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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].

Shuo 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. Nammalvar et al [7], implemented crowded plant height optimization MPPT algorithm inspired by the biological phenomenon. Afaq 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 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]. Al-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. Jose et al [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.

Hossein 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]. Anjanee et al [15], presents a new configuration to nullify zero ripple current and maximize the efficiency using SEPIC converter for a standalone water pumping system. Krithiga S et al [16], proposed a PV fed smart home water pumping system with bidirectional DC-DC converter and battery back for uninterrupted water supply. A.Mukherjee et al [17], investigated the performance of PV fed home electric vehicle charging based on multi output converter. Xingsho et al [18], presents a literature review on MPPT schemes on implementation and provides essential information on operating principles. Mustafa et al [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.

Haider 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]. Romina 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. Moshe 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].

Nurul 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]. Ahmad 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 posses 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]. Mohamed et al [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 I.

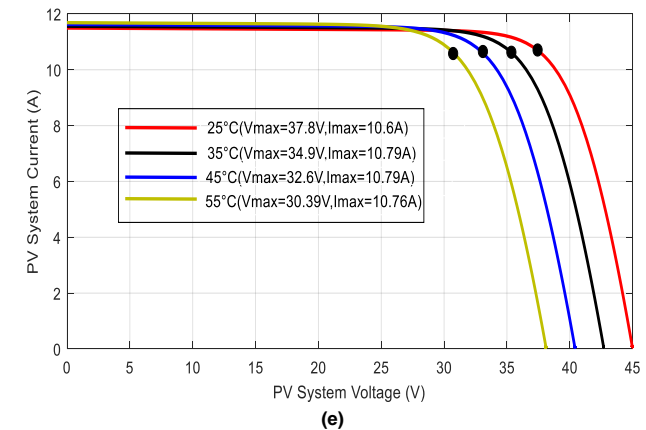
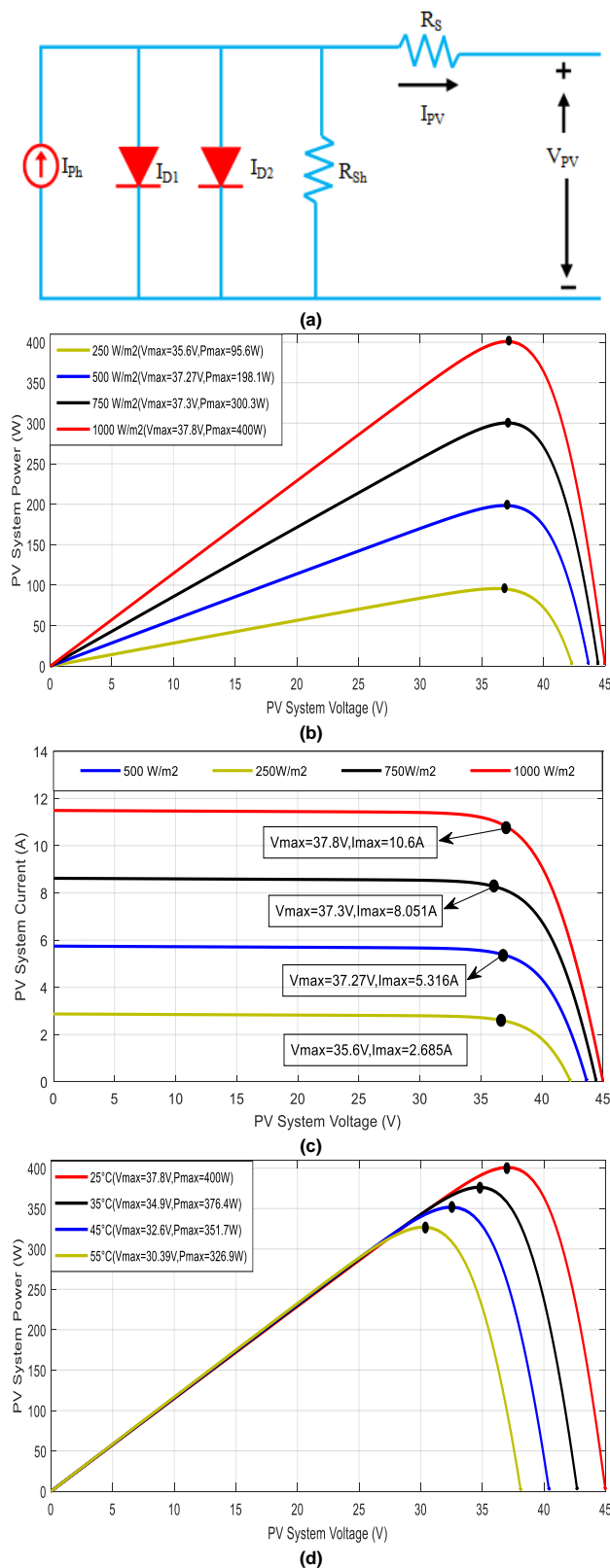


Figure 1. (a) Schematic view of double diode PV cell, P-V characteristics (b) $PV_P - PV_V$, (c) $PV_A - PV_V$, (d) $PV_P - PV_V$ and (e) $PV_A - PV_V$

TABLE I
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

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

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

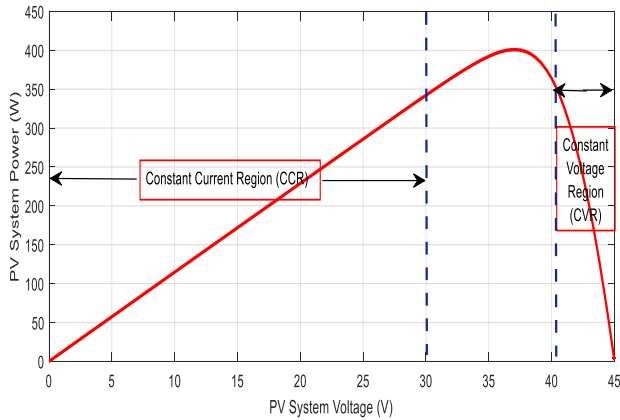


Figure 2. Constant current and voltage regions of P-V curve

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

$$V_N = A + B \quad (2)$$

Where $A = \frac{P(0.9V_{OC}) - P(0.75V_{OC})}{P'(0.7V_{OC}) - P'(0.9V_{OC})}$ and

$$B = \frac{P'(0.75V_{OC})0.75V_{OC} - P'(0.9V_{OC})0.9V_{OC}}{P'(0.7V_{OC}) - P'(0.9V_{OC})}$$

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.

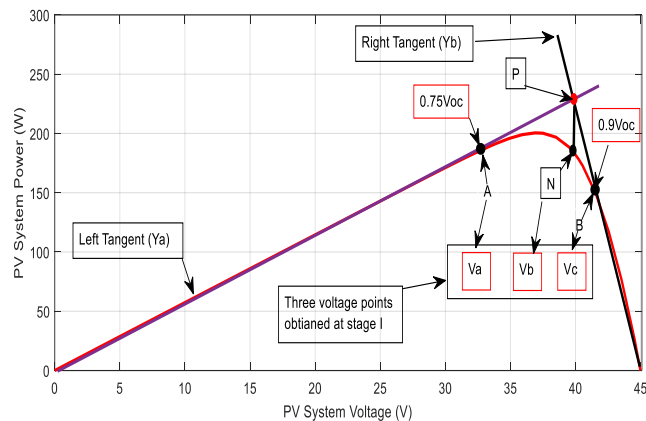


Figure 3. P-V characteristics representing Proposed MPPT scheme

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

$$P(V_{a,b}) = \frac{(V_b - V)P_a(V_a) + (V - V_a)P_b(V_b)}{V_b - V_a} \quad (3)$$

$$P(V_{b,c}) = \frac{(V_b - V)P_b(V_b) + (V - V_b)P_c(V_c)}{V_c - V_b} \quad (4)$$

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

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

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.

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

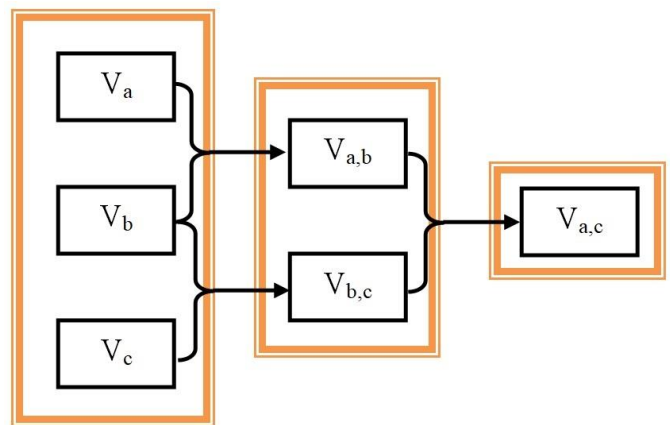


Figure 4. Intermediate steps in Neville Interpolation

Therefore Eq. (6) can be simplified as

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

where $\alpha = \frac{P_a(V_a)}{(V_a - V_b)(V_a - V_c)}$,

$$\beta = \frac{P_b(V_b)}{(V_b - V_a)(V_b - V_c)} \text{ and } \theta = \frac{P_c(V_c)}{(V_c - V_a)(V_c - V_b)}$$

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.

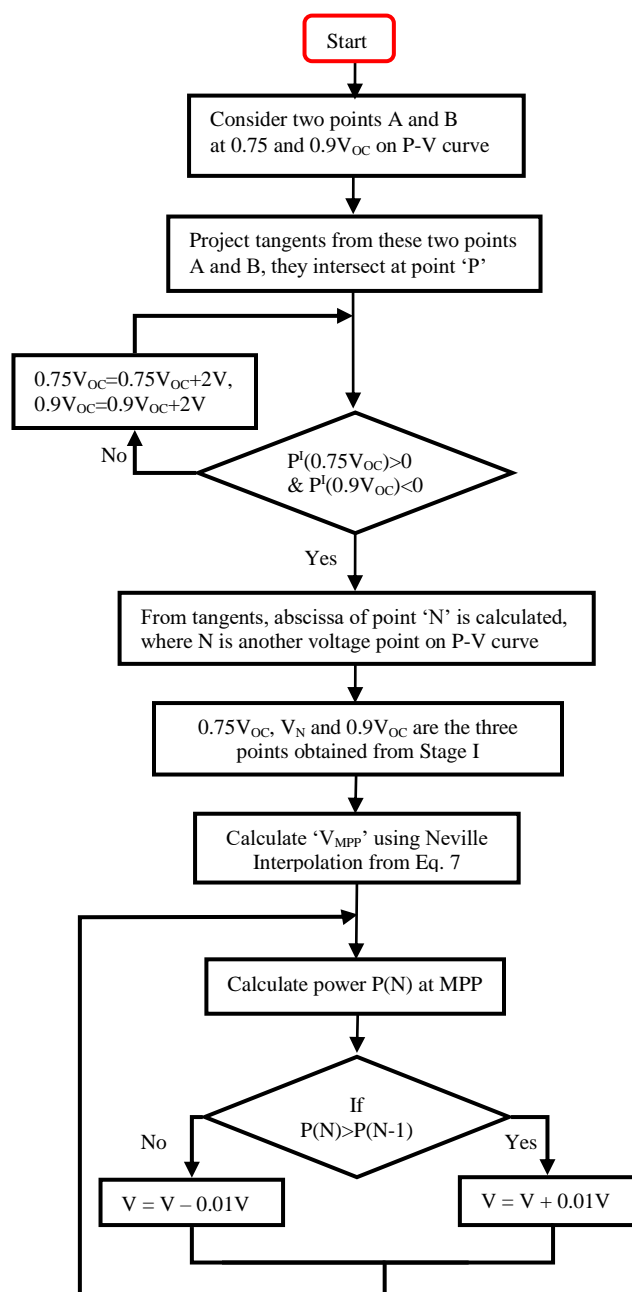


Figure 5. Flowchart of the Recommended MPPT scheme

IV. STEPS TO IMPLEMENT PROPOSED ALGORITHM

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.

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 $25^\circ C$. 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. 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.

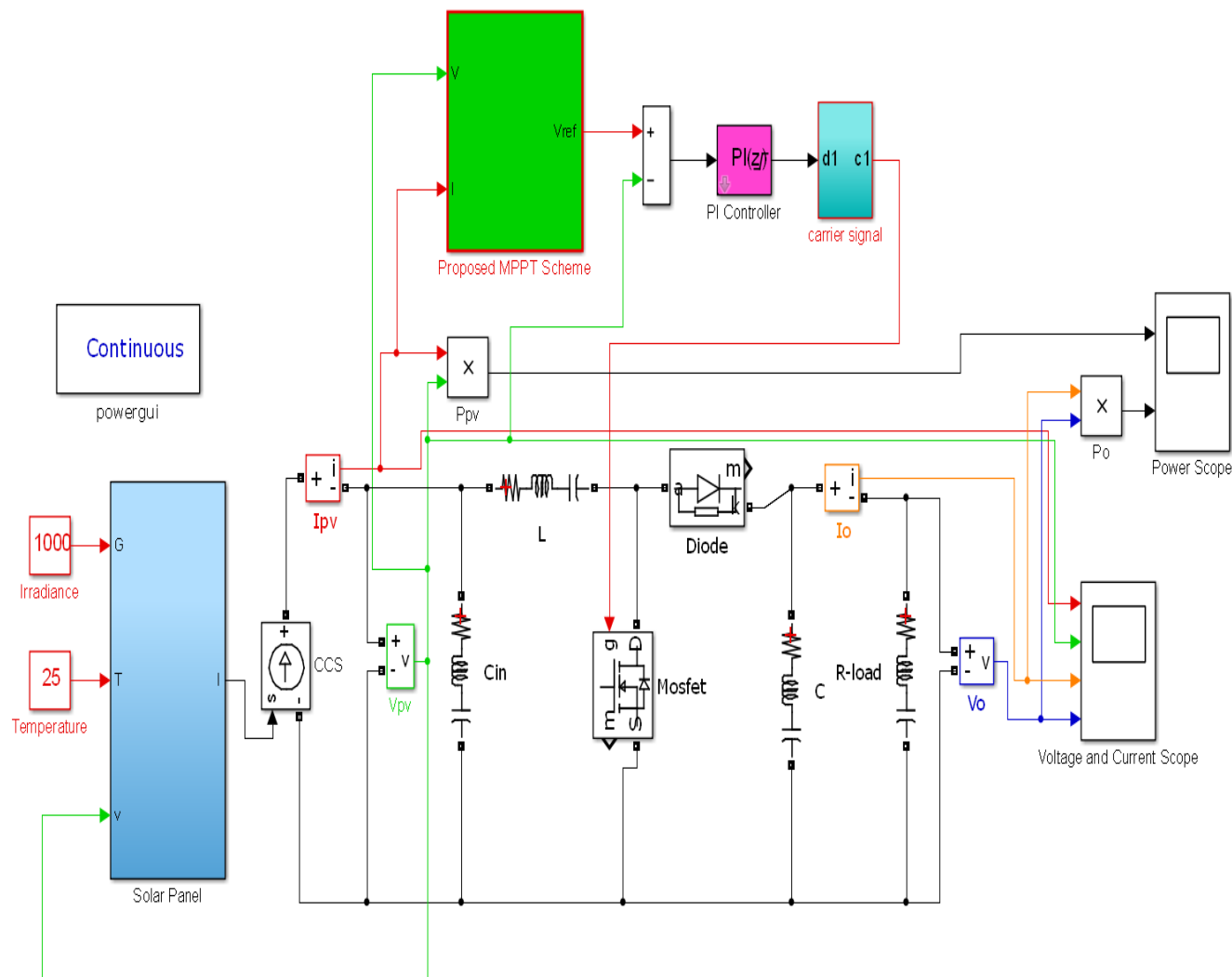


Figure 6. Simulation diagram of the PV system using proposed MPPT Scheme

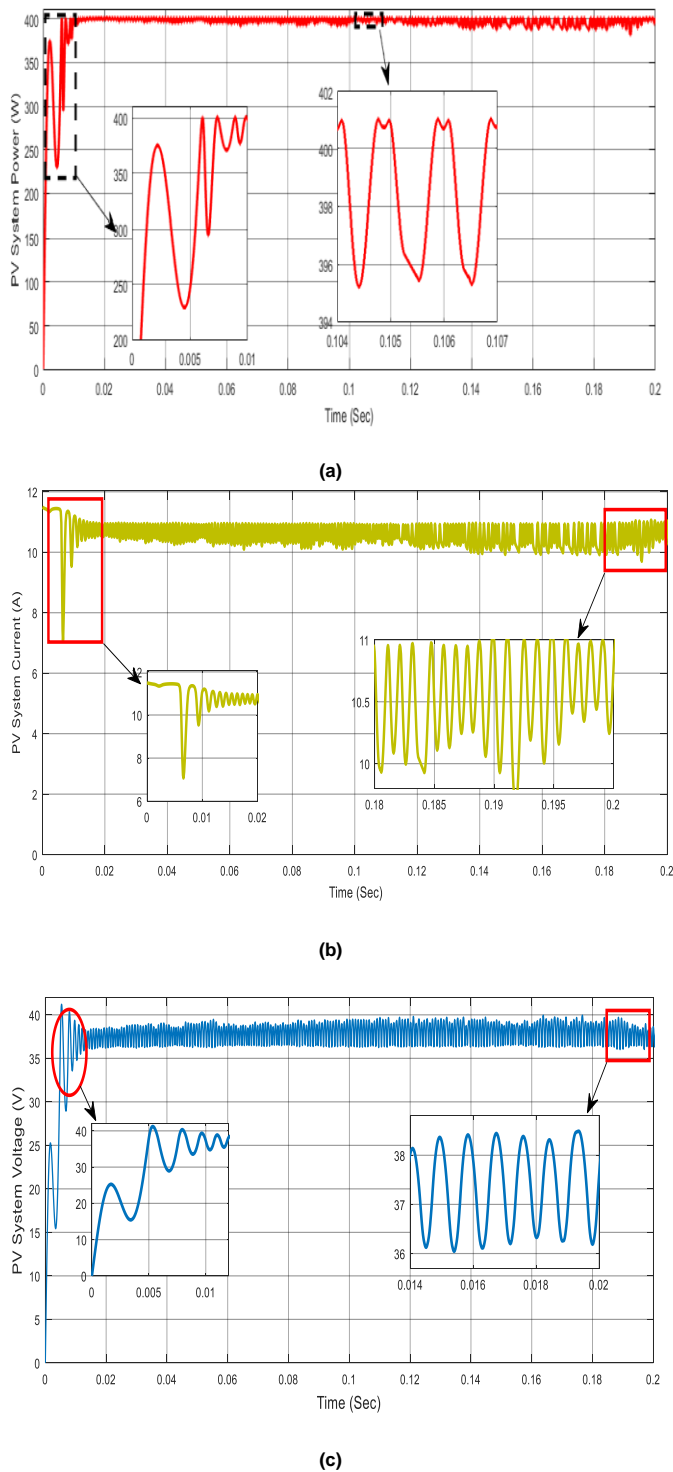
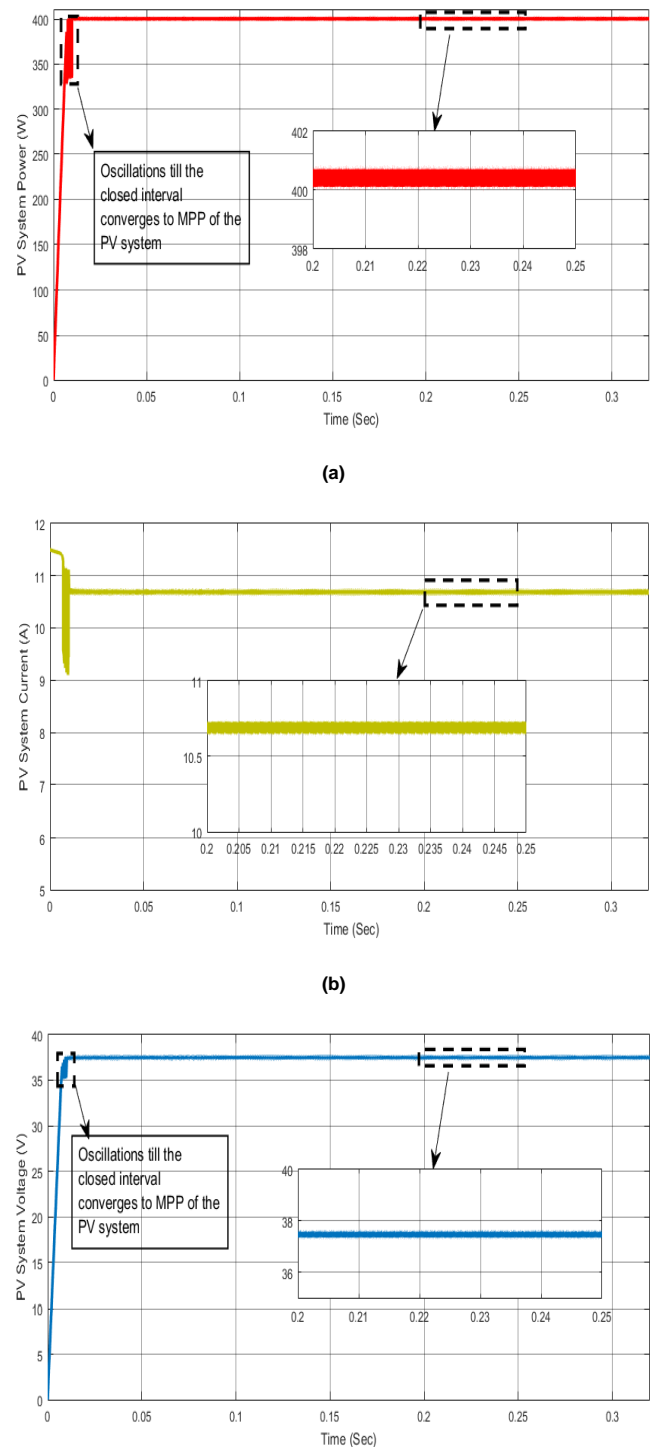


Figure 7. PV system parameters (a) PV_P , (b) PV_A and (c) PV_V using traditional P&O scheme

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

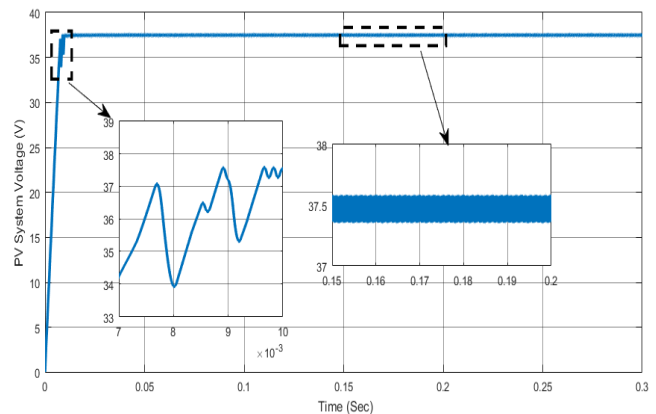
such that exact MPP with respect to irradiance and temperature can be obtained. At the same time, for every updated interval the PV system has to be reinitialized from the first. During fast change in weather conditions it may not be possible to update the closed interval quickly therefore fails to track 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).



(c)

Figure 8. PV system parameters (a) P_V , (b) P_V and (c) P_V using DC algorithm

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

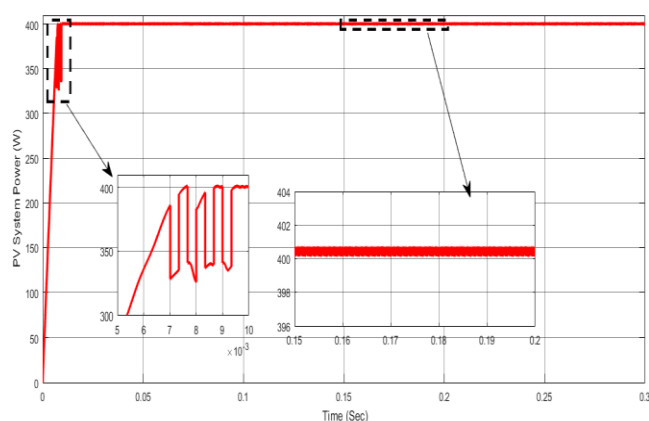


(c)

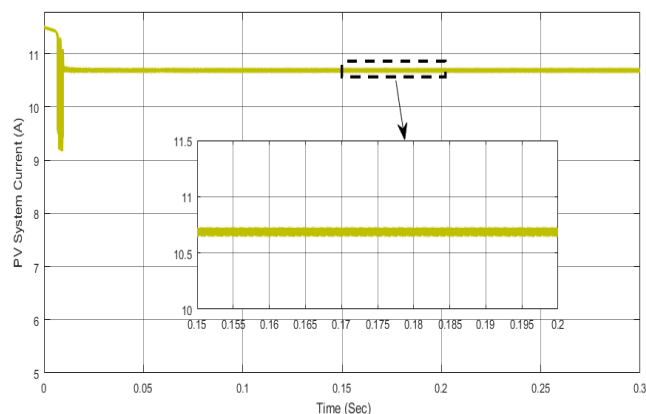
Figure 9. PV system parameters (a) P_V , (b) P_V and (c) P_V using Proposed MPPT

B. TESTING UNDER PRACTICAL CONDITIONS

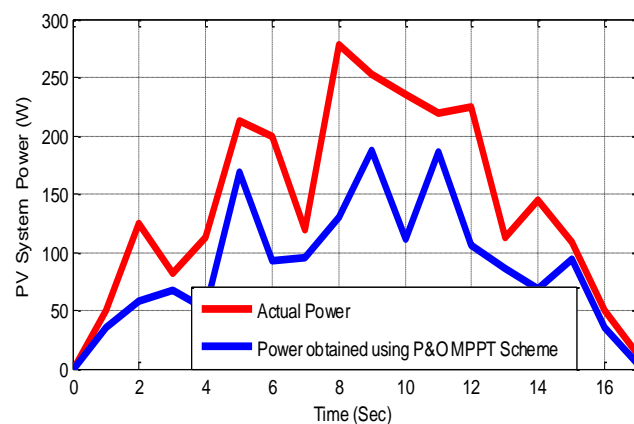
The working efficiency of any MPPT scheme cannot be vindicated under STC. In view of the above statement, the three schemes are simulated by replicating real environmental conditions. Using signal builder graph the tabulated numerical values of irradiance and temperature are given as input to the PV 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.



(a)



(b)



(a)

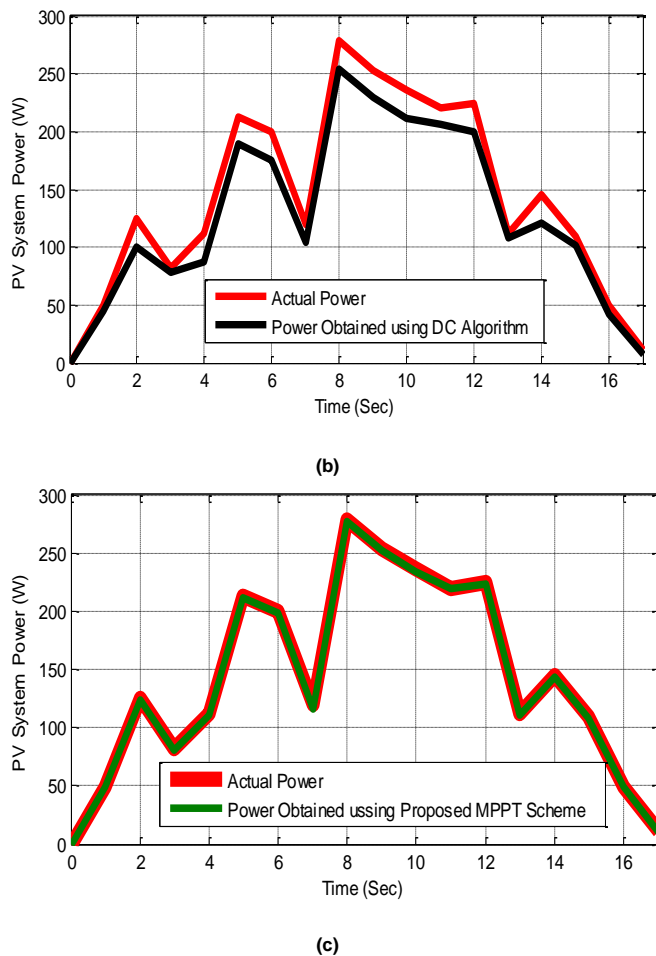


Figure 10. Comparison of PV system power with actual power (a) Conventional P&O, (b) DC algorithm and (c) Proposed MPPT scheme

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 II gives a numerical comparison of the three MPPT schemes.

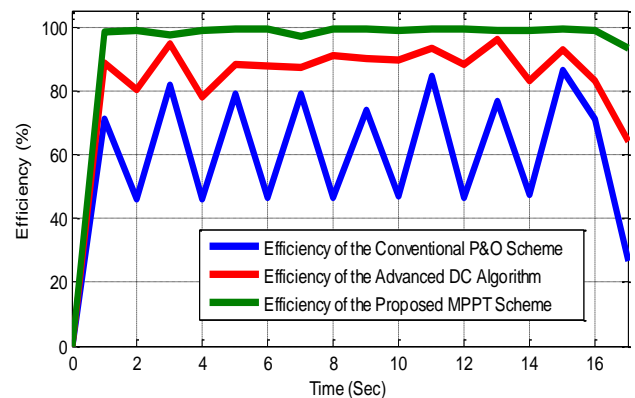


Figure 11. Efficiency of the three MPPT schemes

TABLE II
PERFORMANCE COMPARISON OF P&O, DC AND PROPOSED MPPT SCHEME

S.No.	G W/m ²	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

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.

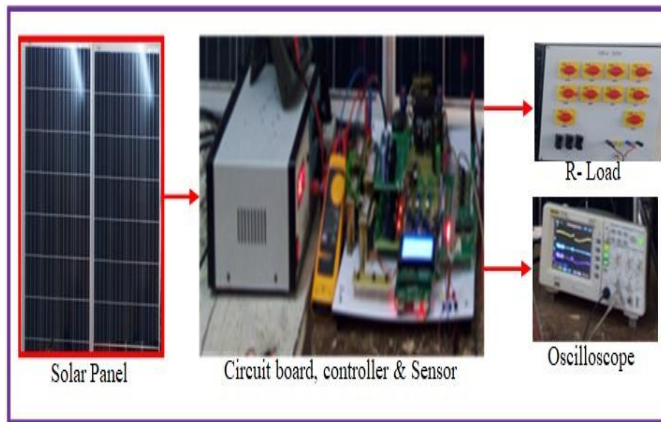


Figure 12. Model layout used for experimentation

Initially, the hybrid tracking scheme is tested under constant irradiance and temperature i.e., $G = 500\text{W/m}^2$ and $T = 30^\circ\text{C}$ 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.

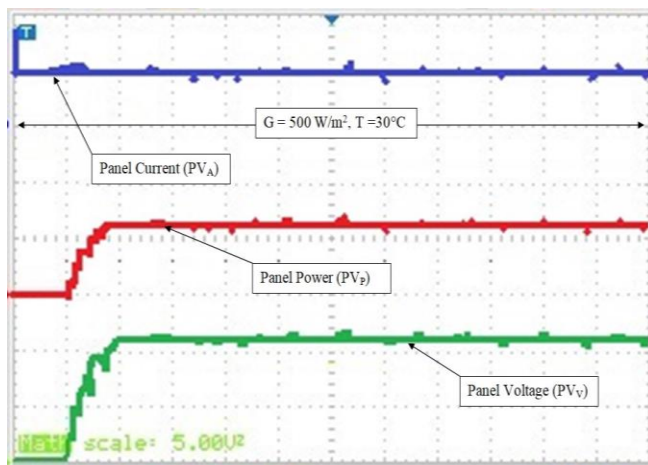
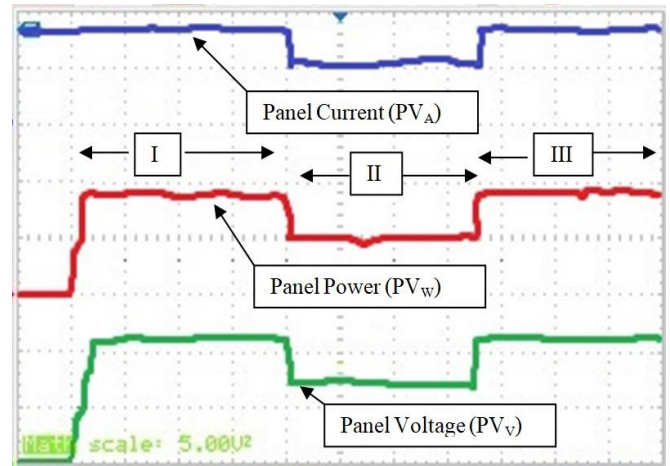
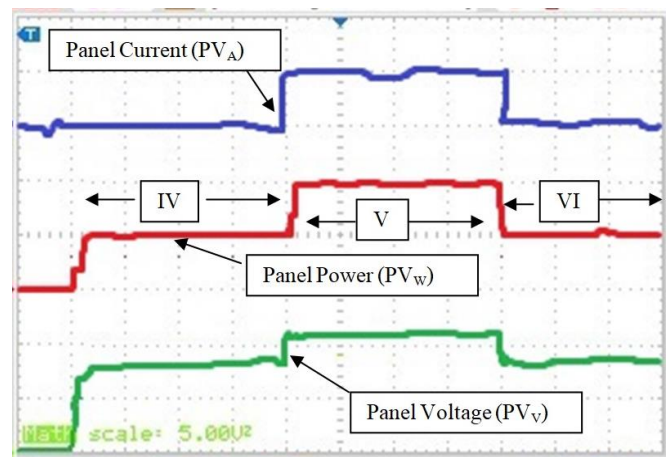


Figure 13. Experimental results at $G = 500\text{W/m}^2$ and $T = 30^\circ\text{C}$.

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 $G = 950\text{W/m}^2$ and after a while the irradiance is decreased to $G = 775\text{W/m}^2$ as shown in Fig. 14 (a). Similarly a drift in irradiance from $G = 775\text{W/m}^2$ to $G = 950\text{W/m}^2$ is depicted in Fig. 14(b). Under both the conditions the hybrid scheme has followed the dynamic path exactly with in a precise time keeping temperature as constant at 30°C . The obtained parameters and time response is shown in Table III.



(a)



(b)

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

TABLE III
EXTRACTED PARAMETERS UNDER SUDDEN INCREMENT AND DECREMENT IN IRRADIANCE WITH TIME RESPONSE

S.No	G (W/m ²)	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

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

VI. 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.

REFERENCES

- [1] Qiang Mei, Mingwei Shan, Liying Liu, Josep M. Guerrero. A novel improved variable step-size Incremental-Resistance MPPT method for PV systems. *IEEE Transactions on Industrial Electronics*, vol. 58(6), pp. 2427-2434, 2011.
- [2] Venkata Reddy Kota, Muralidhar Nayak Bhukya. "A Novel Linear Tangents based P&O Scheme for MPPT of a PV System". *Renewable and Sustainable energy Reviews*, Vol.71, pp.257-267, 2017.
- [3] A. A. Nabulsiet.al., Efficiency optimization of a dsp-based standalone pv system using fuzzy logic and dual-mppt control. *IEEE Trans. Ind. Informat.*, vol. 8(3), pp. 573-584, 2012.
- [4] Sabir Messalti, AbdelghaniHarrag and Abdel Hamid Loukriz. A new variable step size neural networks MPPT controllers; Review, Simulation and Hardware implementation, *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 221-233, 2017.
- [5] Muralidhar Nayak Bhukya, Venkata Reddy Kota. "A New MPPT Scheme based on Trifurcation of PV Characteristic for Photovoltaic Power Generation". *International Journal of Pure and Applied Mathematics*, Vol.114, No.10, pp.439-447, 2017.
- [6] Shuo Li, Abhishek Roy, Benton H Calhoun. "A Piezoelectric Energy Harvesting System with Parallel – SSHI Rectifier and Integrated Maximum Power Point Tracking". *IEEE Solid State Circuits Letters*, Vol. 2, pp. 301-304, 2019.
- [7] Nammalrar Pachaiavannan, Ramkumar Subburam, Umadevi Ramkumar, Padmanathan Kasinathan. "Crowded plant height optimization algorithm tunned maximum power point tracking for grid integrated solar power conditioning system". *IET Renewable Power Generation*, Vol. 13, pp. 2137-47, 2019.
- [8] Afaq Hussain, Hadeed Ahmed Sher, Ali Faisal Murtaza, Kamal Al Haddal. "Improved Restricted Control Set Model Predictive Control (iRCS-MPC) based Maximum Power Point Tracking of Photovoltaic Module". *IEEE Access*, Vol. 7, pp. 149422-432, 2019.
- [9] Jingxin et al. "A Maximum Output Power Point Tracking Controlled Dual Active Bridge Converter for Photovoltaic Energy Integration into MVDC Grids". *IEEE Transaction on Energy Conversion*, Vol. 34, pp. 170-180, 2019.
- [10] Bhukya, Muralidhar Nayak, Kota, Venkata Reddy. "A novel P&OT-Neville's interpolation MPPT scheme for maximum PV system energy extraction." *International Journal of Renewable Energy Development*, vol. 7(3), pp. 251-260, 2018.
- [11] Mohammad Al-Soeidat, Dylan Dah-Chuan Lu, Jiangno Zhu. "An Analog BJT-Tuned Maximum Power Point Tracking Technique for PV system" *IEEE Transactions on Circuits & System II: Express Briefs*, Vol. 66, pp. 637-641, 2018.
- [12] Jose L Diaz-Barnabe, Arturo Morales-Aceredo. "Experimental Study of the Equivalence of the Adaptive Incremental Conductance (AIC) and the Adaptive Perturb & Observe (APO) Algorithms for PV Systems Maximum Power Tracking". *IEEE Latin America Transaction*, Vol. 17, pp. 1237-43, 2019.
- [13] Hossein Dehghani-Tafti, Christopher D. Townsend, Georgios Konstantinou, Josep Pou. "A Multi Mode Flexible Power Point Tracking Algorithm for Photovoltaic Power Plants". *IEEE Transaction on Power Electronics*, Vol. 34, pp. 5038-42, 2018.
- [14] Muralidhar Nayak Bhukya, Venkata Reddy Kota, Depuru Shobha Rani. "A Simple, Efficient and Novel Standalone Photovoltaic Inverter Configuration with Reduced Harmonic Distortion". *IEEE Access*, DOI: 10.1109/ACC ESS.2019.2902979, February, 2019.
- [15] Anjaneer Kumar Mishra, Bhim Singh. "High Gain Single Ended Primary Inductor Converter with Ripple Free Input Current for Solar Powered Water Pumping System Utilizing Cost Effective maximum Power Point Tracking Technique". *IEEE Transaction on Industry Application*, Vol. 55, pp. 6332-6343, 2019.
- [16] Krithiga S., Partha Sarathi Subudhi., "PV fed Water Pumping System in a Smart Home" *International Journal of Engineering & Technology*. Vol.7, pp. 1565-1569, 2018.
- [17] Arindam Mukherjee, Krithiga S., Partha Sarathi Subudhi" Investigation of a PV Fed Improved Smart Home EV Battery Charging System using Multi Output Hybrid Converter". *International journal of renewable energy research* Vol.9, pp. 692-703, 2019.
- [18] Kingshuo Li, Qi wang, Huiqing Wen, Weidong Xiao. "Comprehensive Studies on Operating Principles for Maximum Power Point Tracking in Photovoltaic Systems". *IEEE Access*, vol. 7, pp. 121407-420, 2019.
- [19] Mustafa ErginSahin. "A Photovoltaic Powered Electrolysis Converter System with Maximum Power Point Tracking Control". *International Journal of Hydrogen Energy*, vol. 45, pp. 9293-9304, 2020.
- [20] Haider A. Mohamed- Kazim, Ikhlas Abdel-Qader, Ahmad M. Harh. "Efficient maximum power point tracking based on reweighted zero attracting variable step size for grid interfaced photovoltaic system." *Computers & Electrical Engineering*, vol. 85, 2020.
- [21] Muralidhar Nayak Bhukya, Venkata Reddy Kota. "A quick and effective MPPT scheme for solar power generation during dynamic weather and partial shaded conditions". *Engineering Science and Technology*, an *International Journal*, vol. 22, pp. 869-884, 2019.
- [22] Romina Rodriguez, Jing Guo, Matthias Preindi, James S. Cotton, Ali Emadi. "High frequency injection maximum power point tracing for thermoelectric generators". *Energy Conversion & Management*, vol. 198, 2019.
- [23] Moshe Sitbon, Simon Lineykin, Shmuel Schacham, TeuvoSunito, AlonKuperman. "Online Dynamic Conductance Estimation based Maximum Power Point Tracking of Photovoltaic Generation". *Energy Conversion & Management*, vol. 165, pp. 687-696, 2018.
- [24] Venkata Reddy Kota, Muralidhar Nayak Bhukya. "A Novel Global MPP Tracking Scheme based on Shading Pattern Identification using Artificial Neural Networks for Photovoltaic (PV) Power Generation during Partial Shaded Condition". *IET Renewable Power Generation*, DOI: 10.1049/iet-rpg.2018.5142, April 2019.
- [25] NurulAfiahZainel, Ahmad RazlanYusoff, AjismanApen. "Integrated Cooling System and Maximum Power Point Tracking of Fuzzy Logic Controller for Improving Photovoltaic Performance". *Measurement*, pp. 100-108, 2019.
- [26] Venkata Reddy Kota, Muralidhar Nayak Bhukya. "A Simple and Efficient MPPT Scheme for PV Module using 2-Dimensional Lookup Table". pp. 1-7, *IEEE Power and Energy Conference at Illinois (PECI)*, DOI:10.1109/PECI.2016.7459226, 2016.
- [27] Ahmad Ghamrawi, Jean Paul Gaubert, Driss Mehdi. "A new dual mode maximum power point tracking algorithm based on the perturb & observe algorithm used on solar energy system". *Solar Energy*, vol. 174, pp. 508-514, 2018.

- [28] Mostafa R. Mostafa, Naggar H. Saad, Ahmed A. El-Sattar. "Tracking the maximum power point of PV array by sliding mode control method." *Ain Sham Engineering Journal*, vol. 11, pp. 119-131, 2020.
- [29] Venkata Reddy Kota, Bapayya Naidu Kommula, Muralidhar Nayak Bhukya. "A novel torque ripple minimization scheme for solar powered BLDC motor". *TENCON 2017 - 2017 IEEE Region 10 Conference*, DOI: 10.1109/TENCON.2017.8228140, Pages: 1743 – 1748, 2017.
- [30] Mohamed Lasheen, Mazen Abdel-Salam. "Maximum Power Point Tracking using Hill Climbing and ANFIS Techniques for PV Applications: A Review and a Novel Hybrid Approach." *Energy Conversion & Management*, vol. 171, pp. 1002-1019, 2018.
- [31] Muralidhar Nayak Bhukya, Venkata Reddy Kota. "DCA-TR-based MPP tracking scheme for photovoltaic power enhancement under dynamic weather conditions". *Electrical Engineering*, vol.100, pp. 2383-96, 2018.



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