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Comparative Performance Analysis of Hybrid MPPT for Standalone Photovoltaic Boost DC-DC Converter

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ABSTRACT

In recent days as the conventional source of energies getting depleted, the non-conventional/ renewable sources are getting more priority in electrical energy generation. Among all the resources solar photovoltaic energy production attaining more emphasize due to its clear, environment friendly and reclaimable property. PV systems normally witness the poor energy conversion efficacy accompanied by indecorous immutability and intermittent in nature. Thus, incorporation of MPPT algorithm has become a mandate to assure the maximum power extraction from the solar PV. Conventional MPPT controller performs well under uniform solar intensity and environmental temperature. But when there is rapid change in weather condition the conventional MPPT controllers must get associated with a second level controller. During the extraction of electric power dc-dc power converters play an important role because of their wide use in ample applications. In this initiative conventional Perturb and Observe (P&O) is interfaced with PID controllers are implemented to maintain the true MPP and extract maximum power during non-uniform ambient condition. Particle Swarm Optimization is used here to get the optimally tuned parameters of the proposed controller. Rigidness of the mentioned controller is verified under dissimilar solar intensities. The effectiveness of the system is authenticated by a commercially available PV module Sun Power SPR-215-WHT-U in MATLAB/ Simulink platform.

KEYWORDS

DC-DC Boost or Step-up converter; MPPT; Particle Swarm Optimization (PSO); Perturb and Observe (P&O); PID; 2- DOF PID

1. INTRODUCTION

With ever increasing population and the gradual depletion of conventional resources, the necessity of sustainable resources has become a content of immense significance in research. Global impact about climatic hazards like global warming, greenhouse effect of conventional resources has also accentuated the need of renewable energy. Among all solar power has drawn more priority as one of the eco-friendly renewable energy due to its cleanliness, ease of availability and cheap. As of now this is the second cheapest renewable resource. According to the augmentation in the population growth the installed capacity of solar energy also getting increased per annum. Maximum power point is defined as the point of governance of the PV source where the optimum power can be harvested. Since the P-V and I-V curves of the PV source is nonlinear, to identify accurate MPP an appropriate Maximum Power Point tracking (MPPT) algorithm incorporation is a mandate [1]. As per the all-over photovoltaic market scenario 2019-2023, in the year 2020 the demand will be rising to 12% to reach the consumption up to 144GW, to strike at 158GW in 2021, 169 GW in 2022, and 180 GW in 2023 and around the world the inaugurated potential of photovoltaic generation may strike at 1610GW in 2023. However, there are some constraints that limits the PV generation, among them poor efficiency is one of the challenges. The most promising method to intensify the efficiency of the photovoltaic arrangement is to employ the MPPT control. So, it has become necessary to classify and summarize the various MPPTs for the progress of research [2]. The MPPTs can be categorized in two sections. Conventional MPPTs that can navigate the true MPP under constant surrounding condition. The MPPT algorithms that can work satisfactorily under varying intensities of solar rays and partial shading condition are the stochastic algorithms [3]. MPPTs based on Artificial Intelligence have also been evolved and can be categorized as bionic and evolutionary algorithms. In comparison to evolutionary algorithms associated with GA and DE, the bionic algorithms tuned by PSO, ACO, ABC, SSA, GWO are more preferred by the researchers [4-8]. Recently many authors liked to amalgamate AI based MPPTs with conventional one or to integrate more than one intelligent algorithm to get better performance in PSC [9-10]. This initiative reveals a comparative analysis of the potentiality of the Perturb & Observe (P&O) based PID and P&O based 2DOF-PID in comparison with normal P&O algorithm. PSO is applied to achieve the optimal parameters of the controllers. At the end the robustness of the system is judged under different solar irradiation levels by keeping the ambient temperature and load constant. The remaining paper is designed in the following manner.

Sect II represents system description, Sect III represents the state space model of boost converter, Sect IV shows the optimizing algorithm, sect V depicts the design of the control strategy and finally sect VI and VII represents the result and discussion and conclusion respectively.

2. SYSTEM DESCRIPTION

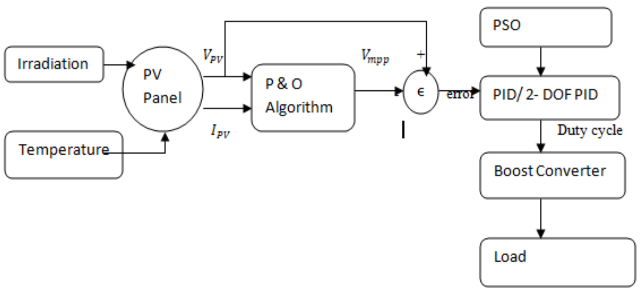


Fig. 1 Structure of Standalone SPV System

Figure 1 shows a standalone SPV system interfaced with the unidirectional DC-DC step up chopper and a DC load. A hybrid MPPT controller is incorporated to harvest maximum power output from the solar system. The hybridization of MPPT controller provides the duty cycle for the DC-DC boost converter [16].

A. rigorous model of SPV cell

A one diode model of solar photovoltaic system is represented in Figure 2.

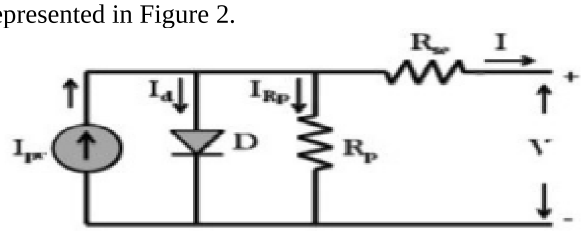


Fig. 2 Equivalent circuit of solar photovoltaic arrangement.

The circuit is the accumulation of the source of photovoltaic current (I_{PV}), presence of diode (D), series and shunt resistance (R_{se}) and (R_{sh}).

An ideal photovoltaic generation system produces an output current of

$$I= I_{PV}-I_d \quad (1)$$

Where I_{PV} is the induced load current of the photovoltaic generation system and I_d represents the equation named after Shockley.

$$I_{pv} = [I_{sc} + K_1(T_c - T_r)]* G_c \quad (2)$$

I_{sc} shows Norton's equivalent current of the Solar Photovoltaic cell. K_1 represents the coefficient of temperature of the short circuit current of the Solar Photovoltaic system and T_r represents the temperature referred to the photovoltaic system.

B. Features of Solar PV generation system

The outcome of the solar photovoltaic cell is completely weather dependent and thus intermittent in nature. Hence the output will vary abruptly along with the constantly changing solar insulation and ambient temperature. As a result of which the nature of the curve of photovoltaic generation system is not linear.

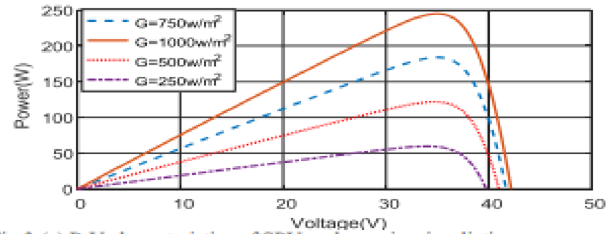


Fig. 3(a) Power-Voltage particularity of PV system under varying irradiation

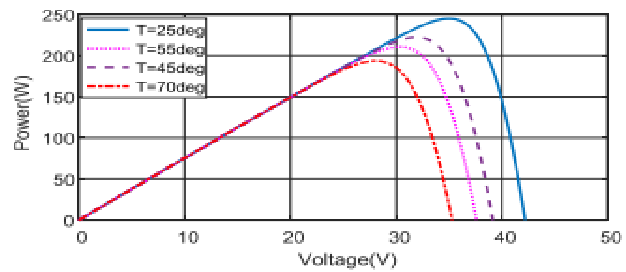


Fig. 3(b) Power-Voltage attribution of PV system under changing ambient temperature

The Power-Voltage features of the solar system under varying intensity of solar radiation and ambient temperature are depicted in Figure 3(a) and 3(b) accordingly.

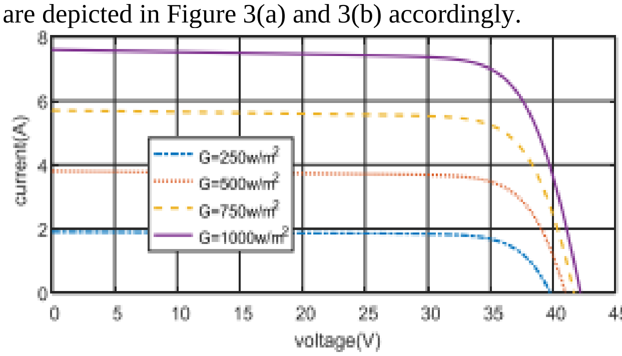


Fig. 4(a) Current-Voltage particularity of PV system under changing radiations

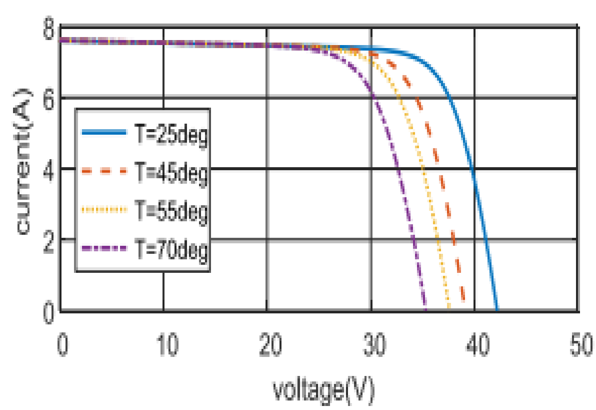


Fig. 4(b) Current-Voltage characteristics of PV system under varying ambient temperature.

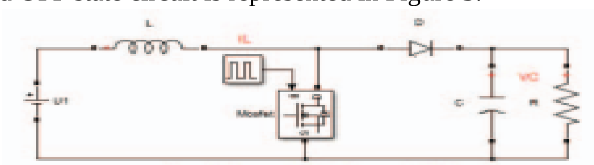
The I-V characteristics of the solar arrangement under varying solar intensities and ambient temperature are depicted in Figure 4(a) and 4(b) accordingly. Table 1, shows, Technical Specifications of Electrical Parameters of PV Generation System.

Table. 1 Technical Specifications of Electrical Parameters of PV Generation System

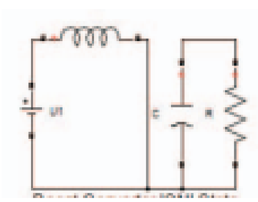
Serial No	Parameters	Range/ Rating
1	Optimum Power	214.92Watt
2	Voltage at open circuit end (V_{oc})	48.3 Volt
3	Current at short circuit end (I_{sc})	6.8A
4	Optimum point voltage (V_{MPP})	39.8Volt
5	Optimum point current (I_{MPP})	6.4A
6	Cell per module (N_{cell})	72

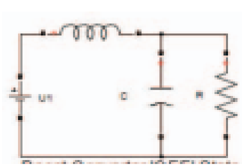
3. STATE SPACE MODEL OF BOOST CONVERTER

The original circuit of DC-DC boost converter and its “ON” and OFF state circuit is represented in Figure 5.



5(a)





5(b) 5(c)

Fig. 5 5(a) Original boost converter configuration, 5(b) and 5(c) boost converter’s ON and OFF state circuit respectively.

The complete boost converter state space equations are represented in 3(a) and 3(b)

$$\dot{x_1} = 0 - \frac{(1-d)}{L}\ x_2\ + \frac{1}{L}\ u_1 \quad 3(a)$$

$$\dot{x_2} = \frac{(1-d)}{C}\ x_1\ - x_2\ \frac{1}{RC} \quad 3(b)$$

The output state space equations are shown in 4(a) and 4(b)

$$y_1 = i_L \quad 4(a)$$

$$y_2 = V_c \quad 4(b)$$

This DC-DC step up chopper is naturally applied to match the load to the PV generation by maintaining the PV producer operating at the optimum Power Point (OPP) via the duty cycle (D). Table. 2 shows, Details of Parameters and The Technical Specifications of DC-DC Boost Converter.

Table. 2 Details of Parameters and The Technical Specifications of DC-DC Boost Converter

Serial No	Parameter Detailing	Range/ Rating
1	Load Voltage (V_{out})	60V
2	Switching frequency	10KHz
3	Inductance (L)	0.0159 H
4	Capacitance (C)	$3.7846e^{-05}$ C

The DC-DC boost converter fabricated by applying conventional fabrication equations.

4. OPTIMIZING ALGORITHM

The PSO algorithm is a multi- extravagant function all-embracing optimization method invented by the foraging nature of the simulating birds’ [11]. It can provide solutions where there are more than one peak problems in more than one variable systems. The purpose of PSO is to get the most suitable particle that focuses on the global optimum result which is the Global MPP of the PV array. In recent days PSO is getting updated and applied at Partial Shading condition (PSC) by several researchers [12]. In combination of PSO with ANN and RBF gives better focusing result [13]. An improved PSO (IPSO) that accepts both global and local data to track the operating point where maximum power can be achieved. [14].

5. DESIGN OF P&O BASED CONTROLLERS

The conventional P&O algorithm works on the principle of incrementing or decrementing the potential or the gate signal of the PV system load end changed, within a periodic discontinuity and to ascertain the upcoming control signal the change in orientation of the power must be observed. It is a very simple, trustworthy, and easily executable algorithm. But it works well under uniform solar intensities and surrounding climatic temperature. When there remains a rapid fluctuation in the aforementioned factors it exhibits oscillations in the output power [15]. Figure 6 and Figure 7 shows, Structure of P&O PID controllers and Conventional structure of PID controller respectively.

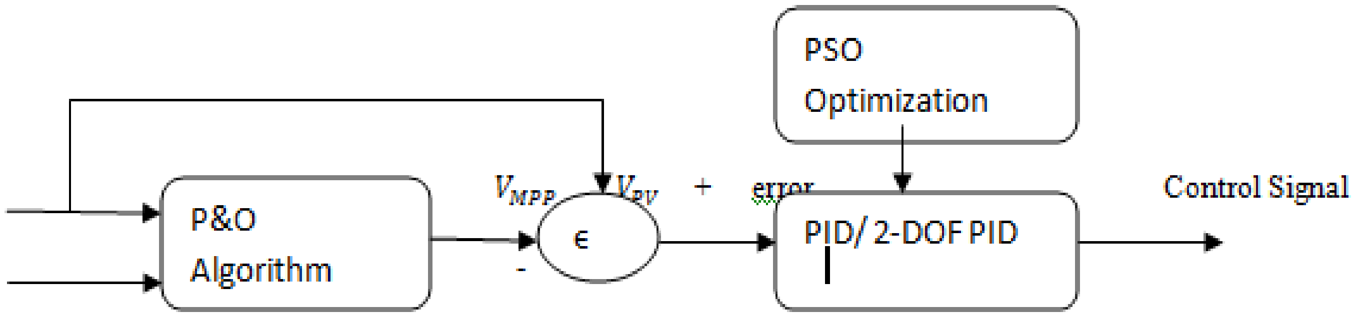


Fig. 6 Structure of P&O PID controllers

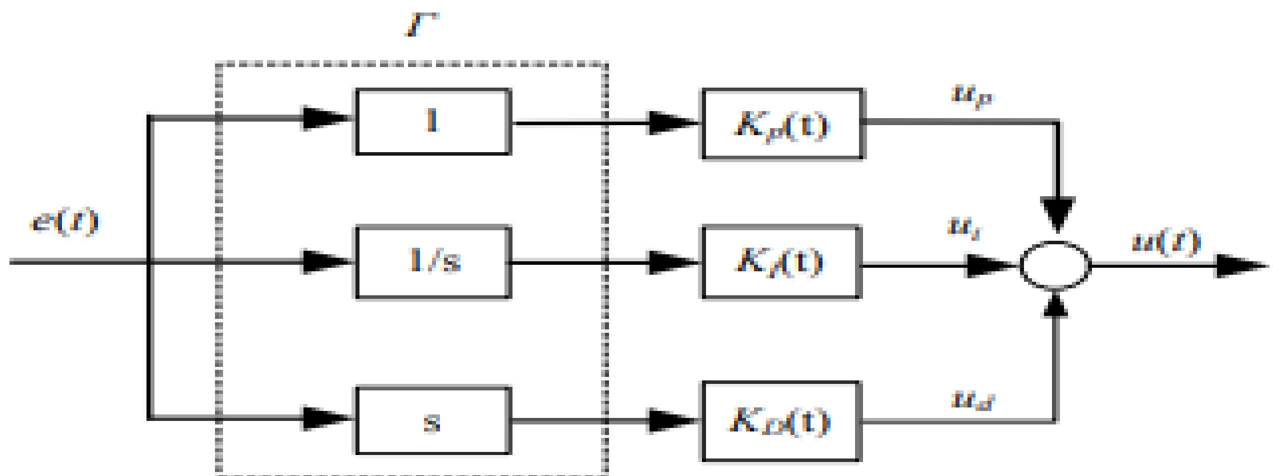


Fig. 7 Conventional structure of PID controller

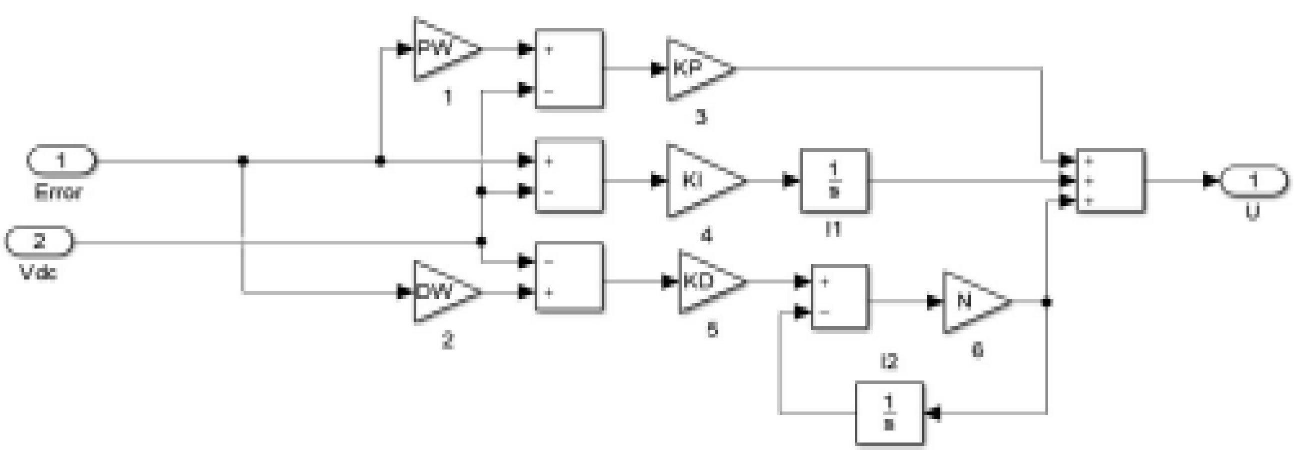


Fig. 8 Conventional structure of 2-Degree of Freedom PID controller.

PID controller

There are three operating units in conventional PID controller such as, proportional unit, integral unit, and derivative unit.

2- DOF PID controller

Figure 8 represents the configuration of 2-DOF PID controller where 'e' shows the error signal, 'V_{dc}' represents the DC-DC boost converter's output and 'u' shows the controller's output. The difference between the conventional PID and 2- DOF PID is that the integral structure which comprises of 6 gain parameters like K_p, K_i, K_d, N, PW and DW are gain of proportion, integral gain, derivative gain, derivative filter co-efficient, proportional, To derive the optimal parameters of the P&O based PID controllers, the error must be minimized. In this initiative Particle Swarm Optimization (PSO) is executed to reduce the integral form of absolute error (ITAE) depicted in Equation (5) to achieve the purpose.

$$\text{ITAE} = | \; V_{MPP} - V_{PV} | = \int_0^{t_{sim}} |error| \, dt \qquad (5)$$

Where V_{MPP} represents the voltage at the operating point where maximum power of the PV system can be tracked, V_{PV} is the PV cell voltage and t_{sim} expresses the simulation time.

6. RESULT AND DISCUSSIONS

In this research conventional Perturb and Observe algorithm is interfaced with normal PID and 2-DOF PID controller to make a comparative study of their performances to enhance the efficacy with reduced oscillations to track the MPPT. To achieve the optimized parameters of both PID and 2-DOF PID are tuned by PSO algorithm. The optimized values of both the controllers are depicted in Table 3.

Table. 3 Optimal Parameters of PID and 2- DOF PID Controllers

MPPT Techniques	K_p	K_i	K_d	PW	DW	N
P&O-PID	0.0010	0.0015	0.0010			
P&O-2-DOF PID	1.1025	1.4015	1.8245	4.6675	1.3672	300.1945

The comparative study is done based on power, voltage and current which are depicted in Figure 9 (a-c) respectively.

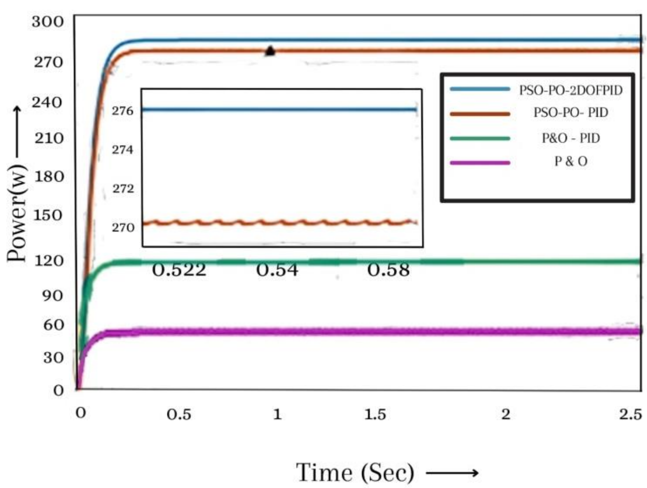


Fig. 9(a) Load Power vs Time plot of DC-DC step up converter after implementing the mentioned controllers.

and derivative set point weight accordingly.

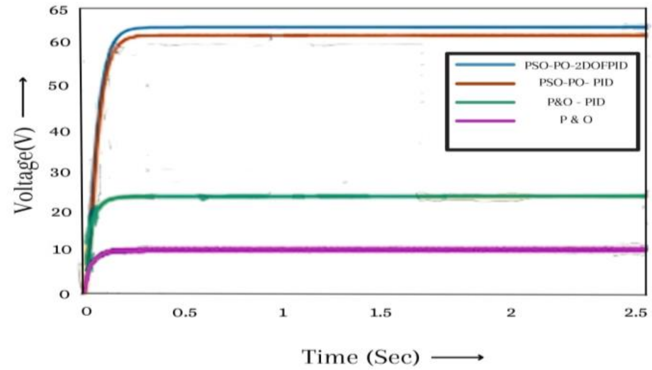


Fig. 9(b) Load Voltage vs. Time plot of DC-DC step up converter after implementing the mentioned controllers.

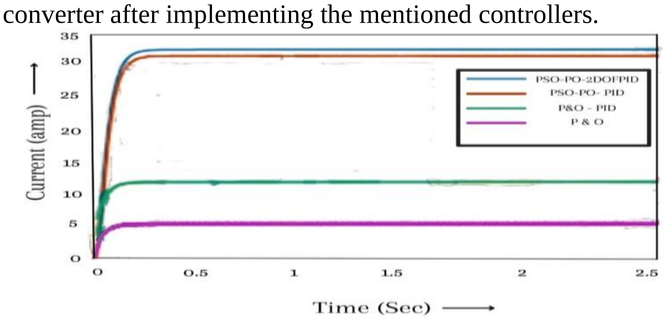


Fig. 9(c) Load Current vs. Time plot of DC-DC step up converter after implementing the mentioned controllers.

The above comparative study it reveals that during the simulation the maximum power point tracking was judged by optimal PO-PID and PO-2DOF-PID controllers for the standalone PV system. From the above plots it is evident that interfacing of P&O with 2-DOF PID controller, oscillations has been minimized and enhanced the output response of the PV system which is under experiment. Table 4 shows performance analysis of DC-DC boost converter.

Table. 4 Performance Analysis of DC-DC boost converters

MPPT Techniques	Maximum output response Voltage (V)	Current (A)	Power (W)	Efficiency
PSO-PO-2DOFPID	63	32	276	78.74%
PSO-PO-PID	60	28	270	75%
P&O-PID	23	12	118	46.3%
P&O	8	4	45	28.76%

Implementation of PSO-2-DOF PID with P&O algorithm exhibited best outcome in comparison to PSO-PO-PID, P&O-PID and conventional P&O algorithm.

7. CONCLUSION

Since the conventional Perturb & Observe (P&O) algorithm does not maintain the track of true MPP under rapidly varying weather condition, the prime aim of this article is to find out an MPP controller with reduced oscillation around the true MPP accompanied by improved efficiency. This was achieved by interfacing 2-DOF PID along with the usual P&O. To obtain optimal parameters, the Particle

Swarm Optimization algorithm is executed for PID and 2-DOF PID. Solar irradiation, temperature and load are the main criterion to analyze the PV performance. P&O 2-DOF PID, PO-PID and P&O MPPT controllers are executed under varying irradiances (1000W/m^2 to 800 m^2) by keeping the temperature constant at 25^0 C and load at 22.7992 ohm. The reference voltage (V_{ref}) is calculated by using conventional P&O algorithm. The converter based PSO-2-DOF PID controller minimizes the oscillations and provides better efficiency of the standalone PV system in comparison with P&O, P&O PID and PSO-PO-PID. The work can be modified by calculating the reference voltage (V_{ref}) by other conventional algorithms like variable step size P&O, Incremental Conductance (IC), Hill Climbing etc. and can be interfaced with the previously mentioned controllers. Since the 2-DOF-PID is adapting the reference voltage from conventional P&O algorithm, this can be concluded as adaptive 2-DOF-PID which is optimized by PSO algorithm. Many other intelligent mppt can be interfaced to get better tracking of true mpp and robustness of the controller. Nonlinear discrete PID controller can also be interfaced.

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