module output current *I* is given in Eq. (4).

$$I = N_p\left[I_{ph} - I_o\lfloor exp\left(\frac{q\left(\frac{V}{N_s}+\frac{IR_s}{N_p}\right)}{knT}\right) - 1\rfloor\right] - I_{sh} \tag{4}$$

where; N_p -number of parallel connected cells and I_{sh} is calculated by Eq. (5).

$$I_{sh}=\frac{\frac{VN_p}{N_s}+IR_s}{R_{sh}} \tag{5}$$

3.2 Mathematical Modeling and Design of the Boost Converter (BC)

The circuit representation of the Boost converter is shown in Fig.5(a) [14].

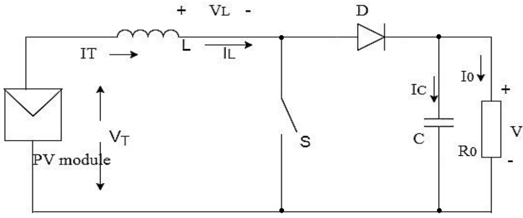

Fig. 5(a). Electrical circuit of boost converter

The converter consists of an inductor L, a switch S, followed by a series diode D and a capacitor C. Let the load be R_0, load voltage is V_0, load current is I_0, terminal voltage across the panel is V_T , panel current is I_T, V_L be the inductor voltage, V_c be the capacitor voltage, I_L be the inductor current and I_c be the capacitor current.

Mathematical modeling of the converter is done using the following equations.

When the switch Q is on, the relationships between input and output quantities are expressed in Eq. (6), Eq. (7) and in Eq. (8).

$$V_{L(\text{on})} = V_T \tag{6}$$

$$I_{C(\text{on})} = -I_0 \tag{7}$$

$$V_C = 1/C_{in}\int I_{pv} - I_s dt \tag{8}$$

where; C_{in} is the input capacitor.When the switch Q is off, the inductor voltage and capacitor current are related as in Eq. (9), Eq. (10) and in Eq. (11).

$$V_{L(\text{off})} = V_T - V_0 \tag{9}$$

$$I_{C(\text{off})} = I_T - I_0 \tag{10}$$

$$\frac{V_0}{R} = I_0 \tag{11}$$

Volt-sec balance is expressed in Eq. (12), Eq. (13) and in Eq.(14).

$$V_{L(\text{on})}\text{T}_{\text{on}} + V_{L(\text{off})}\text{T}_{\text{off}} = 0 \tag{12}$$

$$\text{ie,}(V_T)\text{DT} + (V_T - V_0)(1-D)T = 0 \tag{13}$$

$$\frac{V_0}{V_T} = \frac{1}{1-D} \tag{14}$$

where; D - duty ratio of the converter.

The design of inductor L and capacitor C are done as per the Eq. (15) & Eq. (16) [37].

$$\text{L}=\frac{V_T D}{f_s \Delta I_L} \tag{15}$$

$$\text{C}=\frac{I_o D}{f_s \Delta V_0} \tag{16}$$

where; f_S- switching frequency, ΔI_L- ripple in input current which is taken as 0.3 I_o, ΔV_0- ripple in output voltage and is chosen as $0.05V_0$ [38].

In this study, Su-Kam 100W PV panel is taken as the reference model and a 100W, 18/48V Boost converter is designed for impedance matching with source and load. The simulink model of boost converter is presented in Fig.5(b).

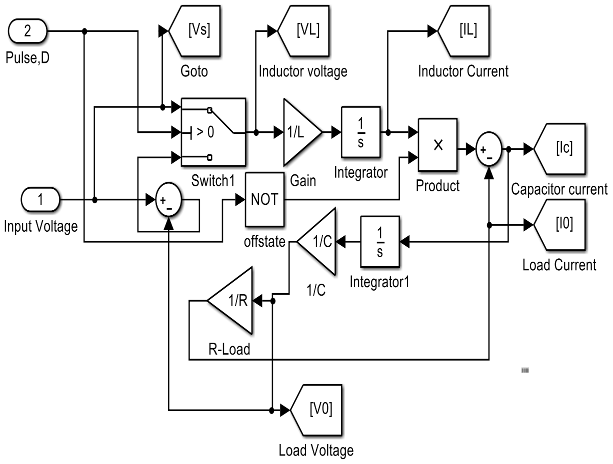

Fig.5(b). Simulink model of boost converter

4. Simulation Results

To validate the performance of the proposed hybrid MPPT method, a 100W standalone PV system is modeled and simulated in MATLAB/Simulink. The system consists of a PV panel, Boost converter, MPPT controller and load. The required data for the PV system are given in Table 2. The simulink model of the complete system is shown in Fig. 6.

Table 2. Specifications of PV system

Sl. No	Parameters	Values
1	Solar PV modules	100W
2	Maximum peak Current, I_{mp}	5.56A
3	Maximum peak voltage, V_{mp}	18V
4	Open circuit voltage, V_{oc}	22.23V
5	Short circuit current, I_{sc}	6.1A
6	Inductor, L of BC	700µH
7	Capacitance, C of BC	100µF
8	Load Resistor, R_0	23.04Ω

The system is simulated with VSS P&O MPPT, VSS Fuzzy MPPT and the proposed hybrid VSS ZOPO-LUT MPPT. Fuzzy MPPT guarantees a very fast response time of 0.035 s with low relative ripple rate of 0.2% [39]. For a 40W, 18/24V boost converter based SPV system, converter efficiency with the VSS P&O MPPT is 97% and takes nearly 0.06 seconds to reach steady state [40].

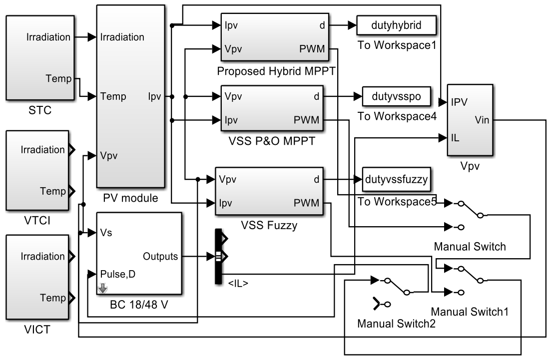

Fig. 6. Simulink model of the complete system

The real time implementation of the system by sensing input parameters such as temperature and irradiation is not cost effective. In this work, LUT is framed with PV voltage and current as inputs which have a strong dependency on temperature and irradiation respectively. Duty ratio entries for each combination are obtained by running the system with normal P&O MPPT. Table 3 shows duty ratio entries for corresponding voltage and current ranges.

Table 3. Duty ratio data entries in Look Up Table with voltage and current as inputs

Voltage(V)	Current(A)					
	3.6	4.2	4.8	5.2	5.7	6.2
12.5	0.60	0.63	0.65	0.67	0.69	0.70
13.5	0.59	0.62	0.64	0.66	0.68	0.69
14.5	0.58	0.61	0.63	0.65	0.67	0.68
15.5	0.57	0.60	0.62	0.64	0.66	0.67
16.5	0.56	0.59	0.61	0.63	0.65	0.66
17.5	0.55	0.58	0.60	0.62	0.64	0.65

4.1 Validation of the PV system

To validate the designed system, the model is simulated with $T = 25°\mathrm{C}$ and $G = 1000\mathrm{W/m^2}$. Figure.7(a) and Fig.7(b) represent the simulated results.

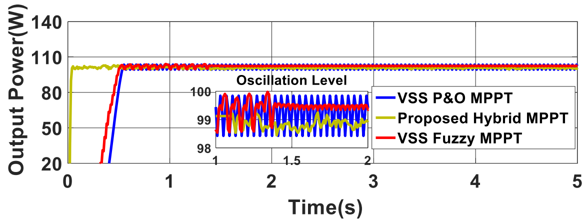

Fig.7(a). Converter output power for T = 25°C and G= 1000W/m^2

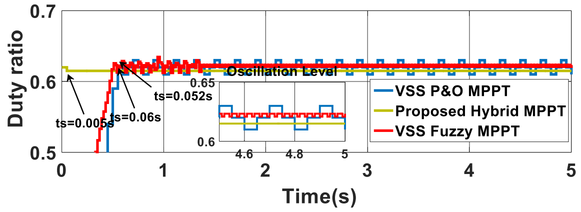

Fig.7(b). Duty ratio for T = 25°C and G= 1000W/m^2

The system is generating a duty ratio of 0.62 (as per Eq.(14)), which means that the developed model is accurate. From Fig. 7(b), it can be inferred that the VSS P&O reaches the optimum set point in 0.06s and Fuzzy controller in 0.052s whereas the proposed hybrid MPPT in 0.005s, indicating a quicker response. The oscillations at the MPP are also negligible.

4.2 Handling Uniform Variation in Irradiance

The effect of uniform change in irradiation on the system parameters is investigated in this section. In this case, constant temperature ($T = 25$°C) and a uniformly varying irradiation of values 1100 W/m^2, 1200W/m^2, 1000W/m^2, 900W/m^2 and 850W/m^2 are applied. Each variation is applied for a duration of 1s. The irradiation pattern used is depicted in Fig. 8. The simulated results of converter output power, converter input power and duty ratio are presented in Fig. 9(a), Fig. 9(b) and Fig. 9(c). The obtained PV voltage and current are illustrated in Fig. 9(d) and Fig. 9(e).

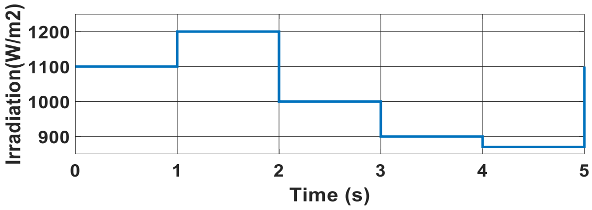

Fig. 8. Uniform variation in irradiation

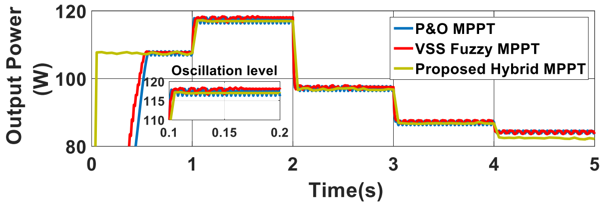

Fig. 9(a). Converter output power for uniformly varying irradiation

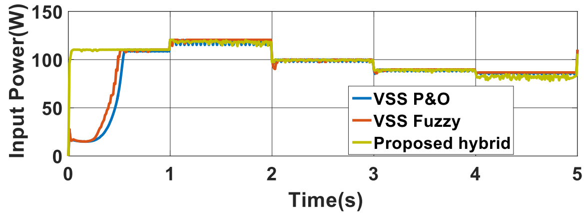

Fig. 9(b). Converter input power for uniformly varying irradiation

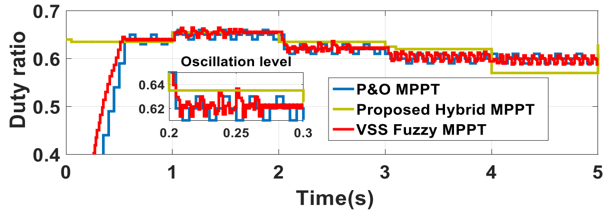

Fig. 9(c). Duty ratio for uniformly varying irradiation

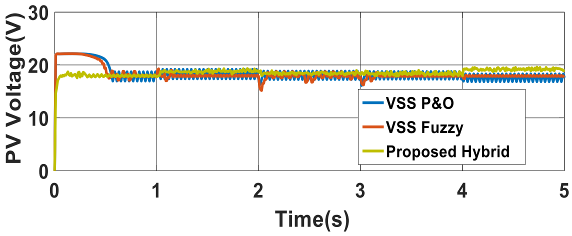

Fig. 9(d). PV voltage for uniformly varying irradiation

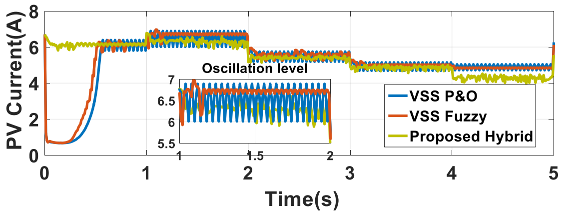

Fig. 9(e). PV current for uniformly varying irradiation

It is inferred from the obtained results that the new hybrid MPPT shows faster response with negligible oscillations and generates more accurate duty ratio when compared to other MPPTs.

4.3 Handling Uniform Variation in Temperature

In this case, uniformly varying temperature of values 25ºC, 30ºC, 35ºC, 40ºC and 25ºC and constant irradiation (G=1000W/m^2) are applied. The temperature configuration is shown in Fig. 10. The output power, input power and duty ratio are shown in Fig.11(a), Fig.11(b) and Fig.11(c). The corresponding PV voltage and current are depicted in Fig.11(d) and Fig.11(e).

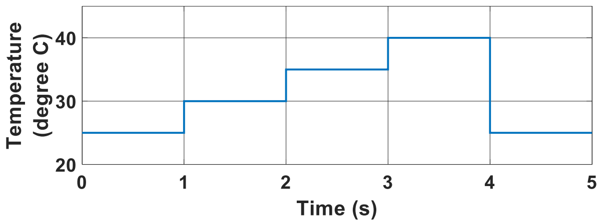

Fig. 10. Uniform variation in temperature

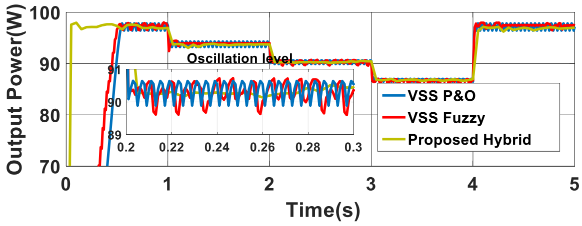

Fig. 11(a). Converter output power for uniformly varying temperature

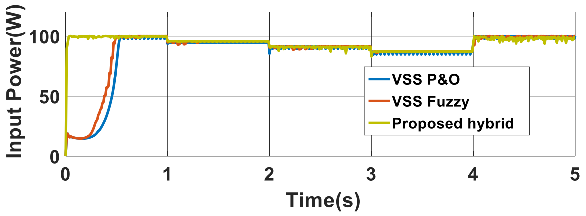

Fig. 11(b). Converter input power for uniformly varying temperature

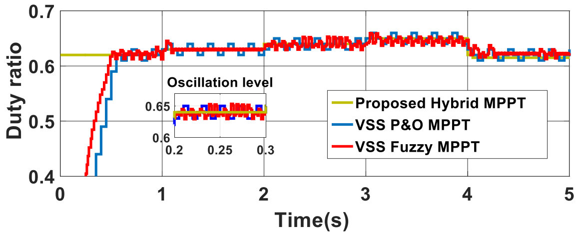

Fig. 11(c). Duty ratio for uniformly varying temperature

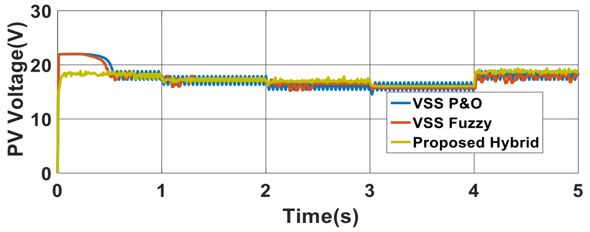

Fig. 11(d). PV voltage for uniformly varying temperature

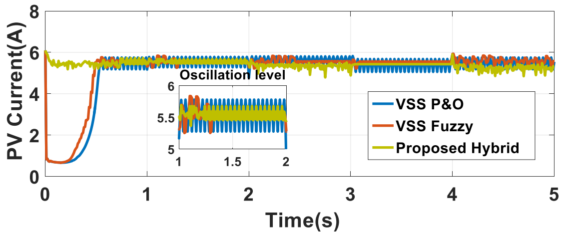

Fig. 11(e). PV current for uniformly varying temperature

The result shows that the proposed MPPT controller is faster and generates more accurate duty ratio with negligible oscillations.

4.4 Handling Non-Uniform Temperature and Irradiance Variations

For analyzing the performance of different MPPTs under non uniform variation in atmospheric conditions, real time data of temperature and irradiation are used. The solar irradiance level (W/m^2) in the month of March (summer days) has been considered for a particular area of Cochin University College of Engineering Pulincunnu, near Alappuzha located at southern part of India with latitude 9°29'N and Longitude 76°20'E. The data is collected on 22nd March 2019, and the samples are given in Fig.12. The prominent variations of irradiation and temperature are observed between 1.15 PM and 3.30 PM. For the performance analysis, irradiation and temperature samples for 10 regular intervals between 1.20 PM and 2.50 PM are taken as shown in Fig. 13(a) and Fig.13(b). For simulation purposes, it is assumed that the variations occur in every 10s as shown in Fig. 13(c) and Fig. 13(d) and the simulation is carried out for 100s.

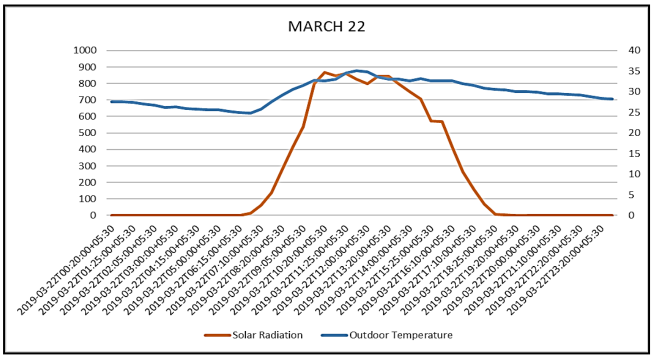

Fig. 12. Non uniform variation in temperature and irradiation

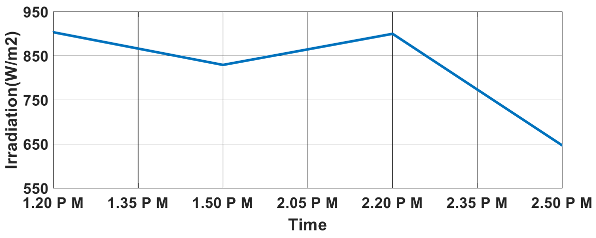

Fig. 13(a). Irradiation samples

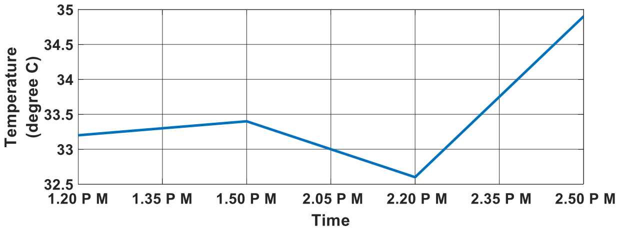

Fig. 13(b). Temperature samples

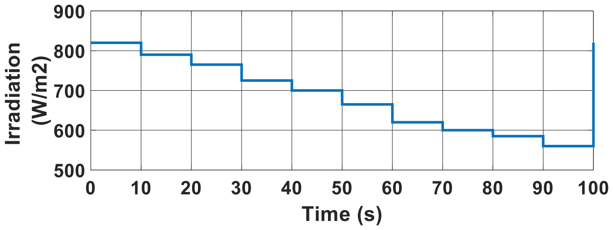

Fig. 13(c). Irradiation samples for simulation

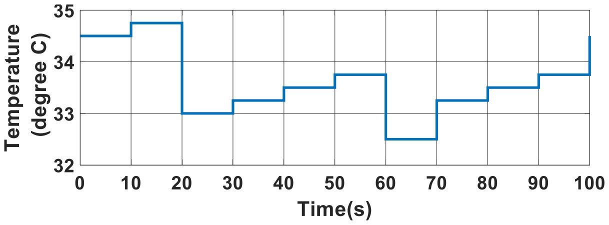

Fig. 13(d). Temperature samples for simulation

The obtained output power, input power, duty ratio, PV voltage and PV current are shown in Fig.14(a), Fig. 14(b), Fig.14(c), Fig.14(d) and Fig.14(e)..

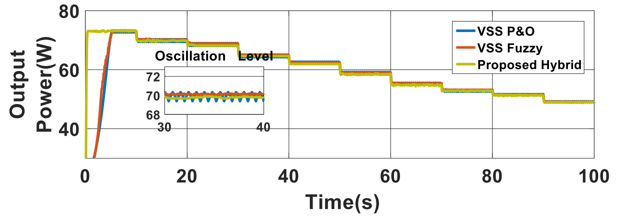

Fig. 14(a). Output power for non-uniform irradiance and temperature variations

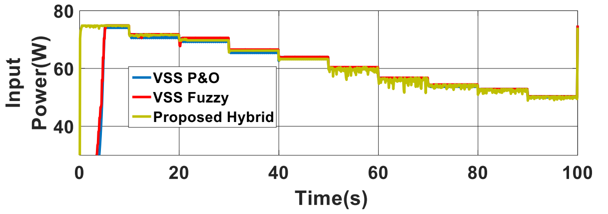

Fig. 14(b). Input power for non-uniform irradiance and temperature variations

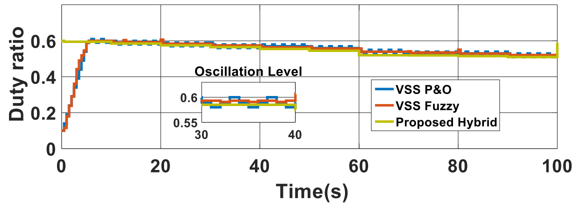

Fig. 14(c). Duty ratio for non-uniform irradiance and temperature variations

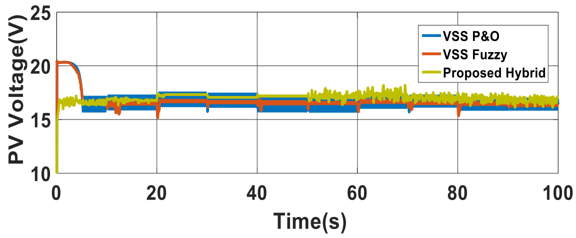

Fig. 14(d). PV voltage for non-uniform irradiance and temperature variations

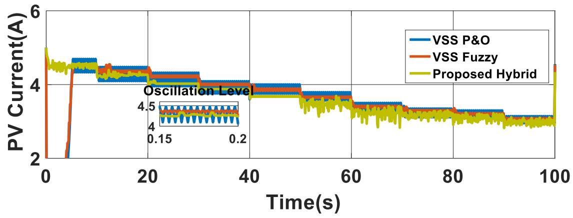

Fig. 14(e). PV current for non-uniform irradiance and temperature variations

The results reveal that the proposed hybrid MPPT method reaches MPP very even at the occurrence of first change and follows the correct path at every change with almost zero oscillation. Thus this method is very suitable for non-uniformly varying atmospheric conditions.

4.5 Handling Partial Shading Conditions

In this work, the ability of the proposed algorithm to handle PSC is analysed. The Su-Kam 100W PV string with 36 cells is modeled with 6 modules (M_1-M_6), each having 6 cells connected in series. Two shading cases are analysed and the performance of the proposed MPPT is compared in terms of tracking speed and efficiency. In case 1, M_5 & M_6 receive irradiation of 700W/m^2 and others receive full irradiation of 1000 W/m^2. In case 2, M_4 receives irradiation of 800W/m^2, M_5 & M_6 receive irradiation of 600 W/m^2 and others receive full irradiation of 1000 W/m^2. Figure 15(a) and Fig.15(b) shows the PV curve for both cases. Fig. 16(a) and Fig. 16(b) represent the obtained output powers.

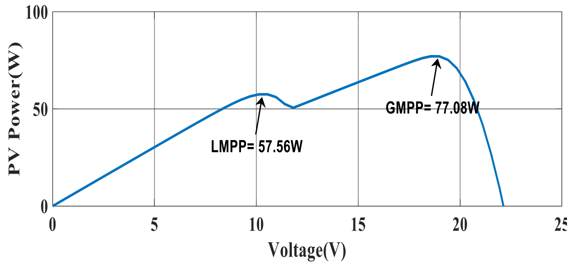

Fig. 15(a). PV characteristics for case 1

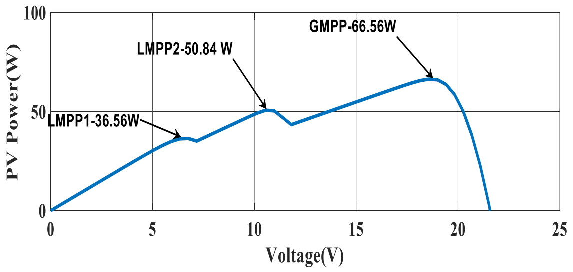

Fig. 15(b). PV characteristics for case 2

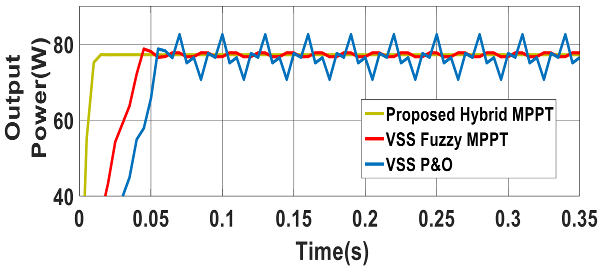

Fig.16(a). Converter output power for case 1

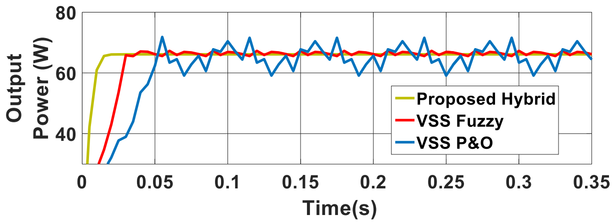

Fig. 16(b). Converter output power for case 2

5. Performance Analysis

The output power is greatly impaired by the duty ratio oscillations, which eventually disrupts the overall system's performance. Ripple analysis is necessary to validate the performance of the proposed hybrid MPPT. The ripple percentage in output power and input current of the three compared methods for the above said atmospheric conditions are presented in Fig. 17(a), Fig.17(b) and Fig.17(c). In all the cases, the proposed system shows lowest ripple because of the negligible oscillations at the MPP. Performance comparison for two modes of PSC are tabulated in Table 4.

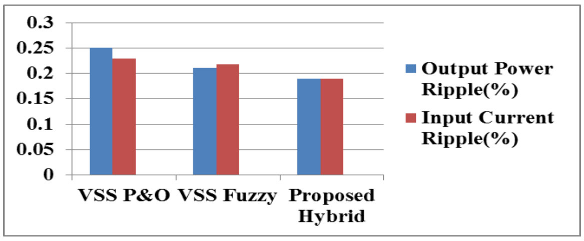

Fig. 17(a). Ripple comparison for uniform variation in Irradiance

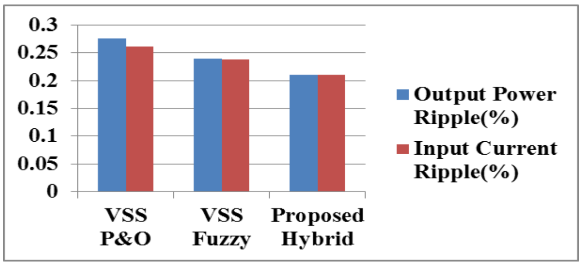

Fig. 17(b). Ripple comparison for uniform variation in temperature

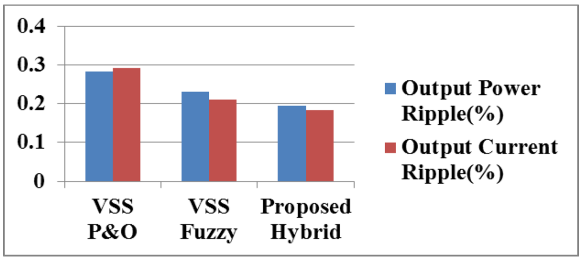

Fig. 17(c). Ripple comparison for non-uniform variation in irradiance and temperature

The result shows that the proposed MPPT controller shows improvement in tracking speed and exhibits negligible oscillations.

Table 4. Analysis for partial shading conditions

		Case 1	Case 2	Average Tracking Time (s)
Irradiance ($\frac{W}{m^2}$)	G_1	1000	1000	
	G_2	1000	1000	
	G_3	1000	1000	
	G_4	1000	800	
	G_5	700	600	
	G_6	700	600	
P_{mp} (W)	Global Power	77.08	65.27	
Proposed Hybrid MPPT		76.50	65.27	.01
VSS P&O MPPT		73.5	63.37	.06
VSS Fuzzy MPPT		74.45	64.35	.035

Let P_{0avg} be the average power output of boost converter, P_{inavg} be the input power of the boost converter. The average power conversion efficiency, $\eta_{avg} = \frac{P_{0avg}}{P_{inavg}}$. The average tracking time and average power conversion efficiency are compared and the plots are presented in Fig.18(a), Fig.18(b) and Fig.18(c).

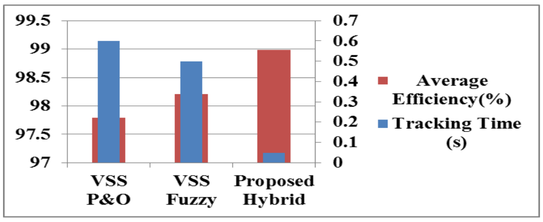

Fig.18(a). Efficiency and tracking time for uniform variation in irradiance

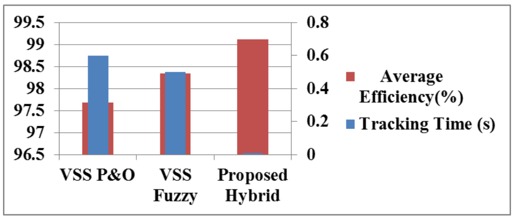

Fig.18(b). Efficiency and tracking time for uniform variation in temperature

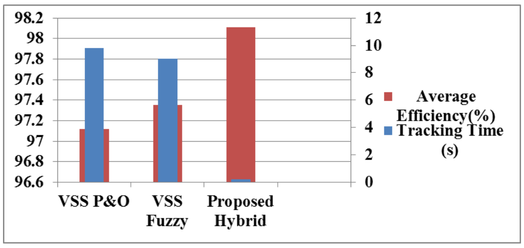

Fig. 18(c). Efficiency and tracking time for non-uniform variation in irradiance and temperature.

6. Conclusion

A hybrid VSS ZOPO - LUT MPPT is proposed in this work. The method is a combination of VSS Zero Oscillation P&O algorithm and LUT. The complete system is modeled in MATLAB/Simulink platform and simulated for uniformly/non-uniformly varying and partial shading atmospheric conditions. In all the cases, the proposed system outperforms both VSS P&O and Fuzzy MPPT. The average power conversion efficiency, average output power ripple percentage , average input current ripple percentage, and the tracking time obtained with hybrid MPPT at STC are 98.11%, 0.173%, 0.194% and 0.1s respectively. The results obtained are higher than those stated in [39] and [40]. The method is very simple, easy to understand and implement compared to the VSS P&O and VSS Fuzzy based MPPT. It also exhibits negligible oscillations around the MPP. Thus the overall performance of the proposed MPPT is superior to other MPPT techniques.

Acknowledgements

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