Mayfly Optimization Algorithm for MPPT of PV System under Partial Shading Conditions

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Abstract: Maximum power point tracking (MPPT)methods are most popular to harvest maximum energy from renewable energy sources for generating electric power. Among many renewable energy sources, solar energy is a primary and mostly available on the earth. Generally photovoltaic (PV) panel are arranging in a proper sequence to produce required electric power. Many conventional MPPT algorithms are available on PV system but working on uniform irradiances. Partial shading is a common phenomenon on PV systems. During partial shading conditions, conventional MPPT algorithms will fail to exhibits its best performance due to occurrence of many local peak powers. Hence, an efficient optimization method must be incorporated to identify global maximum power point among all possible points. Mayfly optimization is one of the best in existing optimization methods. However, perturb and observe (P&O) method must be incorporate with Mayfly technique to produce the best performance under both uniform irradiances and partial shading condition. A boost converter is used as a MPPT device in this paper due to its merits over other converters. Extensive results are carried out on OPAL-RT platform by establishing Hardware – in the – Loop (HIL) to validate the proposed method.

Keywords: MPPT, Partial Shading, Mayfly algorithm, PV, HIL.

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1. INTRODUCTION

Electric power is required everywhere to fulfill our needs by operating equipment [1-2]. Generating electricity through renewable energy sources is one of the best options to reduce global warming as well as to meet the load demand in many countries. Solar energy is a primary energy sources on the earth. Therefore, utilizing solar energy to produce electricity at many places is required nowadays to meet load demand. Generally photovoltaic cells (PVCs) are using to produce electricity directly from solar irradiance.

PVCs are arranging in the combination of parallel and series to produce rate voltage and power as per requirement. This setup can form a PV system. Due to nonlinear characteristics of the PVCs, a maximum power point tracker (MPPT) must be incorporated to harvest maximum energy. Many MPPT circuits are developed and boost converter is one of the best among them. However, an efficient MPPT algorithm is required to obtain maximum possible power with respect to particular irradiance.

Many scholars proposed various algorithms to achieve the operation of MPPT. Perturb and observe (P&O) algorithm is one of the best in terms of tracking time and accuracy [3-4]. However, conventional P&O algorithm can be working efficiently during uniform irradiance. Unfortunately, overlapping uniform irradiances on all solar cells is not possible due to birds, constructions, tress, clouds, dust etc which creates partial shading effect.

Under partial shading conditions (PSCs), the PVCs exhibits multi peaks on power vs voltage curves. Hence, the global maximum must be identifying to work the PV system at its MPPT level for their best utilization. Therefore, conventional P&O algorithm will fail to obtain global maximum point. Hence, an efficient optimization method must be integrated to P&O technique [5]. Mayfly Optimization Algorithm (MOA) has ability to identify the best position of maximum value of nonlinear functions like PV systems as compared with other techniques [6-8]. Therefore, hybrid MOA-P&O (MOPO) mechanism is developed in this paper to identifymaximum power pointposition under PSCs. Further, the MOPO is compared by three existing techniques-GA:Genetic Algorithm [9], PSO:Particle Swarm Optimization [10] and GWO:Grey Wolf Optimization [11].

A sliding mode control (SMC) is developed to produce required pulses for the boost converter. The reference signal generated by hybrid MOPO method will be treated as a reference voltage signal of the sliding mode control. The control of boost converter (i.e., sliding mode control) will force to adjust PV voltage at its reference (corresponding voltage at MPPT) signal produced by hybrid MOPO technique.

The paper is organized by providing description of the system in Section-2. Section-3 compressed with modeling and characteristics of PV system under PSCs. Designing and implementation of hybrid MOPO algorithm is given in Section-4. Sliding mode control for boost converter is developed in Section-5. Results based on hardware – in the – loop (HIL) are presented in Section-6. Conclusion is arranged in Section-7.

2. SYSTEM DESCRIPTION

Boost converter based MPPT of PV system under partial shading condition is shown in Fig. 1. Some PV modules have the effect of partial shading in the PV system. A simple boost converter is incorporated in the system to regulate the voltage. A simple resistive load is connected at the end of the boost converter to consume the generated power by the PV system. A SMC is integrated to MPPT algorithm for producing required duty cycle of the boost converter. Similar kinds of systems are presented by many scholars recently. Authors in [2] presented whale optimization for MPPT of PV system under PSCs, but system is limited to water pumping application. PV system with PSCs which applied for DSTATCOM is implemented by authors in [4]. Authors in [5] proposed MPPT of PV system under PSCs with modified invasive weed optimization technique. Authors are presented GA [9], PSO [10] and GWO [11] for MPPT of PV system. However, Mayfly optimization [6-8] method is superior to many other methods. Therefore, Mayfly optimization algorithm (MOA) is considered in this paper along with integration of P&O to identify global maximum point during normal as well as PSCs.

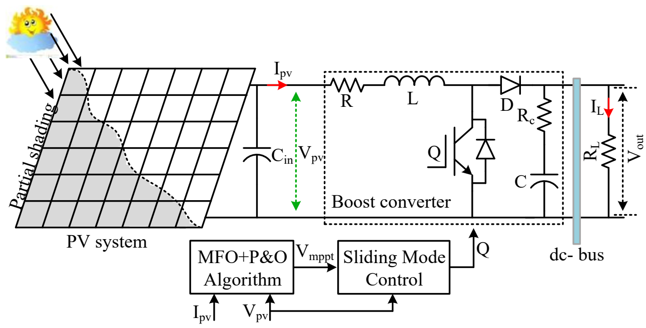

Fig. 1: MOPO based MPPT of PV system under PSCs with SMC.

3. Modeling and Characteristics of PV System

The procedure for selecting the rating of PV system is depending onrequired power byconsumer. In order to obtain 9.6kW, 32 PV modules with each 302W are considered and connected 16 numbers of modules in series to make a PV array for producingrequired voltage. Therefore two arrays are connected in parallel to maintain load current. Theparameters list of a PV module is given in Table-I.

Table-I: Details of a PV array.

Parameter	Value
Short circuit current	8.16A
Current at MPP	7.66A
Voltage at MPP	39.6V
Open circuit voltage	48.5V
Maximum power of each module	302W
modules in PV array	16.0
Number of PV arrays connected in parallel	2.0

Due to connecting 32 numbers of total modules, there will be more chance on occurrence of PSCs. The mathematical expression of conventional P&O mechanism to identify voltage which is corresponding to MPP is represented by.

$$V_{mpp}(i) = V_{mpp}(i-1) + \Delta V \times sign\left(\frac{dP_{pv}}{dV_{pv}}\right) \qquad (1)$$

Three patterns of PSCs are listed in Table-II and Fig. 2 shows the corresponding P-V curves. During the PSCs, many maximum power pointsare appeared and only one can be a global maximum (GM). During convergence to stick at any local maximum point, the conventional P&O mechanism unable to identify GM point. Under this scenario, an efficient optimization algorithm should be integrated with P&O technique to track GM power point quickly. Many optimization techniques are developed recently on MPPT of a PV system during PSC. Authors proposed GA based MPPT algorithm in [9]. Authors were implemented PSO [10] and GWO [11] mechanism on MPPT of a PV system. However, MOA has better tracking behavior as compared with GWO, PSO, GAand many more [6-9]. Therefore, MOA is considered in this paper along with integration of P&O to identify GM during normal as well as PSCs.

Table-II: Patterns of irradiance in PV arrays.

Patterns	Irradiance level of modules in each array
PSC-1	Module:1-4: 1000; 5-7: 910;8-12: 820; 13-16: 705.
PSC-2	Module:1-3: 1000; 4-8: 920; 9-13: 705; 14-16: 545.
PSC-3	Module:1: 804; 2-4: 701; 5-11: 540; 12-16: 305.

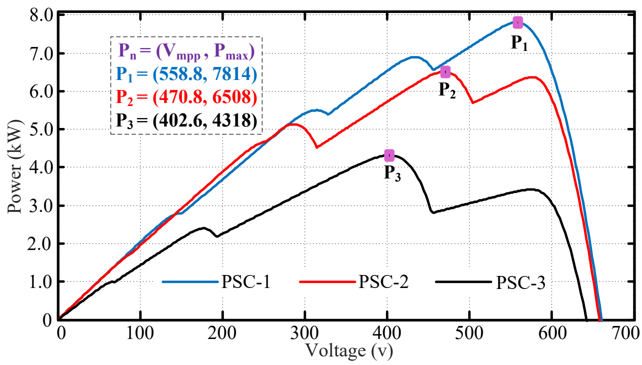

Fig. 2: P-Vcurves of Table-II under PSCs.

4. MOPO System Algorithm

Mostly adult male mayflies are attracting females by performing a nuptial dance where up and down movements are involving to generate a pattern with swarms at above the water surface. Hence, it will be very helpful to search best global position of MPPT of PV system since the process involves up and down movement and fast growing population. Once the best male and female mayflies are attracted each other the mating process begins and it will be for a few seconds to drop the eggs in the water to continue the cycle by increasing population. Mayfly optimization algorithmis implemented by Zervoudakis and Tsafarakis. It is a new technique for achieving solution of complex problems where multi objectives are involve. The steps involved in mayfly algorithm are given as follows:

Male Mayflies Movements: The position of a male mayfly is very important in the process of identify the maximum power location of PV system under partial shading condition and it can be denoted as.

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{2}$$

Where x_i^t represents the present position which is the same as present V_{mpp} of the PV system. By adding the velocity function v_i^{t+1} to current position can be determine the new position x_i^{t+1}. The velocity function of male mayflies is denoted as

$$v_{kj}^{t+1} = g \times v_{kj}^t + a_1 \times e^{-\beta r_p^2} \times \left(pbest_{kj} - x_{kj}^t\right) + a_2 \times e^{-\beta r_g^2} \times \left(gbest_j - x_{kj}^t\right) \tag{3}$$

Where k is mayfly's number in jthdimension at a time t.a_1&a_2 are constants, gravitational coefficient-g.the term β represents a coefficient used to limit a mayfly's visibility to others. The $pbest_k$ represents the optimal position of kth mayfly and jth component of the position of the best male mayfly is denoted as $gbest_j$. Cartesian distance between x_k and $pbest_k$ is r_p while r_g is the Cartesian distance between x_k & $gbest$.

$$pbest_k = \begin{cases} x_k^{t+1} \\ if fitness\left(x_k^{t+1}\right) < fitness\left(pbest_k\right) \end{cases} \tag{4}$$

$$\left|x_k - y_k\right| = \sqrt{\sum_{j=1}^{n}\left(x_{kj} - y_{kj}\right)^2} \tag{5}$$

Here x_{kj} indicates the position ofj[th] element withk[th]fly. y_k either represents $gbest$ or $pbest_k$. Usually, performing the nuptial dance by the best mayflies at a particular time is gives a stochastic path to the algorithms. The expression can be represented by below mathematical equation.

$$v_{kj}^{t+1} = g \times v_{kj}^{t} + d \times r \tag{6}$$

The nuptial dance coefficient is represented by d .‘ r ’ is chosen as random value between [-1, 1].‘d’is progressively reduces as $d_{itr} = d_0 \times \delta^{itr}$. Where, d_0 is initial coefficient value of the nuptial dance. δ is a random value between [0, 1] and ‘itr’ is the current number of iterations.

Movement of female mayflies: the position of female flies will be updated regularly towards males for breeding and this can be represents by:

$$z_i^{t+1} = z_i^{t} + u_i^{t+1} \tag{7}$$

Where, z_i^t is the female position at time ‘t’ and updated through velocity v_i^{t+1} .

The following equation is used to update the velocity of a female.

$$u_{kj}^{t+1} = \begin{cases} if\ fitness\left(z_k\right) > fitness\left(x_k\right) \\ g \times u_{kj}^{t} + a_2 \times e^{-\beta r_{mf}^2} \times \left(x_{kj}^{t} - z_{kj}^{t}\right) \\ else\ if\ fitness\left(z_k\right) \le fitness\left(x_k\right) \\ g \times u_{kj}^{t} + fl \times r \end{cases} \tag{8}$$

Here, v_{kj}^t is the k[th] female’s velocity of the j[th] component at the time t, x_{kj}^t is the j[th] component of the position of male mayfly kand z_{kj}^t is the position of female mayfly k in dimensions j at time t.

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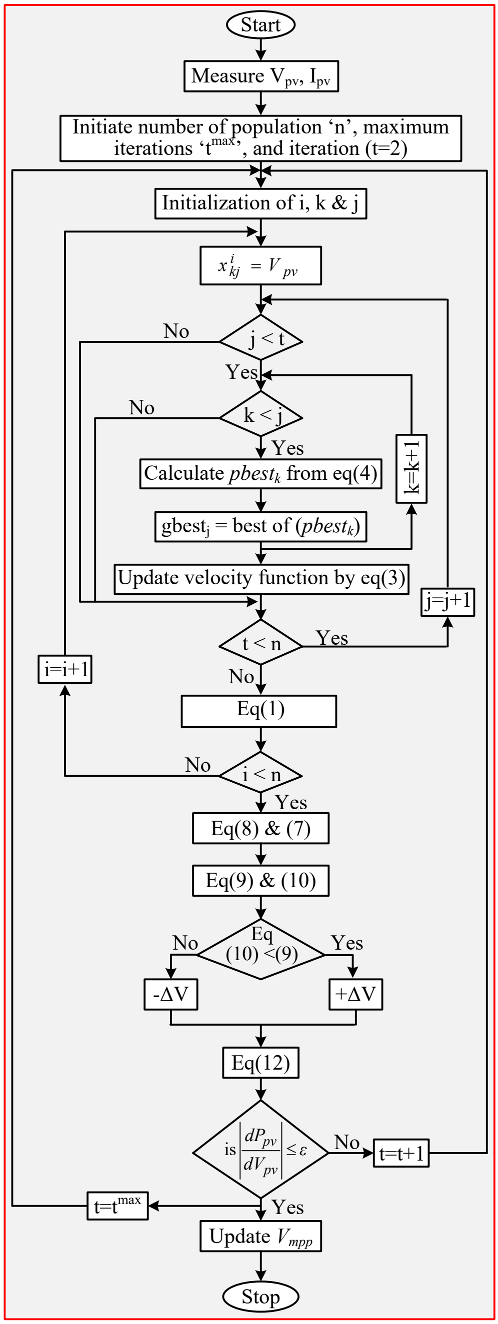

Fig.3: hybrid MOPO Flowchart.

$$offspring1 = (1 - r_{of}) \times female + r_{of} \times male \tag{9}$$

$$offspring2 = r_{of} \times female + (1 - r_{of}) \times male \tag{10}$$

$$offspring'_{n} = offspring_{n} + k \tag{11}$$

$$V^{t+1}_{mpp} = V^{t}_{mpp} \pm \Delta V \times \times offspring'_{n} \tag{12}$$

The flowchart of a proposedMOPO technique is exhibited in Fig. 3.

5. Proposed Control System

Once obtained reference voltage signal from MOPO algorithm, the reference signal will be treated as input target value of the control block. Apart from many, a sliding mode control will give a best performance during sudden changes occurred in the system. Duty cycle (D) is produced by SMC by considering a reference signal which is obtained by MOPO. The proposed model of a MOPO based SMC for boost converter is shown in Fig. 4.

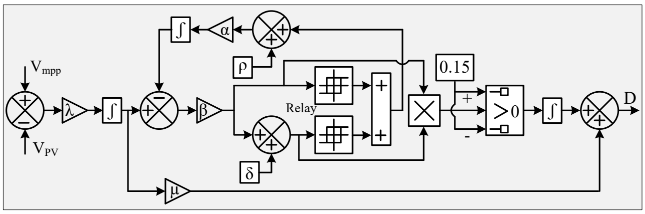

Fig. 4: SMC for boost circuit to work as MPPT of PV system.

6. Resultsand Discussions

A real-time simulator (RTS)based Hardware-in the-Loop (HIL) has been established in this section to evaluate the performance of the proposed system. The RTS is performed with the help of OPAL-RT technologies. The operation of HILis performed by interconnecting of two OPAL-RT units with back to back connection. The Unit-1 consists of a PV, converter,and load (shown in Fig. 1). Proposed control method (Fig. 3 and Fig. 4)is adopted by second unit. The generalized HIL configuration by using two OPAL-RT modules is presented in Fig. 5. The data transferred by analogue and digital signals is established between two OPAL-RT units to supervise real-time dynamics [12-14] effectively. The details block represent of HIL of proposed system with two OPAL-RT units is presented in Fig. 6. Results under below case studies are evaluated to verify the performance of the designed controller.

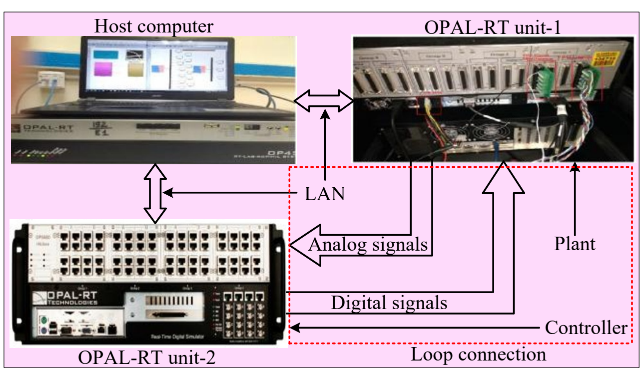

Fig. 5:HIL laboratory setup with two OPAL-RT modules.

Case-1: Response of SMC over PI

Irradiance is decreasing from 1000 to 750W/m^{2}at t = 3.0sec to test the responses of SMC and PI controller. The performance of proposed control method is examined by using theSMCand PI controllers. Due to the fixed gains of PI controller which are tuned at 1000W/m^2, it exhibits best performance at 1000W/m^2, but the same gains may not give

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satisfactory performance at 750W/m^2. However, due to the adjustment facility on gains of theSMC, it can perform wellunderchanges in irradiance. The actual and referencepower of the PV system with PI and SMCare depicted in Fig. 7. By observing Fig. 7, the performance of MPPT is well with SMCas comparedwith PI and also significant priority is there to use SMC in system. Furthermore, oscillations at irradiance 750W/m^{2}are more in voltage at dc-link due to fixed gains of PI. It can be effect on MPPT tracking performance of the PV. Hence, remaining results are presented with the SMC.

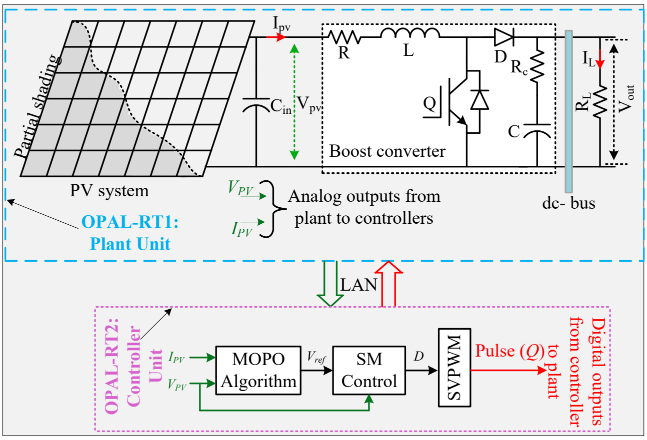

Fig. 6: HIL representation of proposed system.

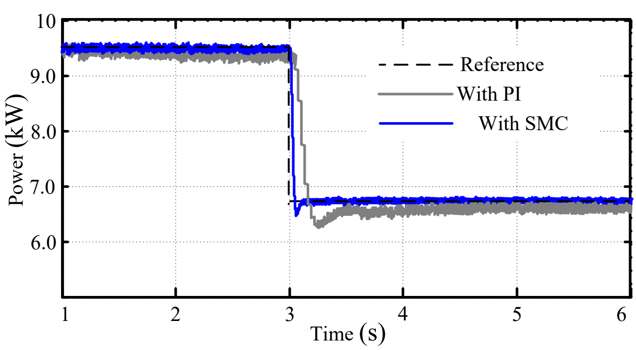

Fig. 7: Performance of MPPT by PI and SMC.

Case-2: Comparison among optimization methods

Time related to the response of tracking MPPT level (i.e., GM) during PSCs is very crucial and important for harvesting maximum electrical energy from solar energy. During the operation of PSCs listed in Table-2, the power generated from PV system with proposed MOPO, GWO, PSO and GA is compared. A bar chat type comparison among MOPO, GWO, PSO and GA is presented in Fig. 8(i).In a similar way, the MPP of PV array also depicted in Fig. 8(ii). By observing Fig. 8, the proposed hybrid MOPO algorithm is having some significance priority over GA, PSO and GWO.

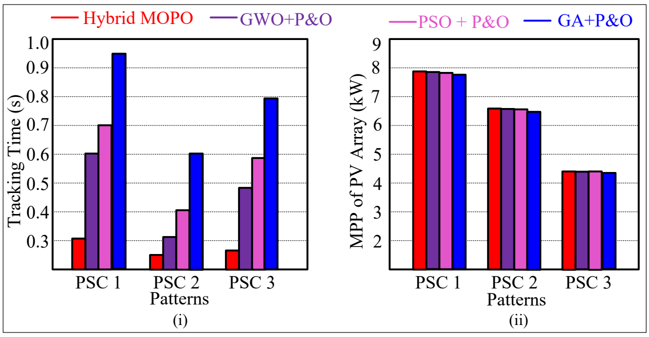

Fig. 8: Bar chat for comparing various responses among MOPO, GA, GWO and PSO.

Case-3: Response of voltage at dc-link

In order to harvest maximum power, proper tracking value of voltage corresponding to global maximum power should be obtained during PSCs. The power generated from PV system through MOPO, GWO, GA and PSO is given in Fig. 9. The tracking behavior of voltage at dc-link with hybrid MOPO, GA, PSO and GWO is depicted in Fig. 10 as per PSCs listed in Table-2. In this condition considered uniform irradiance till t=3sec., PSC-1 has occurred during t=3 sec to 5 sec; PSC-2 occurred during t=5 to t=7sec and during t=7 to 9sec taken by PSC-3.

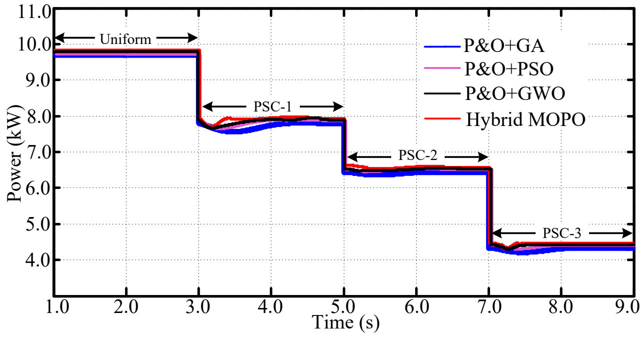

Fig. 9: Power extracted from PV system with MOPO, GA, PSO and GWO during various PSCs.

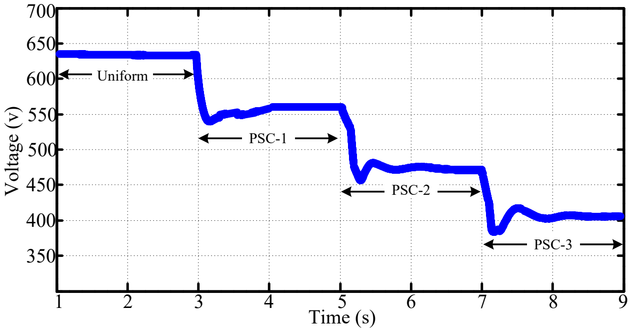

Fig. 10: Voltage at dc-link through MOPO method.

7. Conclusions

Various performances of PV parameters are presented in this paper through hybrid MOPO algorithm in this paper under various PSCs. various comparisons are also presented by using GWO, GA, and PSO for tracking performance of MPPT. By using OPAL-RT devices, HIL is established to present various results. The SMCis implemented on boost converter to produce required pulses. Response of PV system with SMC is also compared with conventional PI controller and observed that the SMC is performing well and best.

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