Improved dP P&O MPPT for Photovoltaic System Using Solar Irradiation Modeling

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Abstract – Maximum power point (MPP) tracking (MPPT) techniques are widely used in photovoltaic (PV) systems to build PV array generate peak power which depends on solar irradiation. In this paper, an improved dP P&O MPPT algorithm is developed based on solar irradiation modeling. This algorithm aims to overcome the confusion in the direction of tracking during rapidly changing solar irradiance using half sine wave modeling of solar irradiation. The proposed algorithm gives fast tracking compared to existing dP P&O method. Operation point of the photovoltaic system is controlled via a boost type DC–DC converter. The complete system is modeled and simulated in the MATLAB using SIMULINK. The proposed MPPT and existing dP P&O MPPT algorithms are simulated and the performance comparison is made. Simulation result shows that the proposed algorithm is faster than the dP P&O algorithm.

Key words: Boost converter, Energy conversion, Maximum power point tracker, Photovoltaic systems, Solar energy.

1. Introduction

Maximum power point tracking is one of the major concerns in PV systems and plays a vital role in utilization of PV systems for practical applications. Each PV cell has a special point named maximum power point (MPP) on its operational curve (i.e. current-voltage or power-voltage curve) in which it can produce maximum possible power. These operational curves change nonlinearly with changes in irradiance and temperature of environment. So, the nonlinear dependency of MPP to environment parameters, motivate the development of various maximum power point tracking algorithms. These algorithms differ in terms of the amount of energy extracted from the PV panel (Tracking factor), dynamic response, complexity, adaptation to environment changes and cost of implementation [1]-[3]. In order to improve the efficiency of the PV system, many MPPT techniques like Constant voltage control, Perturb & Observe, Incremental Conductance and dP P&O method have been developed [4]-[8].

Among these MPPT methods, the Perturb & Observe (P&O) method is most widely used. P&O is also called as hill climbing method because it assures the rise of the curve until MPP and the fall after that point. This method is easy to implement but can cause oscillations in power output and can sometimes show tracking failures in rapid environmental changes [4] i.e. locating operating point away from MPP when there is a sudden change in voltage characteristics. The main problem with the conventional P&O algorithm is slow response in reaching the maximum power point. To overcome this problem, an improved dP P&O MPPT algorithm is developed. The dP-P&O method can overcomes particular draw back in some extent but both of this algorithms show lesser efficiency in lower irradiation levels.

The output power of a PV panel is determined by the solar irradiation and the temperature of the panel. At a certain atmospheric condition, the output power of a PV panel depends on the terminal voltage of the system. To maximize the power output, an efficient low-cost DC/DC converter with appropriate MPPT algorithm is commonly employed to control the terminal voltage of the PV system in various solar radiation conditions. The different DC/DC converter topologies used with PV systems are Buck converter [9], Boost converter [10], [11], Cuk converter [12], [13], Sepic converter [14], [15], Buck Boost converter [16], [17] and so on. In this paper, an improved dP P&O MPPT method with DC-DC boost converter is proposed.

This paper is organized as follows: dP P&O algorithm is reviewed in Section 2. Proposed MPPT algorithm is presented in Section 3. Section 4 presents the simulation results and analysis. Section 5 gives the conclusion.

2. Basics of dP P&O MPPT Method

The limitation of the P&O algorithm under rapidly varying irradiation is addressed and a simple improvement is proposed called the dP−P&O method which was developed by Dezso Sera et al. [18], [19]. It is achieved by the additional measurement of power in the middle of the MPPT sampling period (T) without any perturbation. As shown in Fig. 1 the samples P_k and P_{k+1} are measured at the sampling interval k and k+1. The unperturbed power P_x is chosen in-between the measured samples P_k and P_{k+1}. The change of power between P_x and P_{k+1} reflects the variation in solar irradiation due to the change of environmental conditions. The difference in power of the successive samples is calculated as dP which represents change in power caused by perturbation of MPPT.

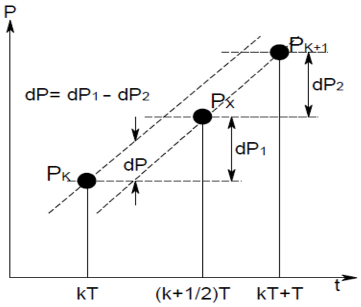


Fig. 1. Measurement of the power between two MPPT sampling instances

Assuming the rate of change in the irradiation is constant over the sampling interval of the MPPT, the dP can be calculated by,

$$dP = dP_1 - dP_2 = (P_X - P_K) - (P_{K+1} - P_X) = 2P_X - P_{K+1} - P_K \quad (1)$$

Determining the dP allows to track in the correct direction during irradiance changes. The output of the dP reflects the changes due to the perturbation of MPPT. The dP P&O algorithm has the ability to track the MPP in the right direction under rapidly changing irradiation unlike the conventional P&O algorithm. The dP P&O method gives higher efficiency under rapid variation in solar irradiation but it less efficient under low irradiation levels and tracking of MPP is time consuming. Hence, improved dP P&O MPPT method is proposed in this work.

3. The Proposed Method

The block diagram of the proposed PV system which consists of PV model, a boost converter, solar irradiation modeling based improved dP P&O MPPT method and PWM generator is depicted in Fig. 2. Proposed MPPT method determines the controller command for any time according to PV output variables and boost converter regulates the voltage and current of PV system. So, output power and PV power level are controlled to obtain maximum power extraction from PV system.

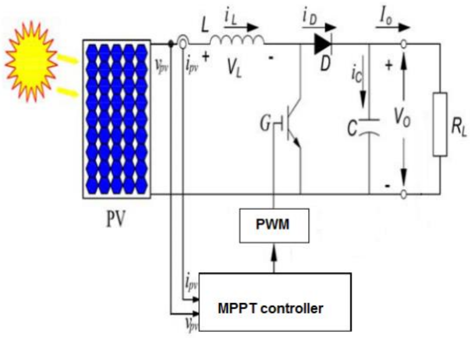


Fig. 2. Block diagram of the proposed PV system

It is known that solar irradiation is a reliable source of renewable energy and using proper modeling the maximum power can be derived from solar radiation. Although many efficient and fast response MPPT algorithms have been developed, few limitations are still not attended by these algorithms. The major challenges in MPP tracking are partial shadowing, local MPP tracking instead of global MPP and precision in tracking MPP in rapidly changing solar irradiation.

The existing dP P&O MPPT method is modified using Half sine wave model for predicting the change in solar radiation levels. The proposed algorithm aims to overcome the confusion in the direction of tracking during rapidly changing solar irradiance using solar irradiation modeling. The existing dP P&O MPPT method overcomes this problem, but it takes much time for tracking. The proposed MPPT method tracks maximum power point with less number of iterations compared to existing technique. This strategy leads to faster and better tracking when the irradiance is changing rapidly and results lower oscillations around the MPP in steady-state conditions.

3.1 Solar irradiation modeling

It is known that sun is a singular source of renewable energy which emits energy as electromagnetic radiation at an extremely large and relatively constant rate, 24 hours per day, 365 days of the year. This energy is more than sufficient to meet current energy demand of the world. Solar irradiance is the rate at which solar energy reaches a unit area at the earth and solar radiation is simply the integration or summation of solar irradiance over a time period.

Solar irradiance is an instantaneous measure of rate and can vary over time. It is measured in watts per square meter (W/m^2). The maximum solar irradiance value is used to determine the peak rate of energy input into the system hence the designer needs to know the variation of solar irradiance over time in order to optimize the MPPT design.

The intensity of the radiation leaving the sun is relatively constant. The total amount of energy accumulated over a year is given as an average solar radiation with respect to the latitude which is shown in Fig. 3 [20]. The solar irradiation model can be classified into two types one is Simple Half Sine Model and another one is Hottel's Clear Day Model.

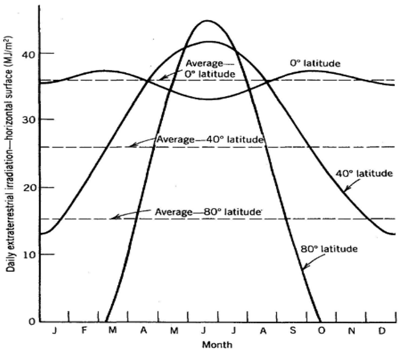


Fig. 3. Seasonal variation of the daily extra-terrestrial solar irradiation incident on a horizontal surface

A simple analytical model of clear day solar irradiance is all that is needed to predict phenomena concerned to solar energy system design. One such model, used in the basic solar energy system model is half sine solar irradiance model. The only input required is the times of sunrise, sunset, and the peak, noontime solar irradiance level.

$$I = I_{noon}\left[\frac{180(t - t_{sunrise})}{(t_{sunset} - t_{sunrise})}\right] \qquad (2)$$

Where, t is the time in hours (24-hour clock), I_{noon} is noon time solar irradiation level, I is solar irradiation level and the sine term is in degrees.

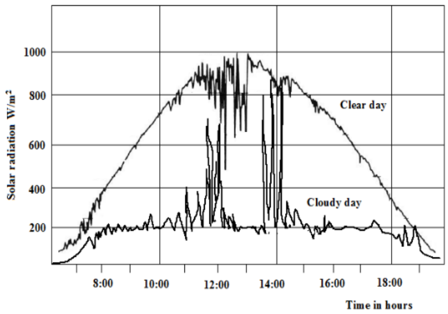


Fig. 4. Solar radiation forecasting based on cloudiness

Forecasting of global solar radiation is limited to twelve hours per day approximately. Moreover, solar radiance forecasting is done based on cloudiness. Fig. 4 shows the solar radiation forecasting for combined clear day and cloudy day. The variation is similar to half sine wave modeling and the use of half sine wave model for representing the variation of solar radiation seems to be a promising option for improving the performance of maximum power point tracking.

3.2 Improved dP P&O MPPT method

The dP P&O method overcomes the drawback of tracking in wrong direction by taking additional sample of power in the middle of the MPPT sampling without any perturbation. This process consumes much time to track the maximum power point. In the Improved dP P&O MPPT method, there is no need to take additional samples to predict the direction of tracking. Using half sine wave solar radiation modeling, the tracking direction is predicted without using the additional samples. Hence, it is faster than the dP P&O method.

The two major steps of the proposed method are computing difference in power between successive samples and MPP tracking. In the half sine wave solar radiation model, the total period of twelve hours is split into three time intervals T_1, T_2 and T_3 based on the variation in solar radiation as increasing, peak and decreasing phases. Normally, first phase is the start of the day when the solar radiation starts increasing towards the peak. After that it keeps decreasing in the third phase. During T_2, solar radiation is approximately maximum. Depends on solar radiation forecasting, exact time intervals are assigned for this three phases. For example in a clear day, T_1 may be from morning 6 AM to 11 AM, T_2 is from 11 AM to 2 PM and T_3 is 2 PM to 6 PM as shown in Fig 5.

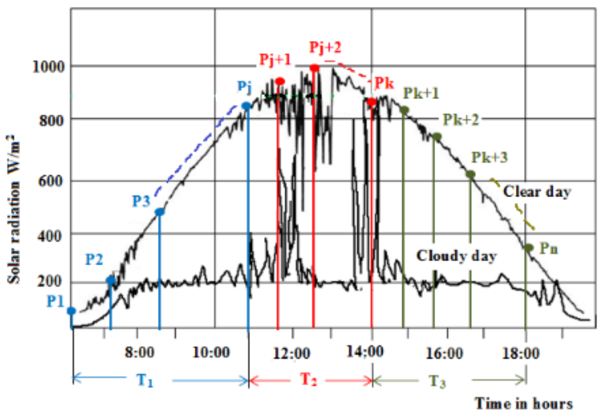


Fig. 5. One day model for solar radiation forecasting based on cloudiness

Assume that 'n' power samples, say Pi where i = 1, 2, 3...……. n are taken during the total time period T per day, whereas T is the sum of T_1, T_2 and T_3. The number of samples taken during each phase is in proportion of 40%, 20% and 40% of 'n'. The variation in solar radiation is modeled as follows:

Based on the half sine wave modeling, the variation in successive power samples measured in each phases is given in table 1.

Table 1. Rate of power samples measured / phase

T_1:	**$P_1 < P_2 < P_3 < \ldots\ldots\ldots P_j$**	**Where, j = 0.4 n**
T_2:	$\{P_{j+1} \approx P_{j+2} \approx P_{j+3} \ldots\ldots \approx P_k\} \geq$ Threshold	Where, k = 0.6 n
T_3:	$P_{k+1} > P_{k+2} > P_{k+3} > \ldots\ldots\ldots P_n$	Where, n = 0.4 n

The difference in power between the successive samples is calculated as, $dP = P_{i+1} - P_i$ Where, dP represents the variation in solar radiation. The relationship among the difference is derived using the half sine wave modeling as given in table 2.

Table 2. Relationship between the perturbed powers

T_1:	**$dP_1 < dP_2 < dP_3 < \ldots. < dP_{j-1}$**
T_2:	$\{dP_{j+1} \approx dP_{j+2} \approx \ldots. \approx dP_{k-1}\} \approx 0$
T_3:	$dP_{k+1} > dP_{k+2} > \ldots\ldots > dP_{n-1}$

This relationship is used for the prediction of MPP without any confusion in the direction and without taking any additional samples within the sampling period. Hence the proposed method is faster than the conventional dP P&O method. The flowchart of the proposed improved algorithm is shown in Fig. 6. The operating voltage of the PV array is perturbed in the pre-defined direction as per half sine wave modeling and the perturbation move towards MPP.

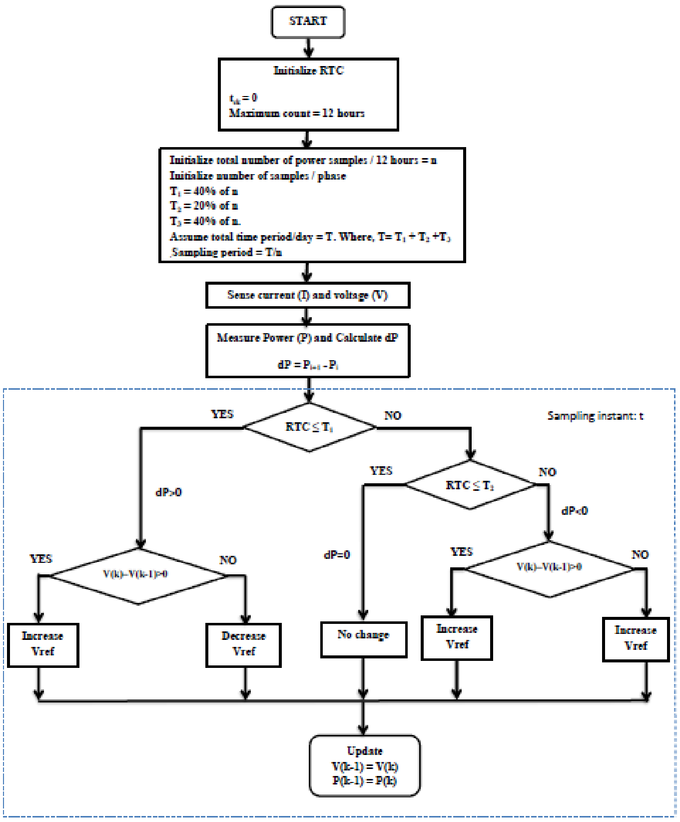


Fig. 6. Flowchart for proposed MPPT method

4. Simulation and Analysis

4.1 Simulation Model and Parameters

A PV system includes the following to investigate the accuracy and performance of the proposed method: PV modules, a DC/DC boost converter, a resistant load, and a control system, which are considered and simulated in MATLAB/Simulink software. The simulation model of dP P&O and improved dP P&O are shown in Fig. 7 and 8 respectively. The parameters of this PV system are shown in Table 3.

Table 3. Design Parameters of PV System

Parameters	Value
Short-circuit current	2.5 A
Open-circuit voltage	23 V
Current at P_{max}	2.2 A
Voltage at P_{max}	18 V
Maximum Power	48 W
C_1	470 µF
C_2	447.66 µF
R_{load}	1500 Ω
Frequency of MOSFET	50 KHz

4.2 Simulation Result and Analysis

The simulation models (Fig. 7 and 8) was simulated and analyzed to compare the performance of the proposed improved dP P&O MPPT method with that of dP P&O MPPT method.

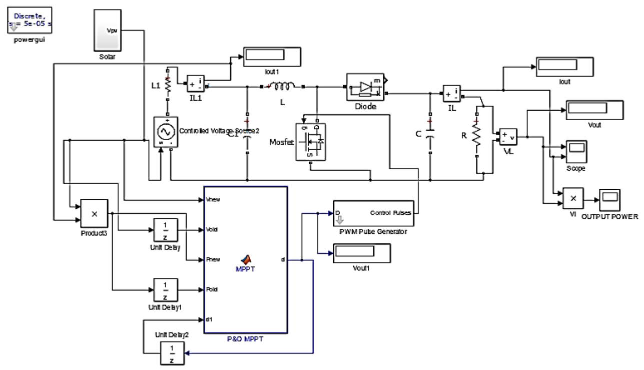


Fig. 7. Simulink block diagram of dP P&O method

In the Fig.7, v_{old} and I_{old} stand for the sampling value of the voltage and current; V_{new} and I_{new} represent the sampling value of the voltage and current in previous cycle.

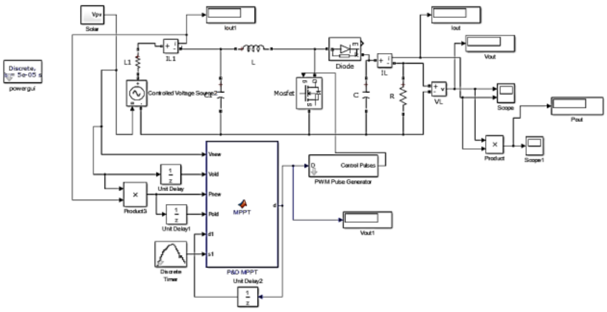


Fig. 8. Simulink block diagram of improved dp P&O method

The input solar irradiation samples (from 6 AM to 6 PM) are obtained from Centre for Research on Alternate Energy laboratory at our institution and the same are given for to test the performance of dP P&O and the improved dP P&O MPPT algorithm. 24 samples are chosen as the input of these systems (1 sample per 30 minutes) as shown in Fig. 10.

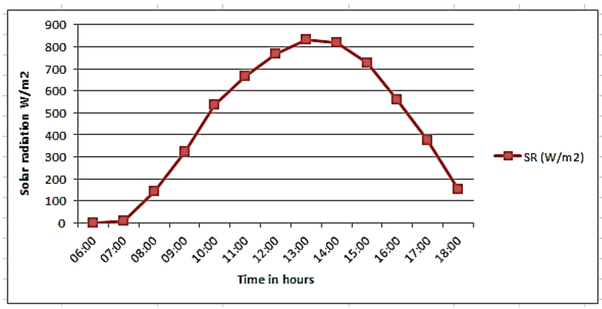


Fig. 9. Sample solar radiation pattern for a day (July 1, 2016)

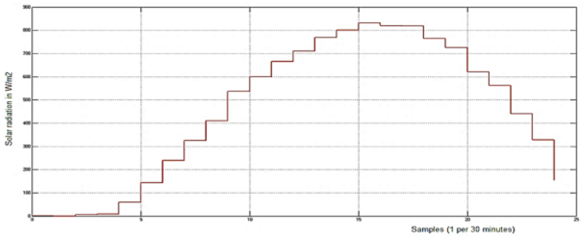
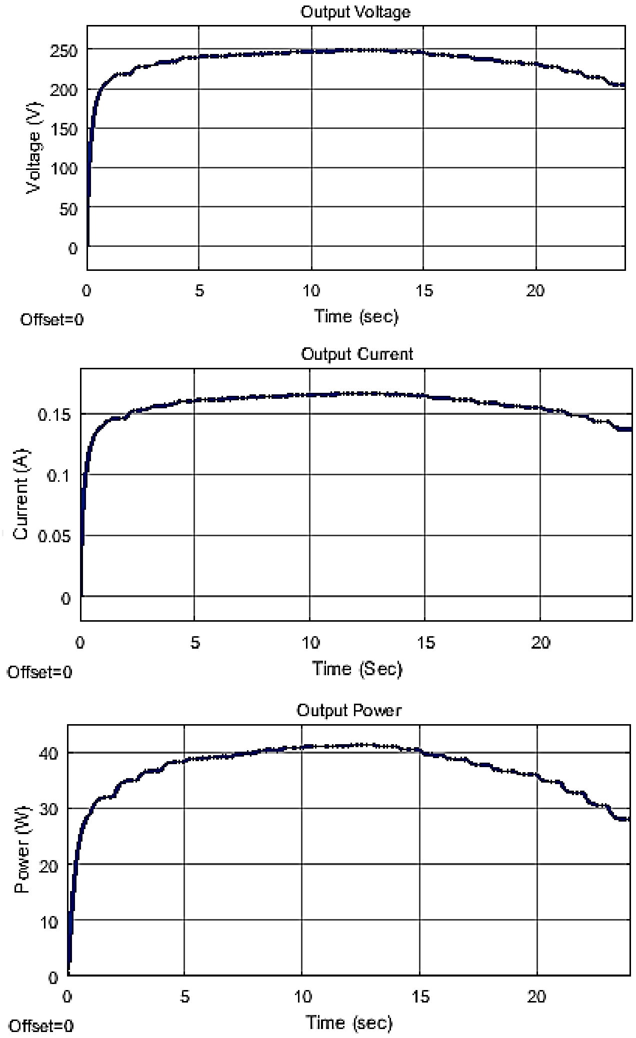
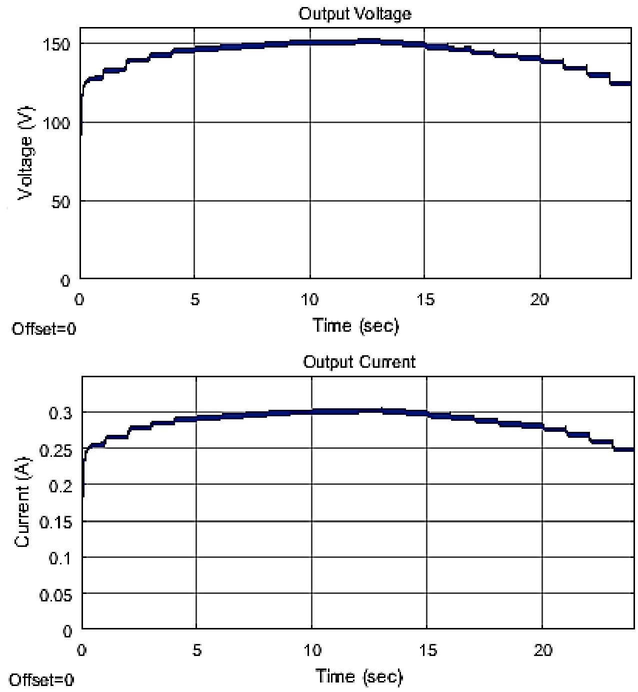


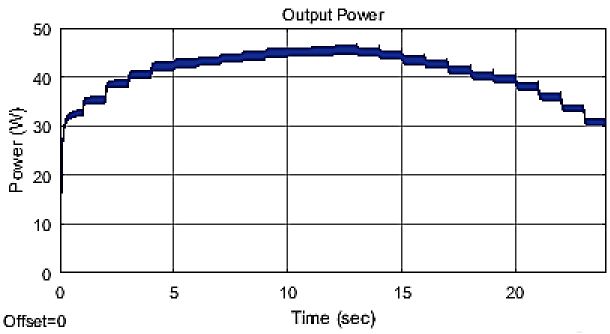
Fig. 10. The sampled radiation data on July, 1, 2016

The voltage, current and power across the load resistance obtained using the dP P&O and improved dP P&O are presented in Fig. 11 and the MPPT trajectories of those methods are shows in Fig. 12. dP P&O and improved dP P&O take approximately 1.7 and 0.5 s, respectively, to reach the MPP. The time response of improved dP P&O is better than the existing method. The accuracy of improved dP P&O is higher than that of dP P&O.



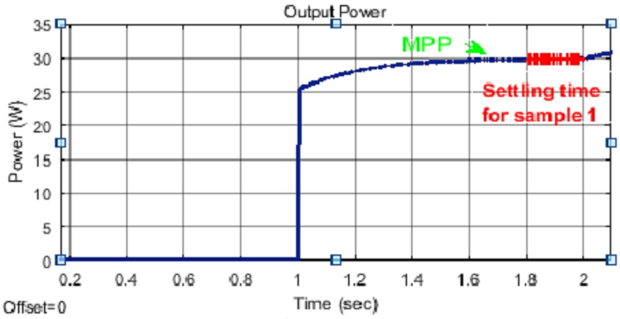
(a)



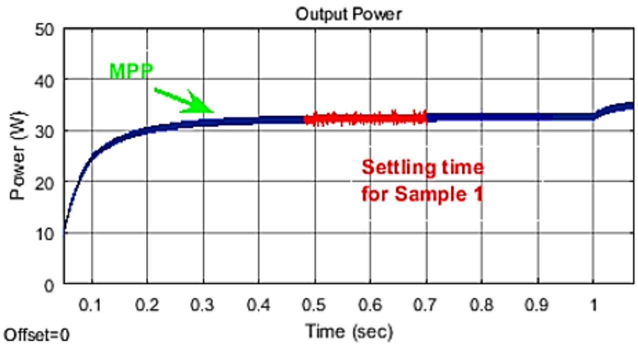


(b)

Fig. 11. Output voltage, Current and Power of load using (a) dP P&O method and (b) Improved dP P&O method



(a)



(b)

Fig. 12. Tracking trajectories of (a) dP P&O and (b) Improved dP P&O method

The average power and response time are compared and given in Table 4 for the existing and proposed MPPT algorithms. The convergence time of improved dP P&O MPPT method is shorter than dP P&O.

Table 4. Performance comparison of existing and proposed MPPT algorithm

Samples/ day, n	MPPT method			
	Average power (W)		Average Tracking time (sec)	
	Existing dP P&O	Improved dP P&O	Existing dP P&O	Improved dP P&O
Phase 1: No of Samples 40 % of n =10	37	41	1.8	0.5
Phase 2: No of Samples 20 % of n = 4	41	45	1.6	0.5
Phase 3: No of Samples 40 % of n =10	36	40	1.7	0.5
Average tracking power and tracking time per day	38	42	1.7	0.5

5. Conclusion

In this paper, an improved dP P&O MPPT algorithm has been developed. PV system, proposed algorithm and Boost converter have been simulated on MATLAB-Simulink. From the simulation results, it knows that the improved dP P&O MPPT method is faster than the existing dP P&O method. In future, different solar irradiation modeling will be used to improve the efficiency of maximum power point tracking.

References

[1] A. Chikh and A. Chandra, "An optimum method for maximum power point tracking in photovoltaic systems," IEEE Power Energy Soc. Gen. Meeting, Detroit, MI, USA, 2011, pp. 1–6.

[2] T.K Soon and S. Mekhilef, "Modified incremental conductance algorithm for photovoltaic system under partial shading conditions and load variation," IEEE Trans. Ind. Electron, Vol. 61, No. 10, 2014, pp. 5384–5392.

[3] Gab-Su Seo, Jong-Won Shin, Bo-Hyung Cho and Kyu-Chan Lee, "Digitally controlled current sensor less photovoltaic micro converter for DC distribution," IEEE Trans Ind Informat, vol. 10, No. 1, February 2014, pp. 117–126.
[4] A.R Reisi, M.H. Moradi and S. Jamasb, "Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review," Renewable & Sustainable Energy Reviews, vol. 19, March 2013, pp. 433-443.
[5] Ali Durusu, Ismail Nakir, Ali Ajder, Ramazan Ayaz, Hakan Akca and Mugdesem Tanrioven, "Performance Comparison of Widely-Used Maximum Power Point Tracker Algorithms under Real Environmental Conditions," Advances in Electrical and Computer Engineering, vol. 14, No. 3, 2014, pp. 89–94.
[6] K. Ishaque and Z. Salam, "A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition," Renew Sustain Energy Rev 19, 2013, pp. 475–488.
[7] MA. Eltawil and Z. Zhao, "MPPT techniques for photovoltaic applications," Renew Sustain Energy Rev 25, 2013, pp. 793–813.
[8] Dorin Petreus, Daniel Moga, Adina Rusu, Toma Patarau and Mihai Munteanu, "Photovoltaic system with smart tracking of the optimal working Point," Advances in Electrical and Computer Engineering, Vol. 10, No. 3, 2010, pp. 40–47.
[9] BN. Alajmi, KH. Ahmed, SJ. Finney and BW. Williams, "Fuzzy logic-control approach of a modified hill-climbing method for maximum power point in microgrid standalone photovoltaic system," IEEE Trans Power Electron, Vol. 26, No. 4, 2011, pp. 1022–1030.
[10] RF. Coelho, F. Concer F and DC. Martins, "A study of the basic DC–DC converters applied in maximum power point tracking," in Proceeding IEEE Brazilian Power Electronics, 2009, pp. 673–678.
[11] A. Belkaid, JP. Gaubert and A. Gherbi, "An improved sliding mode control for maximum power point tracking in photovoltaic systems," Journal of Control Engineering Application Information, Vol. 18, No. 1, 2016, pp. 86–94.
[12] A. Safari and S. Mekhilef, "Simulation and hardware implementation of incremental conductance MPPT with direct control method using Cuk converter," IEEE Trans Ind Electron, Vol. 58, No. 4, April 2011, pp. 1154–1161.
[13] T. Radjai, L. Rahmani, S. Mekhilef and JP. Gaubert, "Implementation of a modified incremental conductance MPPT algorithm with direct control based on a fuzzy duty cycle change estimator using dSPACE," Solar Energy, Vol. 110, 2014, pp. 325–337.
[14] M. Veerachary, "Power tracking for nonlinear PV sources with coupled inductor SEPIC converter," IEEE Trans Aerospace Electron System, Vol. 41, No. 3, 2005, pp. 1019–1029.
[15] SJ. Chiang, HJ. Shieh and MC. Chen, "Modeling and control of PV charger system with SEPIC converter," IEEE Trans Ind Electron, Vol. 56, No. 11, November 2009, pp. 4344–4353.
[16] E. Koutroulis, K. Kalaitzakis and NC. Voulgaris, "Development of a microcontroller-based, photovoltaic maximum power point tracking control system," IEEE Trans Power Electron, Vol. 16, No. 1, January 2001, pp. 46–54.
[17] A. Belkaid, JP. Gaubert and A. Gherbi, "Sliding mode control for tracking maximum power point in buck-boost photovoltaic systems" in proceeding of Electrimacs, 19th–22nd May 2014, pp. 140–147.
[18] Dezso Sera, Tamas Kerekes, Remus Teodorescu and Frede Blaabjerg, "Improved MPPT algorithms for rapidly changing environmental conditions," in proceeding of IEEE_CPEMC, 2006, pp. 547-550.
[19] CPTK. Kumara, JP. Karunadasa, "A Comparative Evaluation of Existing MPPT Algorithms and Development of a Hybrid Algorithm for Photovoltaic Systems," in proceedings of 8th International Research Conference, KDU, November 2015, pp. 147-152.
[20] B. William Stine and Michael Geyer, "Power from the Sun," California, USA, 1986.