IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received February 15, 2021, accepted March 5, 2021, date of publication March 9, 2021, date of current version May 13, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3064936

An Effective Design and Implementation of Hybrid MPP Tracking Scheme Based on Linear Tangents & Neville Interpolation (LT-NI) Technique for Photovoltaic (PV) System

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ABSTRACT Solar power is free from environmental pollution and also offers economic benefits to the investors. In order to optimize at most solar power, tracking schemes are employed and traditional schemes from the family of perturbation suffer from slow response, due to specific step size disruption and oscillations around operating point. Therefore, this paper proposes an effective design and implementation of a hybrid Maximum Power Point Tracking (MPPT) scheme based on Linear Tangents - Neville Interpolation (LT-NI) techniques. Two tangents are drawn on the P-V characteristics at 75% and 90% of open circuit voltage (V_{OC}).The chosen two tangents intersect and gives rise to a third voltage (N) point. In continuation, the three voltage points ($0.75V_{OC}$, N & $0.9V_{OC}$) are computed using Neville Interpolation. The performance of the proposed LT-NI scheme is compared with Perturb & Observe (P&O) and advanced Divide and Conquer (DC) algorithms.

INDEX TERMS Linear tangents, Neville interpolation, photovoltaic system, divide and conquer.

I. INTRODUCTION

Nowadays renewable energy is widely used in power generation, transportation, rural area electrification, cooling, and heating technologies. A vigorous research is still in process to improve the efficiency of the renewable systems [1]. It is not only difficult but also expensive to transmit and distribute electrical energy generated from fossil fuel to rural areas, for such cases, it is advisable for isolated renewable power generation [2]. Among renewable energy resources, power generation through solar energy is very compatible. But still, solar power generation is far away from its target. Abundant freely available solar energy has prominent features compared to other renewable energy resources [3]. A little percentage of solar energy itself has the capability to replace conventional suppliers of energy. Approximately 10^{16} Watts of solar power is radiated from the sun to the earth surface. Whereas utmost power demand around the globe is numerically equal to 10^{13} Watts. Nations, like India, are naturally feathered with maximum sunlight throughout the year [4]. Apart from the demerits such as solar power plant installation requires a large area and inconsistent solar energy [5].

Li *et al.* [6], integrated P&O with synchronized switch harvesting on inductor rectifier. The system achieves high performance under normal conditions by extracting piezoelectric harvesting system. Pachaivannan *et al.* [7], implemented crowded plant height optimization MPPT algorithm inspired by the biological phenomenon. Hussain *et al.*[8], improved undershoot and overshoot by 68% and 35% compared to the conventional scheme by proposing a two stage algorithm. Jingxin *et al.* [9], presented a new strategy to scale

The associate editor coordinating the review of this manuscript and approving it for publication was Dwarkadas Pralhaddas Kothari.

high range of PV system to medium level using dual active bridge converter. The predictive response of the topology is checked by simulation as well as experimental results [10]. AI-Soeidat *et al.* [11], improved efficiency of conventional MPPT scheme by comparing the linear relation between MPP during highest to lowest irradiance level and the linear characterization between the bipolar junction transistors. In addition eliminated the usage of PID controller but the proposed method fail to opt the actual power path under dynamic weather conditions. Diaz-Barnabe and Morales-Aceredo [12], implemented AIC, APO, Conventional INC and P&O schemes through simulation and experimental studies under static and dynamic conditions by selecting sensitive parameters to attain an efficiency of 98% but, it is not possible to select the parameters corresponding to PV system.

Tafti *et al.* [13], proposed a novel flexible scheme to regulate active power generated. The flexible tracking modulates the performance under static conditions by PI controller [14]. Mishra and Singh [15], presents a new configuration to nullify zero ripple current and maximize the efficiency using SEPIC converter for a standalone water pumping system. Krithiga and Subudhi [16], proposed a PV fed smart home water pumping system with bidirectional DC-DC converter and battery back for uninterrupted water supply. Mukherjee *et al.* [17], investigated the performance of PV fed home electric vehicle charging based on multi output converter. Li *et al.* [18], presents a literature review on MPPT schemes on implementation and provides essential information on operating principles. Sahin [19], generated hydrogen with electrolytic process using P&O MPPT controller. A buck converter is employed to possess a low voltage and required value of current which are essential for the generation of hydrogen. The proposed procedure is most acceptable for electric vehicles but the conventional P&O scheme can be replaced by a best optimization algorithm for the efficient performance under any desirable weather conditions.

Mohamed-Kazim *et al.* [20], optimized the performance of smart grid connected PV system using an individualized spare aware time adjusting step size adaption technique. The proposed framework predicts and estimates numerical values required for PV system optimal operation. Under static and dynamic conditions its performance is well presented but the numerical values is estimated based on previous PV panel voltages. Therefore, the proposed frame work is independent of weather conditions [21]. Rodriguez *et al.* [22], proposed high frequency injection scheme to generate thermal energy from thermoelectric generator and experimentally evaluated tracking efficiency over 99.73%. It is worth to state that the author has a significant impact compared to literature. Sitbon *et al.* [23], presented a novel loop variable considering dynamic and static conductance as reference. The integrative controller ensures the tracking of power path with zero error. The analytical model has a robust voltage control structure under grid connected PV system [24].

Zainel *et al.* [25], experimentally embarked the necessity to maintain optimum temperature and to improve performance as well as efficiency. Combinations of PV cooling system, fuzzy and constant voltage method are used to maintain the system under acceptable temperature and improve the effectiveness under any weather conditions [26]. Ghamrawi *et al.* [27], modified perturb & observe, a dual mode switch is incorporated based on the ratio of power with respect to voltage. If the resultant of derivative is less than threshold value second mode is activated and continued till the value equals to zero. Mostafa *et al.* [28], conventional P&O scheme possess high oscillations and takes much time to track MPP. Therefore, a SMC technique is proposed to nullify the effects of conventional scheme. The simulation results benchmark the performance of sliding mode control under different irradiance and temperature values [29]. Lasheen and Abdel-Salam [30], presented a review on conventional MPPT schemes at the same time proposed a hybrid tracking scheme based on HC and ANFIS techniques. Using ropp and sinusoidal irradiance profiles the proposed scheme is tested by comparing with different online and offline methods in terms of accuracy, implementation, speed and gain factor.

The proposed hybrid tracking scheme is a combination of Linear Tangents - Neville Interpolation (LT-NI) technique. With the projection of linear tangents at 75% and 90% of V_{OC}, eliminates constant regions where the derivative of power with respect to voltage is equal to zero. The projection of tangents gives three voltage points which are further computed by Neville Interpolation to attain MPP. The effectiveness of the proposed MPPT scheme is compared with P&O and Divide and Conquer Algorithm [31] under standard test and real environmental conditions. The rest of the paper is organized as follows: schematic view of double diode PV cell along with the P-V and I-V characteristics is presented in Section II. Hybrid LT-NI technique is well diagrammatically articulated using P-V curves representing constant region and projection of tangents in Section III. Performance comparison and observations using simulation and experimental results are presented in Section IV and V. Conclusion is presented in Section VI.

II. MATHEMATICAL MODELING OF PV SYSTEM

P-V and I-V characteristic of 400W solar module under uniform irradiance along with schematic view of double diode PV cell is depicted in Fig. 1(a)-(e). PV system parameters for respective change in temperatures are mentioned within the figure. The electrical specifications of the PV system are depicted in Table 1.

III. PROPOSSED MPP TRACKING SCHEME

The factors affecting the performance of the MPPT controllers are perturbation in constant current and constant voltage region consumes time, oscillations around MPP reduces system efficiency, poor steady state and dynamic performance, unable to distinguish exact MPP during low irradiance and controller operation is independent of P-V characteristics. During fast change in weather conditions Divide and Conquer (DC) algorithm schemes also fail to

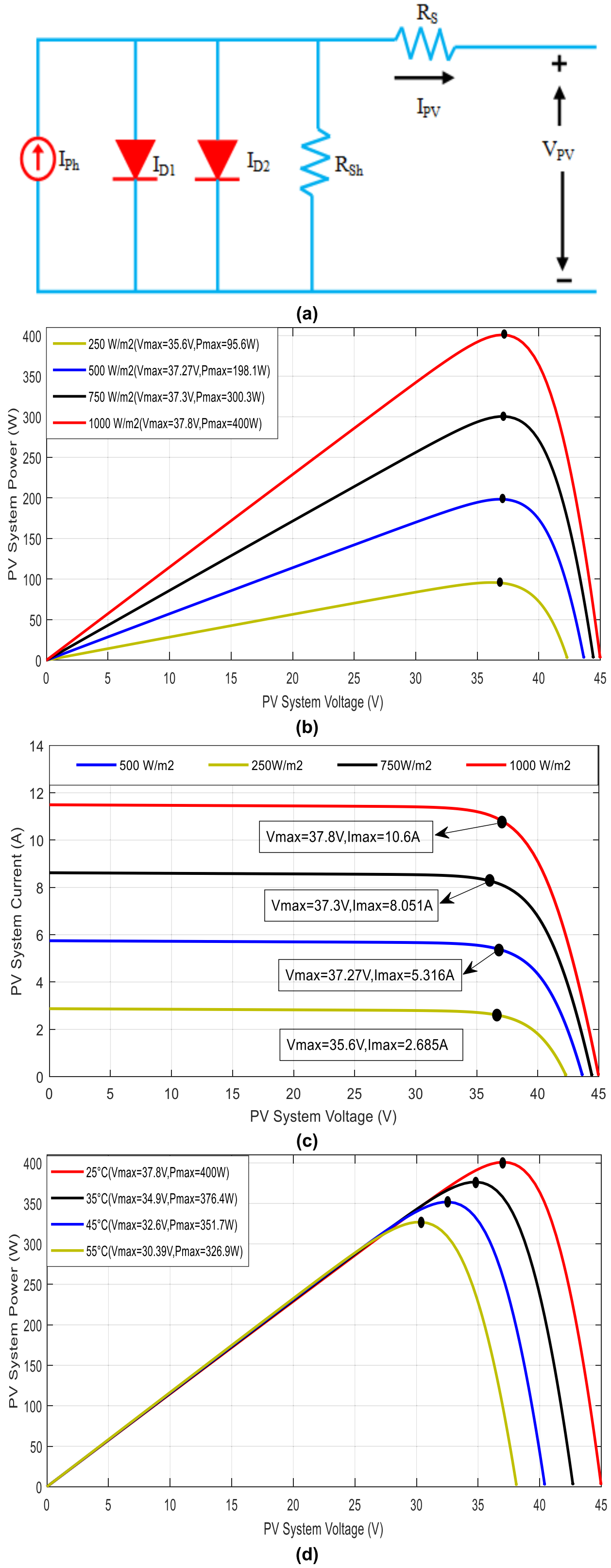

FIGURE 1. **(a) Schematic view of double diode PV cell, P-V characteristics (b) PV_P –PV_V, (c) PV_A-PV_V, (d) PV_P- PV_V and (e) PV_A - PV_V.**

track the power path for a while due to re-initialization of the program. In view of the above limitations an effective and

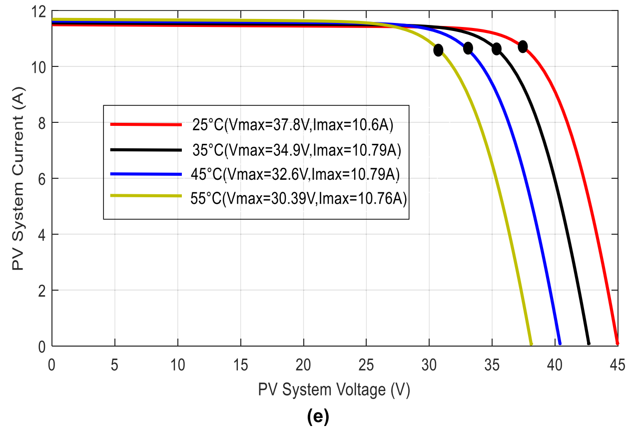

FIGURE 1. ***(Continued)*** **(a) Schematic view of double diode PV cell, P-V characteristics (b) PV_P –PV_V, (c) PV_A-PV_V, (d) PV_P- PV_V and (e) PV_A - PV_V.**

TABLE 1. **Electrical specifications of 400W module.**

S.No	Parameter	Range
1.	P_{Max}	400W
2.	V_{OC}	45V
3.	I_{SC}	12A
4.	V_{Max}	37.8V
5.	I_{Max}	11.2A

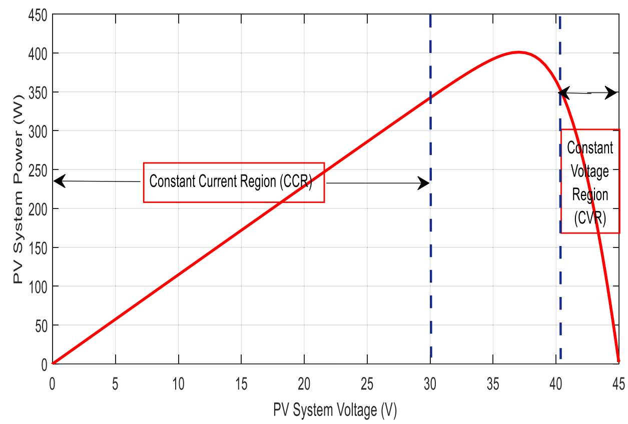

FIGURE 2. **Constant current and voltage regions of P-V curve.**

simple MPPT scheme is developed based on Linear Tangents and Neville Interpolation (LT-NI) techniques. The proposed hybrid LT-NI MPPT scheme is executed in two stages to obtain actual MPP of the PV system.

Stage I: In the P-V characteristics, constant current region lies between 0 to 75% of V_{OC}. Similarly, constant voltage region lies from 90 to 100% of V_{OC} as shown in Fig. 2. Therefore, two points are considered at 75% and 90% V_{OC} on P-V characteristics as depicted in Fig. 3. Where A lies at the end of constant current region and B lies at the starting of constant voltage region. The linear tangent equation representing these two points (A & B) are given as

$$\left.\begin{aligned} Y_A &= P^I(0.75V_{OC})(V-0.75V_{OC})+P(0.75V_{OC}) \\ Y_B &= P^I(0.9V_{OC})(V-0.9V_{OC})+P(0.9V_{OC}) \end{aligned}\right\} \quad (1)$$

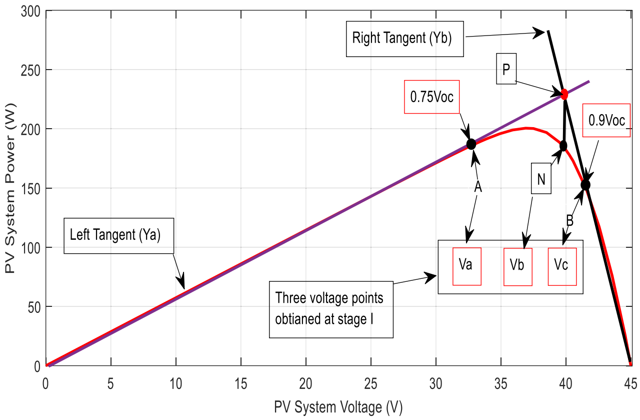

FIGURE 3. P-V characteristics representing proposed MPPT scheme.

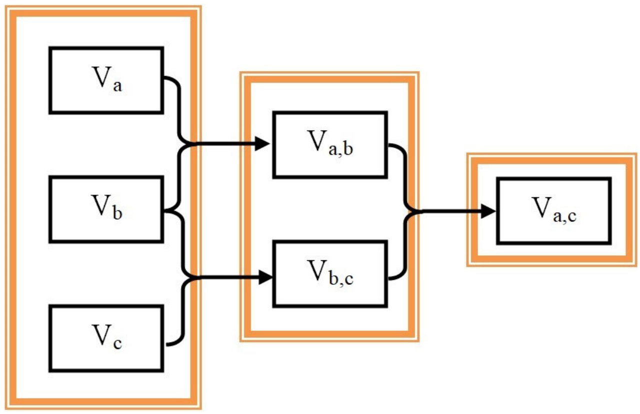

FIGURE 4. Intermediate steps in Neville interpolation.

where Y_A is left and Y_B is right tangent line and 'P' is the intersecting point as shown in Fig. 3. In continuation 'N' is the equivalent point of 'P' on P-V characteristics. Therefore voltage at point 'N' is given as

$$V_N = A + B \tag{2}$$

where

$$A = \frac{P(0.9V_{OC}) - P(0.75V_{OC})}{P^I(0.7V_{OC}) - P^I(0.9V_{OC})} \quad \text{and}$$
$$B = \frac{P^I(0.75V_{OC})0.75V_{OC} - P^I(0.9V_{OC})0.9V_{OC}}{P^I(0.7V_{OC}) - P^I(0.9V_{OC})}$$

Finally, the two voltage points $0.75V_{OC}$ and $0.9V_{OC}$ and the obtained voltage V_N are forwarded to the next stage to obtain actual MPP.

Stage II: Based on these three voltage points Neville Interpolation starts as depicted in Fig. 4. For convenience voltage points are represented as V_a, V_b and V_c. The polynomial equations '$V_{a,b}$' and '$V_{b,c}$' are represented in terms of power as

$$P(V_{a,b}) = \frac{(V_b - V)P_a(V_a) + (V - V_a)P_b(V_b)}{V_b - V_a} \tag{3}$$
$$P(V_{b,c}) = \frac{(V_b - V)P_b(V_b) + (V - V_b)P_c(V_c)}{V_c - V_b} \tag{4}$$

The final Neville Interpolation equation for the term $V_{a,c}$ is expressed as

$$P(V_{a,c}) = \frac{(V_c - V)P(V_{a,b}) + (V - V_a)P(V_{b,c})}{V_c - V_a} \tag{5}$$

At this condition, the derivative of power with respect to voltage will be equal to zero and MPP of the PV system is obtained by the below equation.

$$\frac{d\left[P(V_{a,c})\right]}{dV} = \left.\begin{array}{l} \frac{(V_c - V)(V_b - V)}{(V_c - V_a)(V_b - V_a)}P_a(V_a) \\ \frac{(V_c - V)(V_a - V)}{(V_c - V_b)(V_a - V_b)}P_b(V_b) \\ -\frac{(V_b - V)(V_c - V)}{(V_c - V_b)(V_c - V_a)}P_a(V_a) \\ +\frac{(V_b - V)(V_a - V)}{(V_c - V_b)(V_b - V_a)}P_c(V_c) \end{array}\right\} \tag{6}$$

Therefore Eq. (6) can be simplified as

$$V_{MPP} = \frac{\alpha(V_b + V_c) + \beta(V_a + V_c) + \theta(V_a + V_b)}{2(\alpha + \beta + \theta)} \tag{7}$$

where

$$\alpha = \frac{P_a(V_a)}{(V_a - V_b)(V_a - V_c)}, \quad \beta = \frac{P_b(V_b)}{(V_b - V_a)(V_b - V_c)} \quad \text{and}$$
$$\theta = \frac{P_c(V_c)}{(V_C - V_a)(V_c - V_b)}$$

Eq. 7, gives MPP voltage of the PV system and Fig. 5 depicts flowchart of the LT-NI technique based MPPT scheme. Therefore, LT-NI MPPT scheme is succeeded in maintaining constant duty cycle.

IV. STEPS TO IMPLEMENT PROPOSED ALGORITHM

V. RESULTS & DISCUSSION

Initially, the LT-NI tracking scheme along with traditional P&O and advanced DC schemes are implemented using MATLAB/Simulink platform as shown in Fig. 6. The MPPT schemes are programmed in embedded function, which generates essential gate pulses to the converter. All the three MPPT schemes are tested under two conditions i.e., at first simulated under standard test conditions thereafter their performance is evaluated under real environmental conditions.

A. TESTING UNDER STANDARD TESTING CONDITIONS

The simulation model consists of 400watt PV module, filter inductor, capacitor, IGBT switching device, DC capacitor, resistive load and MPP tracking scheme. In numerical terms, isolation and temperature at STC are specified as 1000W/m^2 and 25°C. The PV system does have the capacity to generate identical parameters offered by the manufacture under STC. Fig. 7 shows output PV power, voltage and current of the PV system using P&O scheme. Refer to specific step size, the P&O operator encounters output power oscillations that are clearly illustrated by the inset image at 0.104Sec to 0.107Sec shown in Fig. 7(a). Hence, the net power obtained by using P&O controller at STC is 398W.

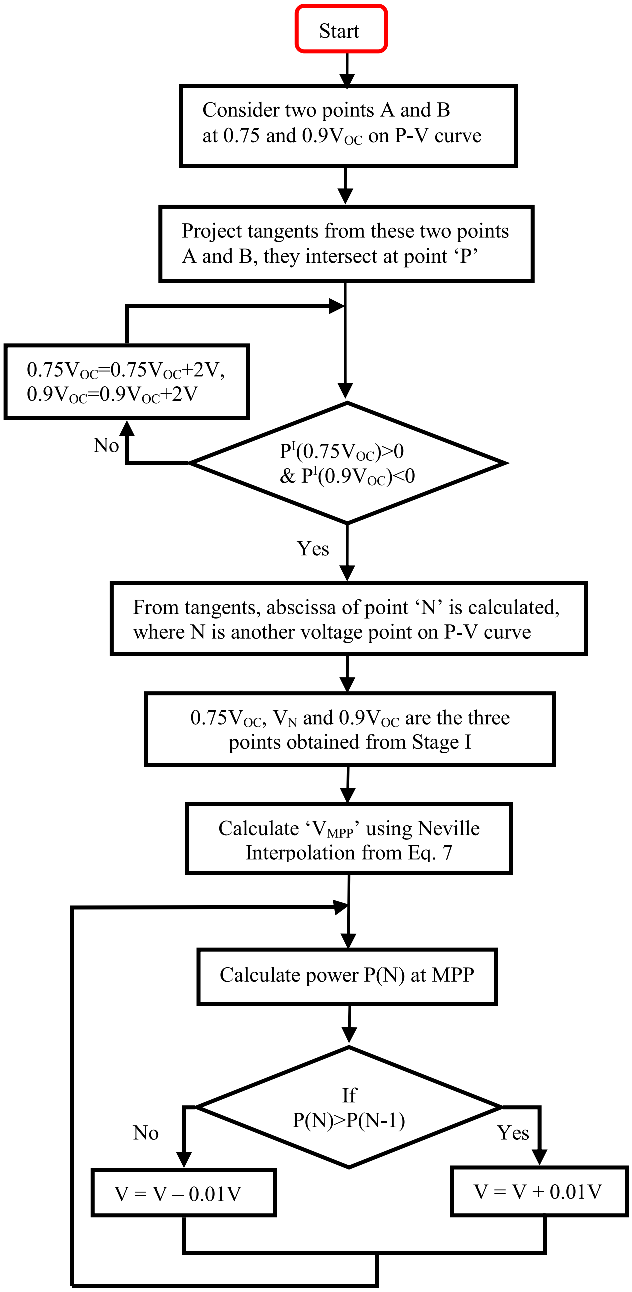

FIGURE 5. Flowchart of the recommended MPPT scheme.

Step 1: A & B
Two points (A & B) at 75 percent and 90 percent of the V_{OC} on the P-V characteristics.
Step 2: Y_A & Y_B
Linear tangents are drawn on the two points using Eq. 1.
Step 3: V_N
From the point 'P', respective point on P-V curve 'N' is noticed as shown in Fig. 3.
Step 4: ($0.75V_{OC}$, V_N, $0.9V_{OC}$)
At this instant three voltage points are obtained ($0.75V_{OC}$, V_N, $0.90V_{OC}$).
Step 5: Fig. 4
The obtained voltage points are further forwarded to Neville Interpolation technique.
Step 6: Eq. 3, 4 & 5
The intermediate polynomial equations are obtained using Eq. 3, 4 and 5.
Step 7: Eq. 6
The power derivatives in relation to volt give MPP the condition of operation.
Step 8: Eq. 7
Finally, MPP is obtained by implementing Eq. 7.

From the inset diagrams presented in Fig. 7(a), it is clear that the P&O controller takes much steps to reach MPP and the frequency of the output power oscillations is very high. From the results, it is observed that it takes much time to reach MPP and oscillations around MPP reduce the PV system output power.

The advanced DC algorithm segregates one third of the P-V characteristics at every iteration and converges to the MPP of the PV system. Initially, closed interval [0, V_{OC}] has to be chosen from the PV system. The major limitation associated with the proposed MPPT is during varying weather conditions, the interval limit has to be modified such that exact MPP with respect to irradiance and temperature can be obtained. At the same time, for every updated interval the PV system has to be reinitialized from the first. During fast change in weather conditions it may not be possible to update the closed interval quickly therefore fails to track power path until MPP is obtained. Till the time MPP is decided, PV system experiences oscillations. The advanced scheme harvests a maximum solar power of 400Watt as depicted in Fig. 8 (a)-(c).

Fig. 9 (a)-(c) depicts PV system power, voltage and current using hybrid LT-NI MPPT technique. As discussed earlier, first tangents are projected on the P-V characteristics such that constant current and voltage regions are eliminated and the region of MPP is obtained quickly, from that instant three points are chosen by Neville Interpolation to obtain exact MPP. From the graph present in the Fig. 9(a), the proposed LT-NI scheme has reached the MPP very quickly. Thereby due to the computations involved in the Neville Interpolation technique a little bit oscillations are observe till the exact operating point is decided. From Fig. 9, it is clear that the proposed Linear Tangents - Neville Interpolation techniques has eliminated the contradiction associated with conventional P&O scheme and also modified the time response and

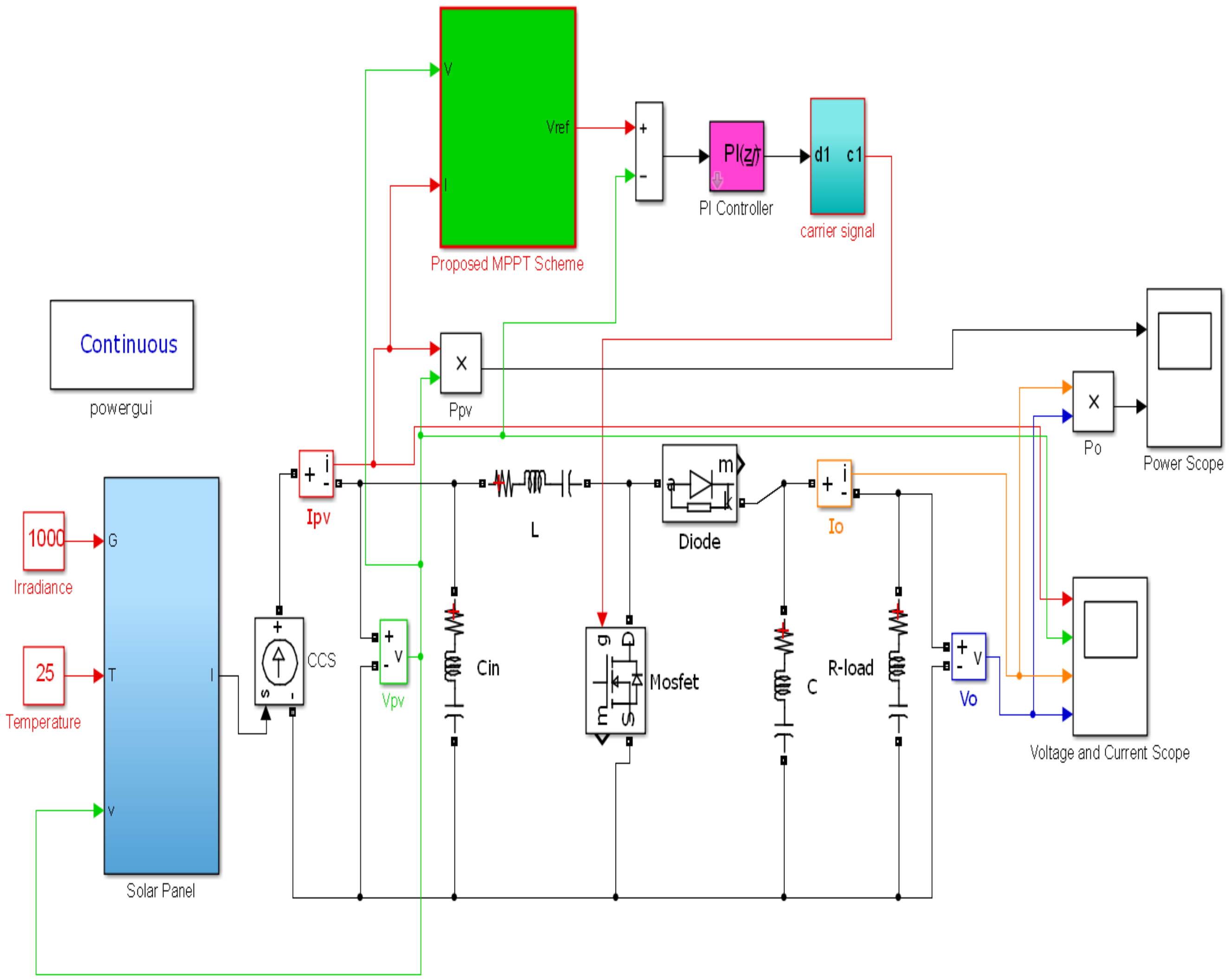

FIGURE 6. Simulation diagram of the PV system using proposed MPPT Scheme.

oscillations around MPP. It is worth to conclude that the proposed MPPT scheme has improved the efficiency of the PV system.

B. TESTING UNDER PRACTICAL CONDITIONS

The working efficiency of any MPPT scheme cannot be vindicated under STC. In view of the above statement, the three schemes are simulated by replicating real environmental conditions. Using signal builder graph the tabulated numerical values of irradiance and temperature are given as input to the PV system. Fig. 10 (a)-(c) under actual conditions, PV device output capacity is represented using three MPPT schemes. The actual power is compared with the obtained power by the tracking schemes.

From Fig. 10(a), it can be benchmarked that the traditional scheme was unable to track the actual power values. Due to limitation in the logical operation of traditional P&O scheme. Similarly, Fig. 10(b) represents a comparison between actual and obtained powers using DC algorithms. As stated earlier, the closed interval considered needs to be re-initialized with any change in irradiance levels and temperature values. Due to this constraint there exists a difference between the actual and obtained powers. Fig. 10(c) depicts a comparison between actual and obtained power using proposed LT-NI tracking scheme. on close observation, it is clear that the difference between the two power graphs is comparatively low compared to the power graphs obtained from P&O and DC algorithms shown in Fig. 10(a) & (b). As the projection of linear tangents on P-V curve eliminates computation in constant current and voltage regions. Therefore the region of MPP is obtained as quickly as possible under any condition. Interpolation involved in the tracking scheme computes quickly the three obtained voltage points to obtain the MPP. In continuation the efficiency of the three MPPT schemes are depicted in Fig. 11 and Table 2 gives a numerical comparison of the three MPPT schemes.

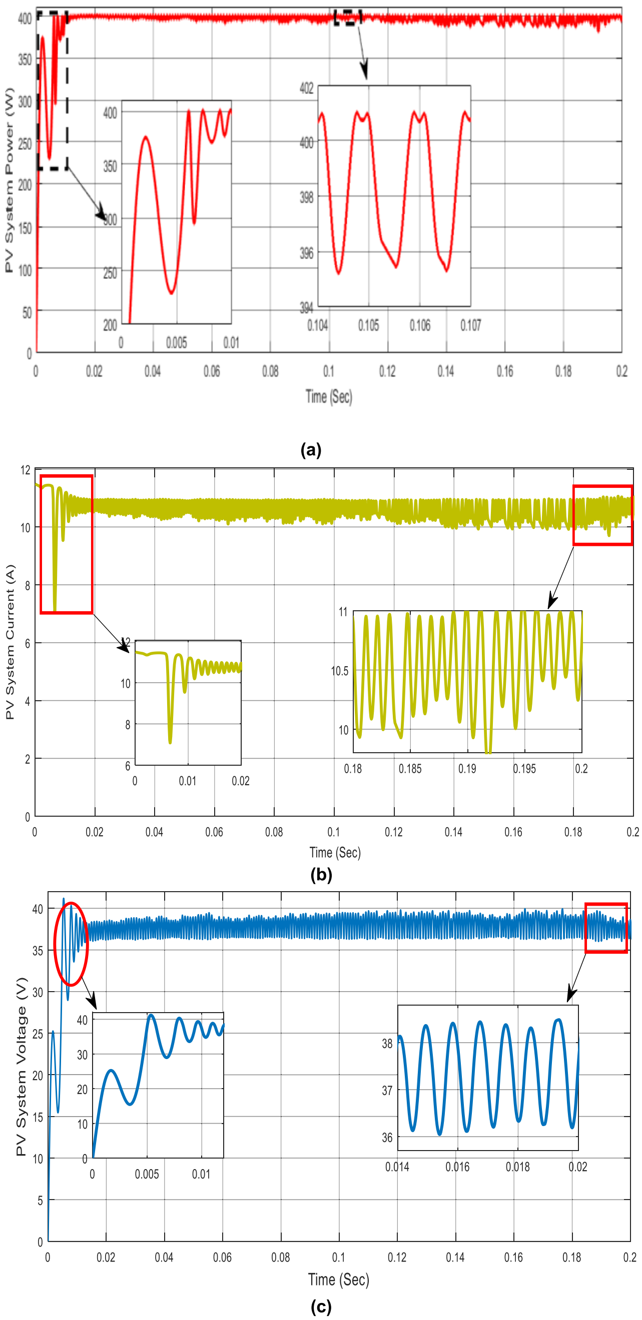

FIGURE 7. PV system parameters (a) PV_P, (b) PV_A and (c) PV_V using traditional P&O scheme.

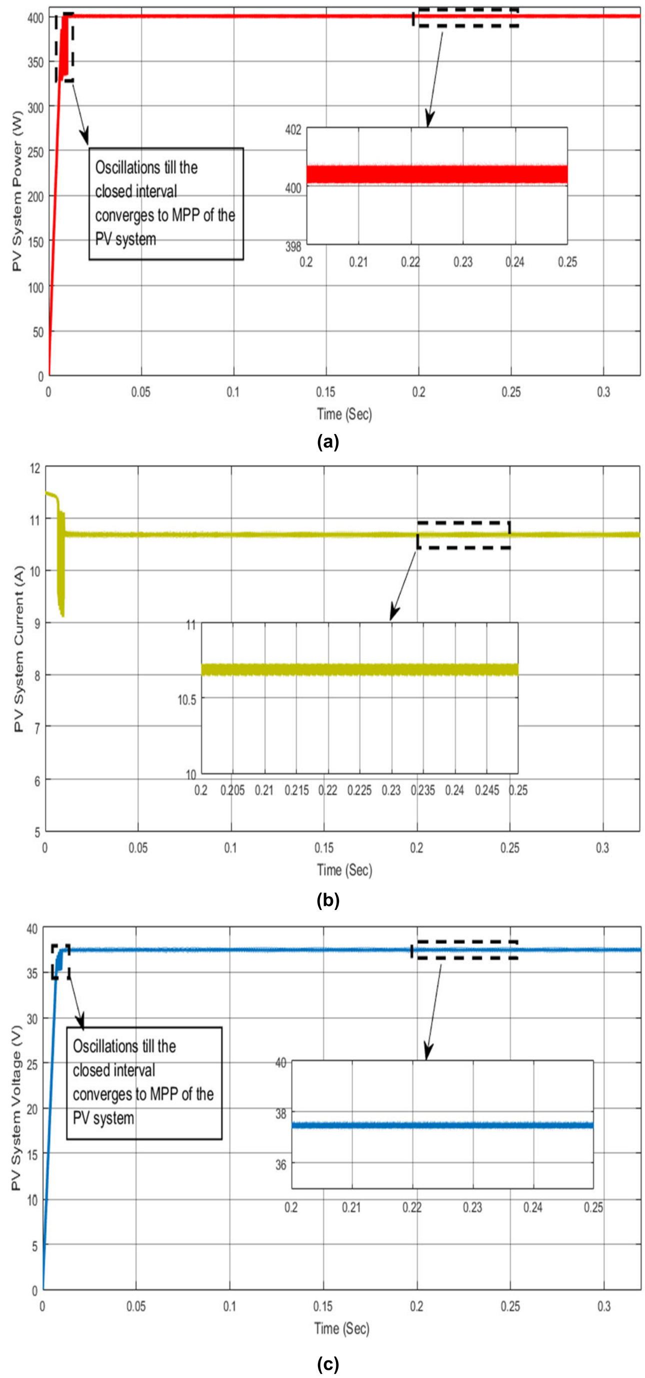

FIGURE 8. PV system parameters (a) PV_P, (b) PV_A and (c) PV_V using DC algorithm.

VI. EXPERIMENTAL RESULTS

A 400W PV module is used to test the proposed tracking scheme and the experimental model layout is shown in Fig. 12. The proposed LT-NI tracking scheme is programmed using DSP30F4011 microcontroller. PV current and voltage are initially connected to LM339 IC circuit. This decreases the magnitude of voltage and current to the voltage level (0-5) V. The obtained voltage is given to the LA25P current sensor and the 7840IC voltage monitoring circuit. Based on the discriminated panel voltage and current, the 30F4011 microcontroller generates critical PWM pulses given directly to the IGBT. The integrated 4027 and 4028 flip flop controller continuously monitors current and voltage protection.

Initially, the hybrid tracking scheme is tested under constant irradiance and temperature i.e., $G = 500W/m^2$ and $T = 30°C$ and the results are plotted in Fig. 13. Under constant parameters the tracking scheme had extracted a maximum solar power (PVP) of 180W and similarly panel voltage and current are 36V and 5.0A respectively.

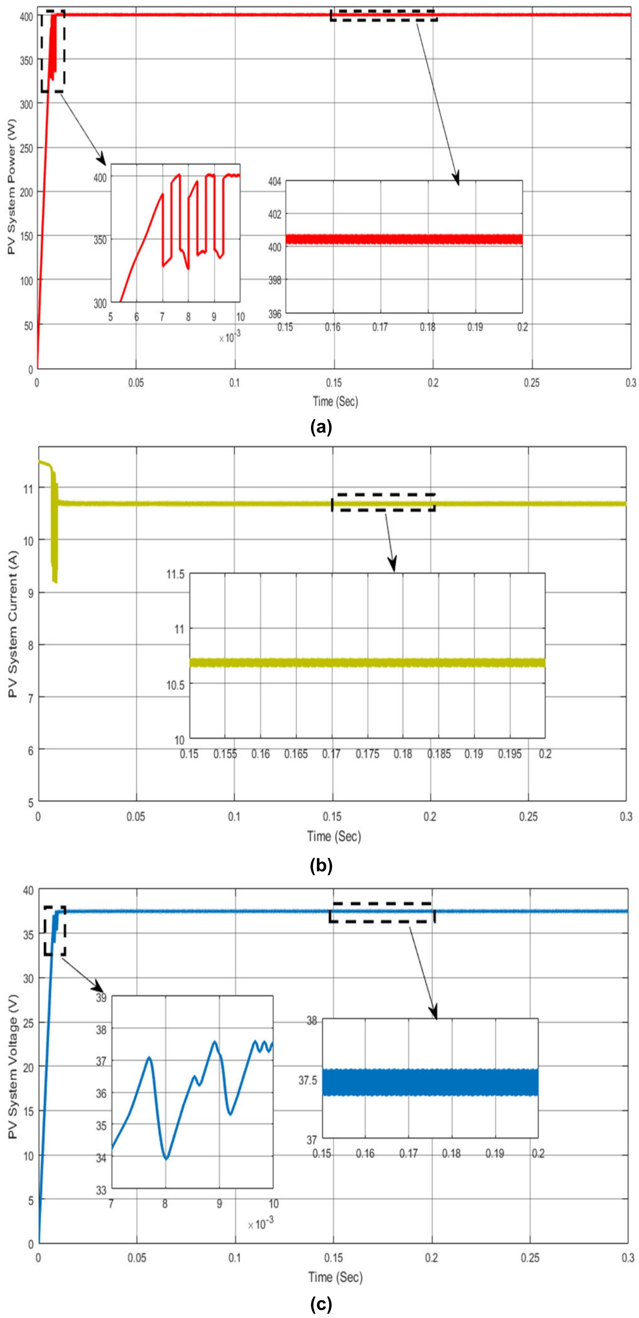

FIGURE 9. PV system parameters (a) PVP, (b) PVA and (c) PVV using Proposed MPPT.

The robustness of the proposed hybrid tracking scheme is tested by exposing to sudden increment and decrement to irradiance as depicted in Fig. 14 (a)-(b). PV system is operated with G = 950W/m^2 and after a while the irradiance is decreased to G = 775W/m^2 as shown in Fig. 14 (a). Similarly a drift in irradiance from G = 775W/m^2 to G = 950W/m^2 is depicted in Fig. 14(b). Under both the conditions the hybrid scheme has followed the dynamic path exactly within a precise time keeping temperature as constant at 30°C. The obtained parameters and time response is shown in Table 3.

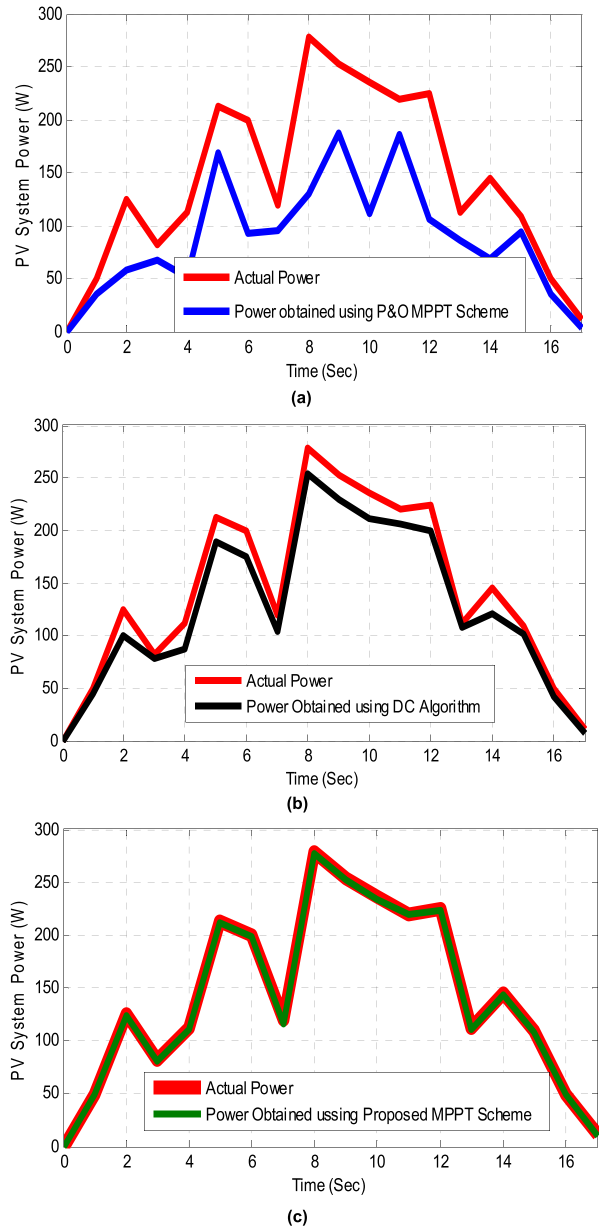

FIGURE 10. Comparison of PV system power with actual power (a) Conventional P&O, (b) DC algorithm and (c) Proposed MPPT scheme.

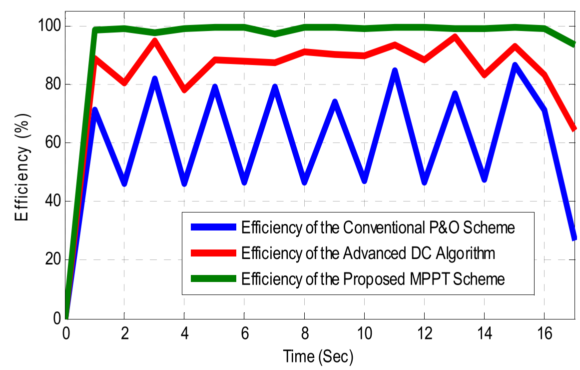

FIGURE 11. Efficiency of the three MPPT schemes.

From the Table 3, it is clearly observe that time required to track the maximum power from the PV system is in the range

TABLE 2. Performance comparison of P&O, DC and proposed MPPT scheme.

S.No.	G W/m²	T °C	Actual Power	Power (W)		
				P&O	DC	Proposed
1	138.1	27.6	49.4	35.24	44	48.8
2	327.7	28.8	124.72	57.7	100.52	123.6
3	221.8	28.7	82.24	67.4	78.04	80.4
4	298.4	29.5	112.12	52	87.92	111.2
5	551.5	30.2	212.6	169	188.8	212.2
6	523	31.3	199.72	93	175.72	198.8
7	320.6	31.6	119.32	94.76	104.52	116.4
8	729.9	32.7	278.4	130.5	254.6	277.36
9	662.8	32.3	253.12	187.2	229.32	252.44
10	623.5	33.4	235.84	111.4	212.04	234.4
11	580.9	33	219.84	186	206	218.88
12	596.8	33.7	224.72	105.5	199.52	224
13	305.4	33.2	112.16	86.6	107.96	111.2
14	391	33.9	144.96	68.8	120.76	143.92
15	298.4	32.7	108.8	94.3	101.6	108.4
16	143.1	32.3	49.68	35.36	41.48	49.2
17	37.6	31.6	10.68	2.84	6.88	10

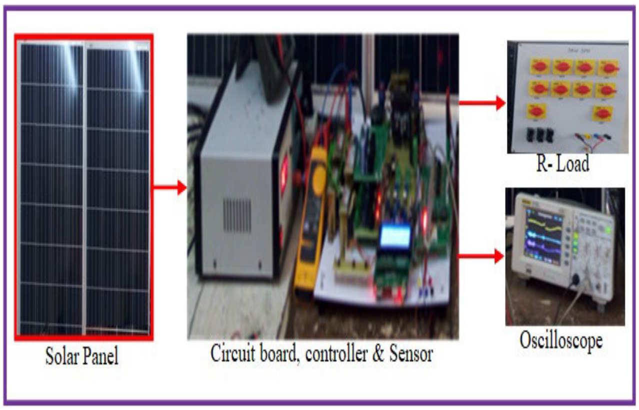

FIGURE 12. Model layout used for experimentation.

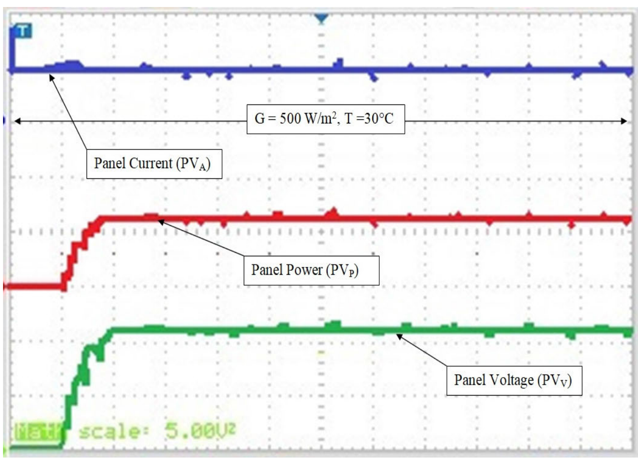

FIGURE 13. Experimental results at G = 500W/m² and T = 30°C.

of 0.04 Sec to 0.09 Sec. The proposed hybrid scheme ensures that every time system gives maximum power for continuous changes in the irradiance.

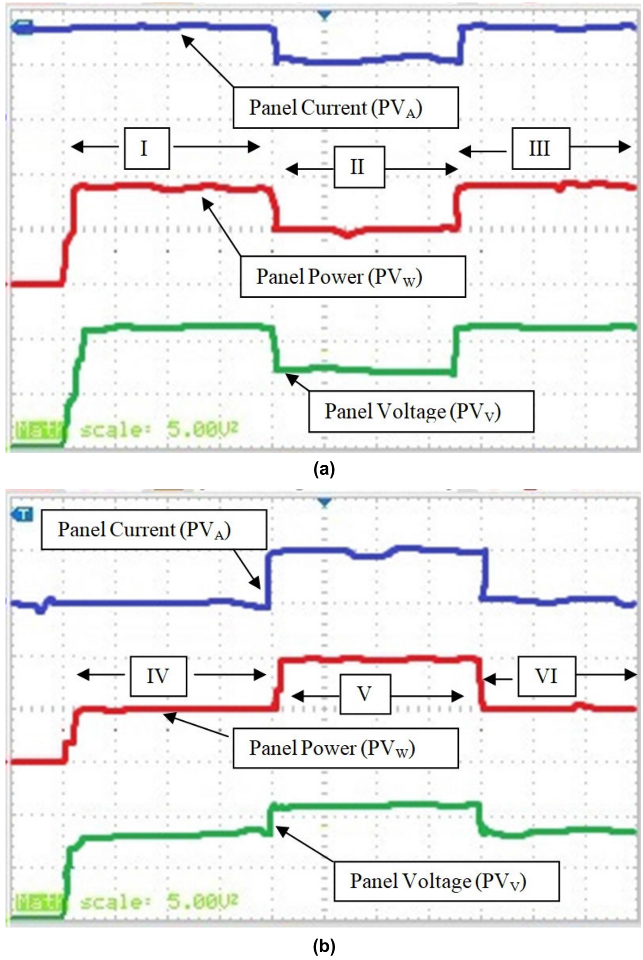

FIGURE 14. Experimental results during dynamic tracking (a) Increment in irradiance and (b) Decrement in irradiance.

TABLE 3. Extracted parameters under sudden increment and decrement in irradiance with time response.

S.No	G (W/m²)	T (°C)	PV_P (W)	PV_V (V)	PV_A (A)	Time Response (Sec)
I	950	30	365	33.1	11.0	0.04
II	775	30	278	35.1	7.9	0.07
III	950	30	368	33.2	11.0	0.068
IV	775	30	280	35.04	7.9	0.091
V	950	30	368	33.4	11.0	0.05
VI	775	30	275	35.1	7.89	0.087

VII. CONCLUSION

This paper presents a hybrid MPPT scheme based on Linear Tangents – Neville Interpolation (LT-NI), thereafter addresses the problems associated with conventional P&O and advanced DC algorithms. The DC MPPT Scheme segregates one third of the P-V characteristics and achieves MPP of the PV system based on the closed interval chosen [0, V_{OC}]. From simulation results it is observed that the MPPT scheme has achieved MPP with in a precise time.

During fast changing weather conditions, the re-initialization of the DC scheme delays the response time. At the same time, perturbation in constant regions and output oscillations involved in P&O are addressed. In view of the above constraint, a novel and simple MPPT scheme based on Linear Tangents – Neville Interpolation (LT-NI) is proposed. The LT-NI MPPT scheme is practically validated by programming in DSP 30F4011 PIC microcontroller and tested under different irradiance and temperature values. Under uniform irradiance, all the three MPPT schemes has acceptable performance, still these scheme fail to accomplish global maximum power point of the PV system during partial shaded conditions.

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