MPPT of PV System under Partial Shading Conditions by Novel Control with Modified Grey Wolf Optimization Technique

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Abstract: Solar energy is a primary source on earth and photovoltaic (PV) cells are using to produce electricity through solar energy. Due to nonlinear behavior of power vs voltage curves of PV system, a maximum power point tracking (MPPT) circuits must be employed to harvest maximum energy. Among many MPPT techniques, a Perturbed and Observed (P&O) algorithm is one of the best methods. Generally partial shading conditions (PSCs) are commonly appearing on the PV systems. Under these PSCs, the P-V curve exhibits multiple peaks where one can be a global maximum and other are local maximum points. The global maximum location needs to be identifying to harvest more energy during PSCs. Hence, modified grey wolf optimization method is integrated with P&O algorithm to make a hybrid control method of a boost converter to operate PV system at its best utilization point. Hardware – in the – Loop (HIL) is designed with the help of two OPAL-RT modules to present various results under different operating conditions.

Keywords: PV, MGWO, Partial Shading Conditions, MPPT.

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1. Introduction

Photovoltaic systems (PVSs) are using to produce electricity from solar energy worldwide. The world is looking to utilize maximum amount of renewable energy to reduce the consumption of fossil fuels for reducing harmful gasses in the atmosphere [1-4]. However, the cost of PVSs is very high, hence the systems must be operated at its maximum utilizing point. Generally PVSs are establishing by arranging many PV cells in the combination of series and parallel based on the requirements of power and operating voltage. A maximum power point tracker (MPPT) must be used to harvest maximum energy from PVS through solar irradiance. Among many algorithms, Perturbed and Observed (P&O) algorithm is one of the best.

Conventional P&O method is having highest efficiency to track exact voltage which corresponding to MPPT point. However, partial shading conditions (PSCs) are common phenomena occurred on PV systems which can exhibit multiple peaks where conventional P&O algorithm fails to identify global maximum point. To avoid this issue, an efficient optimization method is required to identify the global maximum point. Modified Grey Wolf Optimization (MGWO) can able to help on identifying the best MPPT level. This technique is further integrated with P&O [2] method to work in all the conditions including uniform solar irradiance.

A simple boost converter is employed between PVS and load bus to operate the PVS at its best utilization point with the help of proposed hybrid MPPT algorithm (i.e., MGWO+P&O). Generally the P&O algorithm will stick at any local maximum which may not be a global maximum. This problem can be resolved with MGWO algorithm which can identify global maximum point easily. The proposed method is also comparing with genetic algorithm (GA), particle swarm optimization (PSO) and conventional GWO method.

Further work is presented in this paper under following sections. A simple MPPT model of the PV system is presented in Section-2. Modified GWO is given in Section-3. Results and discussions are presented in Section-4 with the help of Hardware – in the – Loop (HIL) formed by two OPAL-RT devices. Conclusion is listed in Section-5.

2. System Description

Proposed system is shown in Fig. 1. A PV system, converter, dc-load, and proposed control method are considered. Sliding mode control (SMC) is considered in this paper. The voltage corresponding to MPPT location (i.e., V_{mpp}) is obtained through integration of proposed GWO and P&O method. Detailed modelling of various blocks of Fig. 1 is listed below.

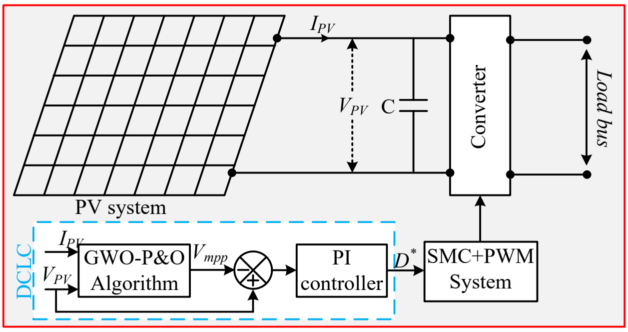

Fig. 1: MPPT of PV system with proposed method.

Ratings of the PV System:
Reference [5-11] is used to model the PV under PSCs and obtained required ratings which are listed in Table-1.

Table-1: Parameters of array.

S.No	Parameter	Rating
1	Voltage when circuit opens	48.5V.
2	Current when Short circuit	8.16A.
3	Voltage at P_{max}	39.6V.
4	Current at P_{max}	7.66A.
5	P_{max}/module	303.0W.
6	Number of modules in series	16.
7	DC-link voltage maximum	633V.

The conventional P&O method is implemented by using below expression:

$$V_{mpp}(k+1) = V_{mpp}(k) + \Delta V_{pv} \times sign\left(\frac{dP_{pv}}{dV_{pv}}\right) \quad (1)$$

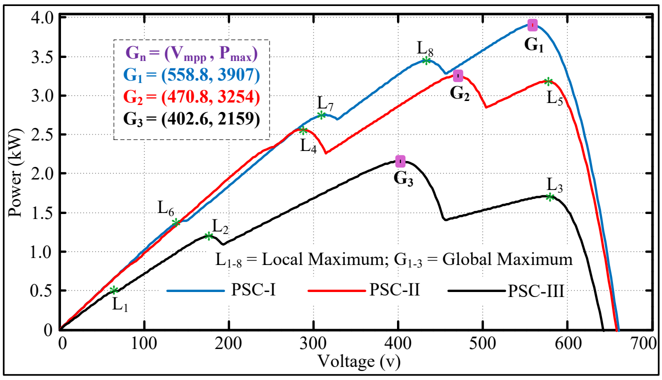

Fig. 2: P-V characteristics under PSCs {Table-2}

Table-2: list of PSCs patterns

Patterns	Irradiance in W/m^2
PSC-1	Modules: 1 to 4: 1000; 5 to 8: 900; 9 to 12: 800; 13 to 16: 700.
PSC-2	Modules 1 to 3: 1000; 4 to 7: 950; 8 to 13: 700; 14 to 16: 550.
PSC-3	Modules: 1st: 800; 2 to 4: 700; 5 to 11: 550; 12 to 16: 300.

List of power vs voltage characteristics under PSCs (listed in Table-2) of the PV system is depicted in Fig. 2.

3. Modified GWO

The process of hunting method by grey wolfs is used to develop Grey Wolf Optimization method [12]. A modified method is developed by using below equations:

$$\vec{W}_{\alpha} = \left|\vec{F}_1 \cdot \vec{P}_{\alpha}(i) - \vec{P}(i)\right|, \ \vec{W}_{\beta} = \left|\vec{F}_2 \cdot \vec{P}_{\beta}(i) - \vec{P}(i)\right|,$$

$$\vec{W}_{\delta} = \left|\vec{F}_3 \cdot \vec{P}_{\delta}(i) - \vec{P}(i)\right| \quad (2)$$

$$\vec{P}_1 = \vec{P}_{\alpha}(i) - \vec{D}_1 \cdot \vec{W}_{\alpha}, \ \vec{P}_1 = \vec{P}_{\alpha}(i) - \vec{D}_1 \cdot \vec{W}_{\alpha},$$

$$\vec{P}_1 = \vec{P}_\alpha(i) - \vec{D}_1 \cdot \vec{W}_\alpha \,, \tag{3}$$

$$\vec{P}(i+1) = \frac{\vec{P}_1 + \vec{P}_2 + \vec{P}_3}{3}, \;\; \vec{D} = 2\vec{b}\cdot\vec{r}_1 - \vec{b} \tag{4}$$

Where, current iteration is indicated by 'i'. $\vec{P}$ indicated the position of a grey wolf. The prey position is denoted by $\vec{P}_{p=\alpha,\beta,\delta}$. $\vec{W},\vec{D},\vec{F}$ are the coefficient vectors. A detailed flowchart of MGWO is depicted in Fig. 3.

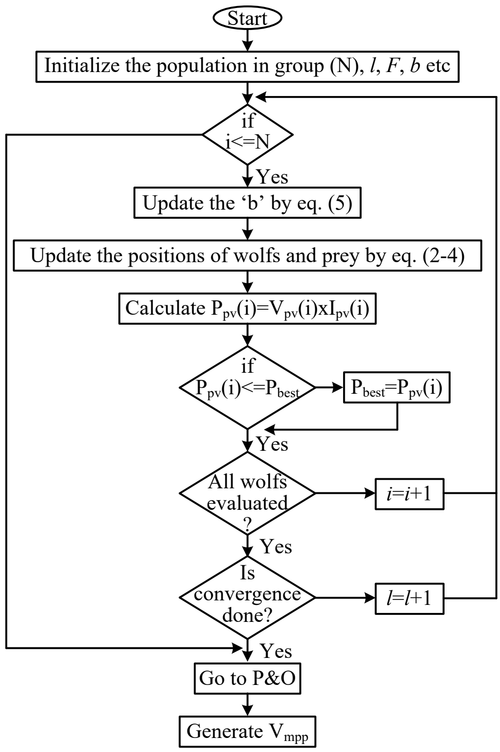

Fig. 3: Hybrid propose modified GWO+P&O based flowchart for MPPT.

The omega (ω) updates their locations based on the position of three best wolfs.The factor *'b'*isdecreasing linearly from [2 - 0] with the number of iterations (*l*). However, theconvergence process of conventional GWO technique is not linearly convergent. Therefore, the factor '*b*' is adopted by using a tangentfunction given by (5) in modified GWO (MGWO):

$$b = b_{ini} - (b_{ini} - b_{fin}) \times \tan\left[\frac{\pi l}{\varepsilon l_{\max}}\right] \tag{5}$$

Here, '*ini*' represents initial and '*fin*' refers final value. The term '*l*' represents the iteration for converging the solution. Adjustment coefficient is considered as 'ε'.
The dc-link voltage varies accordingly the variation in power from PV, at the same time the power balance is maintained by regulating the voltage across the dc-link at its reference. The model of SMC is designedby using references [13-14]. With the help of a proposed control method shown in Fig. 1 is used to generate required pulses for the converter.

4. Results and Discussions

In this work, the system's performance is improved under diverse scenarios using real-time simulators (RTS). The RTS modules such as OPAL-RT devices are connected to obtain HIL setup in the laboratory. Two OPAL-RT devices are used to establish HIL for making real time experience on testing of proposed complex controllers. The plant which consists of PV system, load and converter is dumped in OPAL-RT module 1 (i.e., OPAL RT-1). All the controllers are dumped in OPAL-RT module 2. The analog signals from the plant are converted to digital for making input to the controller unit (i.e., OPAL RT-2) through data cards. The controller module can perform as per designed controllers and generates respective switching pulses for converters used in the plant. The digital pulses will be converted to analog signals to make input signals for plant through external data cards. The required results are carried out by using a laptop instead of an oscilloscope for presenting with better visualization. The basic HIL setup with two OPAL-RT devices is depicted in Fig. 4.

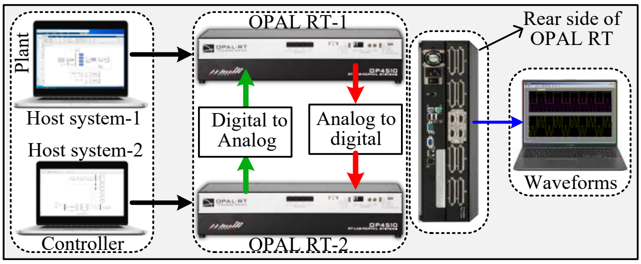

Fig. 4: HIL setup for results.

Case-1: Proposed MPPT Performance under PSCs

In this case study, considered three patterns of solar irradiances to evaluate performance of GA, PSO and proposed MGWO as signified in Fig. 5(a). The reference dc-link voltage (V_{mpp}=V^*_{dc}) is plotted in Fig. 5(b) for the above mentioned events and compared with the MGWO. The hybrid MGWO-P&O mechanismcan able to updates the V^*_{dc} to help the PV system to operate at MPPTfollowed byclimatologically changes.From the Fig. 5, it can be identified the significance of proposed MGWO-P&O technique for a better dynamic response ofV_{mpp} with faster converge as compared to the PSO integrated P&O [15] and GA integrated P&O [16]. The efficiency of the system is listed in Table-3. Other parameters are considered from [17].

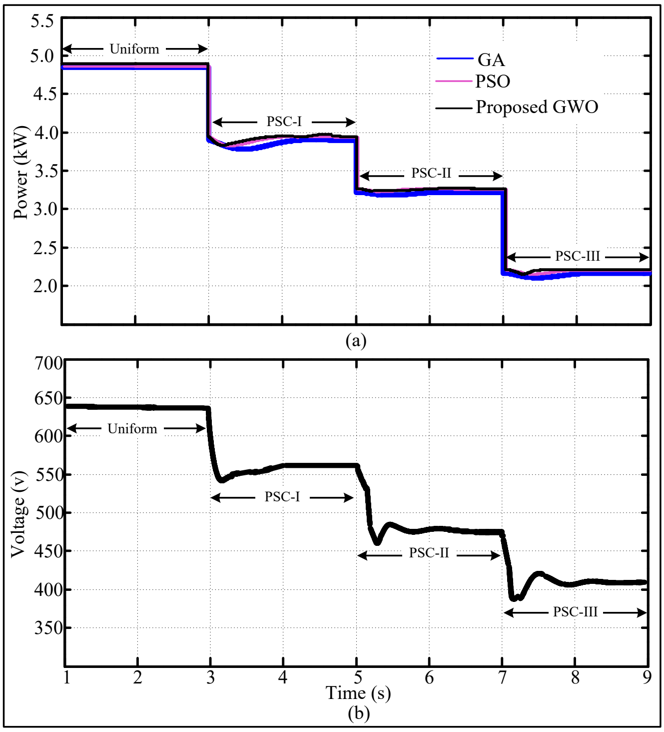

Fig. 5: (a) Power, (b) Actual DC-link voltage (V_{dc}).

Table-3: Comparative efficiency (η_{MPPT})

Factor	GA [16]	PSO [17]	MGWO
Efficiency	99.841%	99.916%	99.997%

Case-2: Under variations in irradiance

The system is examined during decreasing in solar irradiance at t=3.0sec from 1000 to 400 W/m^2. During this sudden change, the power availability of PV is reduced and corresponding reference signal of control technique will be adjusted by proposed method to achieve its maximum utilization. The converter can receive respective signals for switches of the converter from proposed block by comparing reference and actual voltage obtained from load bus. The actual power produced by PV system with the help of proposed method is following by reference power which is calculated from mathematical equations. Under this situation, ideal converter is considered while testing the system in HIL. Corresponding response of various powers is presented in Fig. 6. Due to changes in solar irradiance, the voltage at dc-bus is changed. The corresponding voltage at dc-bus' is depicted in Fig. 7.

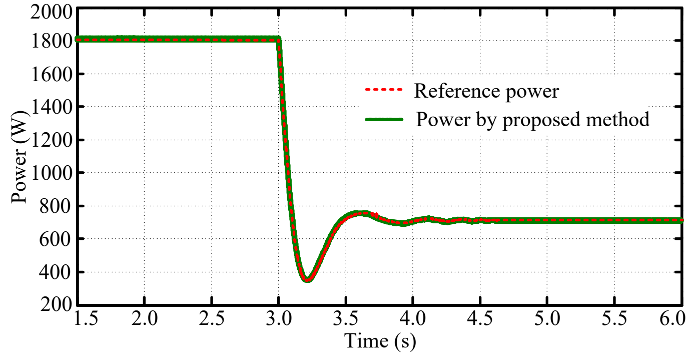

Fig. 6: Powers {reference and actual).

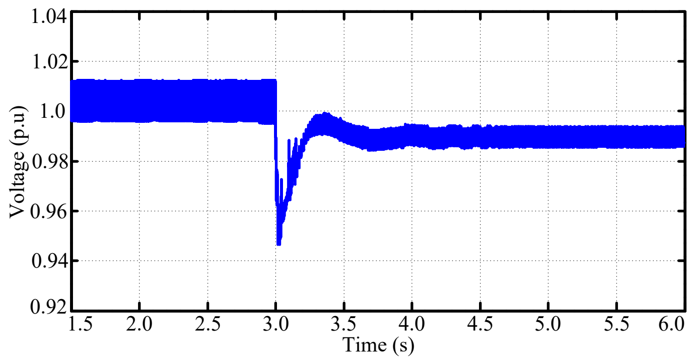

Fig. 7: Change in voltage at load bus.

5. Conclusions

The novel controller technique for achieving the operation of MPPT of PV system is presented in this paper with the help of MGWO technique. In order to identify the location (i.e., voltage position) corresponding to maximum power under partial shading conditions, MGWO is implemented and integrated with the control method of the converter. The efficiency of proposed method is also compared with other methods implemented recently. The proposed mechanism for obtaining maximum energy from PV system is significantly increased by using proposed method. Extensive results are examined by using HIL. The proposed method is regulating the converter, hence the converter is working as a MPPT of the PV system.

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