Modified Grey Wolf Optimization for Maximum Power Point Tracking in Photovoltaic System under Partial Shading Conditions

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Abstract: Maximum power point tracking (MPPT) is a method often used to maximize photovoltaic (PV) power output. In this paper, a modified gray wolf optimization (MGWO) is proposed to improve MPPT capability for PV in partial shade conditions. In the gray wolf optimization standard (GWO), it cannot maintain a balance between exploration of global optimization parameters and exploitation of local optimization parameters, which results in inaccurate optimal results. Therefore, the GWO is modified by updating alpha every iteration to increase the convergence speed and avoid local optima trapped by partial shading conditions. The proposed algorithm is implemented by an interleaved boost converter and a low-cost microcontroller. Simulation and experimental results show that the proposed algorithm can improve tracking performance speed and accuracy. The contribution of this invention can be applied to intelligent electronic devices (IEDs) as maximum power tracking based on embedded controllers.

Keywords: Photovoltaic (PV), Modified Grey Wolf Optimization (MGWO), Maximum Power Point Tracking (MPPT), partial shading conditions.

1. Introduction

Nowadays, renewable energy has an important role to fulfil the demand. The most widely used renewable energy is photovoltaic (PV).

When compared with other renewable energy, PV is found abundant in nature, has good environmental impact, and requires low maintenance. Since PV has low energy conversion efficiency, it requires a large investment cost [1]. Moreover, PV characteristics depends on irradiance and temperature. Therefore, to maximize the PV power output it requires to tracks the maximum power point (MPP), namely maximum power point tracking (MPPT).

There are many MPPT techniques to track the MPP [2]-[3]. The MPPT methods include perturb and observation (P&O) [4], Incremental conductance (IC) method [5], the factional short circuit current (FSCI) technique [6], the fractional open circuit voltage (FOCV) technique [7], the fuzzy logic inference system [8]-[10], artificial neural network [11], adaptive neuro fuzzy inference system [12] and the other intelligence techniques [13]-[15].

P&O algorithm is the most widely used for MPPT because it is simple and easy to implement. However, this method oscillates around at maximum power point (MPP) which yields low accuracy. To improve oscillations and accuracy, the modified P&O is proposed. This method improves not only the oscillations and accuracy, but also the perturbance size and rate [16]. However, this method is trapped in local optima for tracking the MPP under partial shading conditions.

This research focuses on tracking the MPP in the global optimal under partial shading conditions. To avoid the local optima trapped when tracking the MPP from partial shading conditions, the nature of optimization algorithm is used. The algorithm, such as firefly algorithm [13], [14], particle swarm optimization [15], Evolutionary Algorithm [17], genetic algorithm [18], Differential Evolution [19], modified Incremental Conductance (IncCond) [23] are developed to track the MPP. Genetic algorithm for MPPT under partial shading is introduced by Daraban, S. et. al. [18]. However, in partial shading conditions, simulation studies indicate that genetic algorithm cannot guarantee global convergence. Moreover,

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particle swarm optimization has simple computation for MPPT [20]. But, disadvantage of particle swarm optimization tends to random cause reduce efficiency of MPPT [21]. Recently, grey wolf optimization (GWO) for MPPT is developed by Mohanty, S. et al. [22].

However, GWO requires balance between exploration and exploitation, which affects inaccurate optimal result. Therefore, the modified grey wolf algorithm (MGWO) is proposed to maintain the balance. The algorithm, implemented by interleaved boost converter and low-cost microcontroller, is used to increase the performance of MPP tracking under partial shading conditions.

This paper is organized in several sections. Section I is the introduction. Section II is the characteristics of the PV system under partial shading conditions. Section III describes the proposed algorithm to track the MPP. Section IV presents the simulation and experimental results. Finally, section V presents the conclusion.

2. Characteristics of PV

The characteristics of PV module are presented by the current versus voltage (I-V) and the power versus voltage (P-V) curves. Figure 1-3 demonstrate the I-V and P-V characteristics of PV module at various irradiance and temperature levels.

Figure 2 and 3 show that the higher the irradiance level, the bigger the MPP from PV module, whereas the higher the temperature level, the smaller the MPP in P-V module. The parameter of PV module is shown in the Table I. In partial shading condition, three PVs connected in series. Each PV is given various irradiance, 300 W/m2, 1000 W/m2 and 350 W/m2 respectively. Figure 4 presents P-V characteristic at partial shading conditions, during partial shading conditions, PV arrasy produces multiple peaks are local and global maximum points, which its are observe in the P-V characteristics curve. Partial shading conditions occur because one of several PV modules closed.

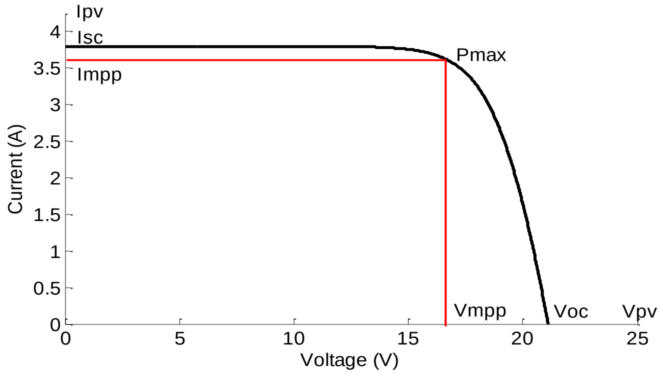

Figure 1. I-V characteristic of the PV module

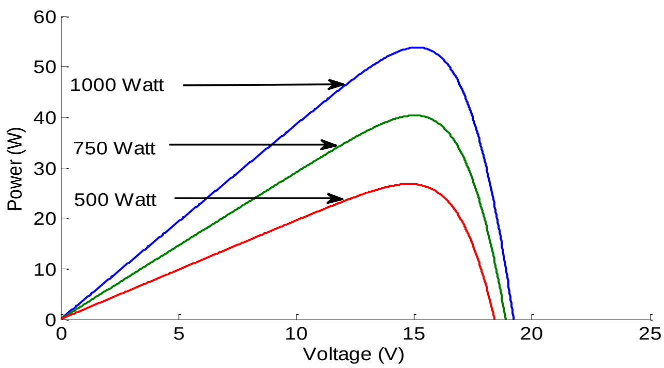

Figure 2. P-V characteristics at constant temperature and variable irradiance level

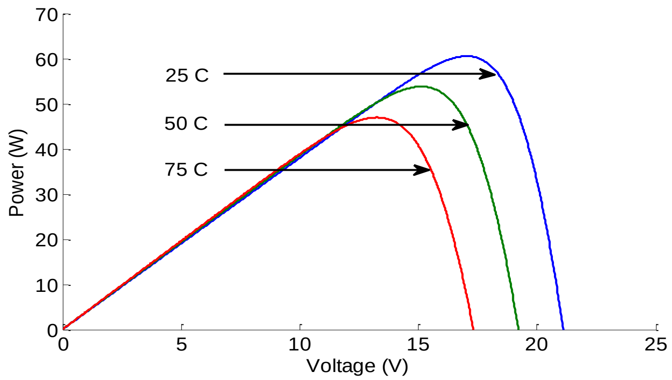

Figure 3. P-V characteristics at variable temperature and constant irradiance level

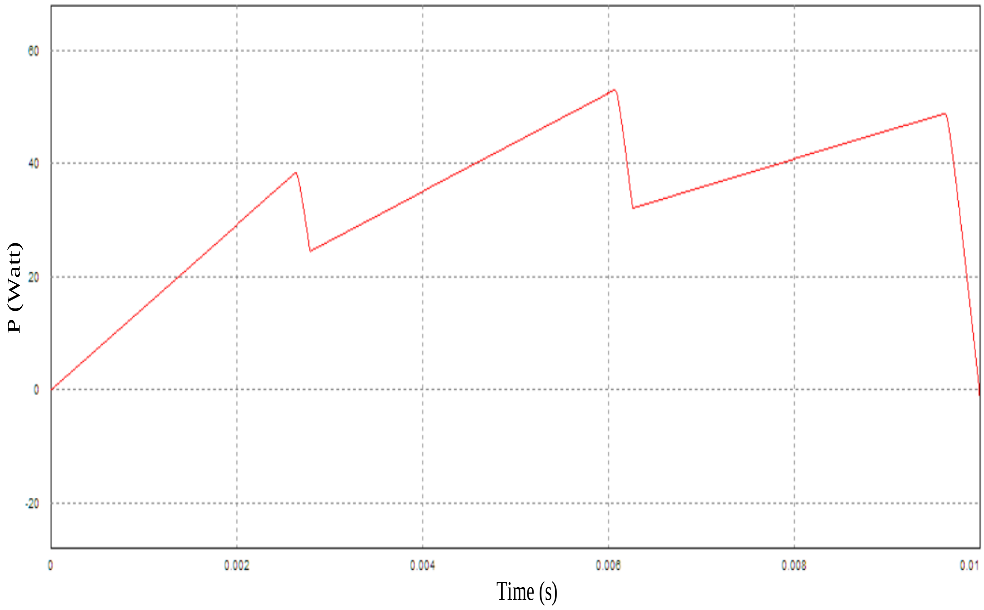

Figure 4. P-V characteristic at partial shading condition

3. Grey Wolf Optimization for MPPT

Grey Wolf Optimization (GWO) is an algorithm that is inspired by the life of grey wolf in nature. GWO used to simulate the leadership hierarchy for this algorithm has four types: alpha (α), beta (β), delta (δ), and omega (ω). Alpha (α) is the best solution for the result of this algorithm. Beta (β) and Delta (δ) are better solutions for GWO than Omega (ω). The main steps of the GWO algorithm are hunting, chasing, tracking prey, encircling prey, and attacking prey for designing GWO algorithm. The attacking behavior of prey can be modeled by the following equation:

$$\vec{D} = \left|\vec{C}.\vec{X}_p(t) - \vec{X}(t)\right| \quad (1)$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad (2)$$

Here, t is the current iteration, while *D*, *A*, and *C* are the coefficient vectors. *Xp* is the prey position vector, and *X* is the vector of the grey wolf position. The vectors *A* and *C* are calculated as follows:

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \quad (3)$$

$$\vec{C} = 2.\vec{r}_2 \quad (4)$$

Here, *a* is the component decreasing linearly from 2 to 0 during the iteration. r1 and r2 are random vectors at [0, 1]. To implement the GWO algorithm for MPPT, duty cycle *D* is defined as a grey wolf, so equation 2 can be modified to:

$$\mathrm{D}_i(\mathrm{k}+1) = D_i(\mathrm{k}) - A.\mathrm{D} \quad (5)$$

The fitness value of MGWO is presented by equation (6) as follow

$$P(d_i^k) > P(d_i^{k-1}) \quad (6)$$

Where *P* is power, *d* is duty cycle, *i* is the number of current grey wolves, and *k* is number of iterations.

4. The Proposed Algorithm for MPPT

The general approach in an algorithm is the division of the optimization process into two main issues of exploration and exploitation. Exploration encourages solutions to change suddenly and can lead many solutions. Exploitation aims to maintain the quality of solutions from exploration. With exploration, the algorithm can find the optimal results in the search space, and exploitation can reduce the variety of search results and maintain the quality of solutions. Therefore, it takes the right combination of both to find the optimal results when using population-based algorithms. In GWO algorithm, the change between exploration and exploitation is caused by the changing values from a and A. In this case, the half of iteration is exploration ($|A| \geq 1$), and the other is exploitation ($|A| \leq 1$).

In GWO for MPPT, the value of a decreases linearly from 2 to 0 using every changing equation, such as:

$$a = 2\left(1 - \frac{t}{T}\right) \quad (7)$$

Here, T denotes the maximum number of iterations, and t is the current iteration. GWO for MPPT uses exponential function to decrease α during iteration. The algorithm is named modified grey wolf optimization (MGWO).

$$a = 2\left(1 - \frac{t^2}{T^2}\right) \quad (8\_$$

5. Simulation Case Studies

To verify the proposed MPPT, the simulations were performed for 4 PV modules in which the configuration of series-parallel was under partial shading conditions. Figure 5 shows the block diagram of the system. The block diagram consists of PV system in PV array. DC-DC Interleaved Boost Converter was used for the implementation of MPPT. The voltage and current sensors were used for the MPPT parameters input. MPPT controllers are microcontroller and load. The parameters of the PV module were used for modelling as follows: Pmax = 100 W, Imp = 5,62 A, Vmp = 17,8 V, Voc = 21,8 V, Isc = 6,05 A. The PV modules were connected for 2 series 2 parallel, and 4 parallel. The components of DC-DC Interleaved Boost Converter were used in the simulation, and the experimental set up was chosen as L = 244,205 µH, Co = 20,979 µF, and the frequency switching was 40 kHz. Figure 6 shows the flowchart of the MGWO for MPPT.

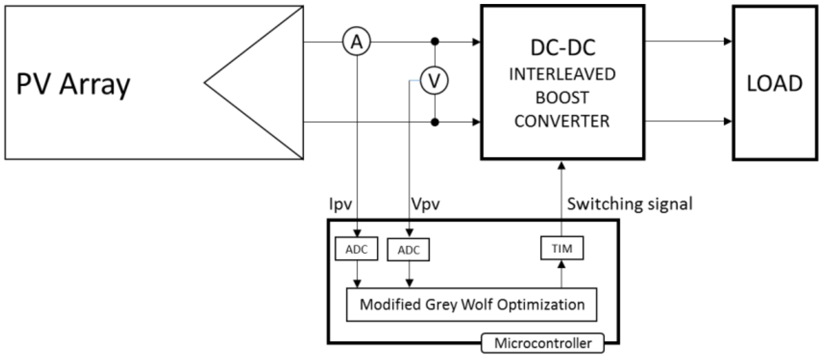

Figure 5. Diagram of Proposed MPPT Method

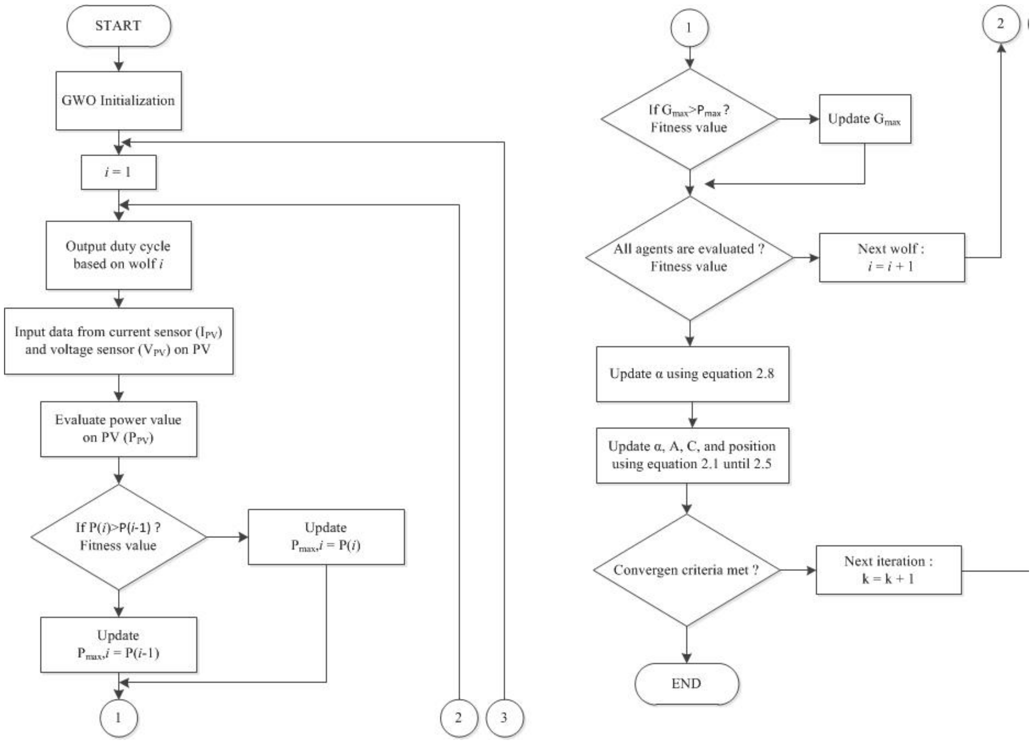

Figure 6. Flowchart of Modified Grey Wolf Optimization Algorithm

6. Result and Discussion

A. Simulation Result

To evaluate the performance of MGWO Algorithm, the performances were compared to the performances of GWO algorithm. Two methods were implemented with partial shading conditions. The configurations of photovoltaic are 4 parallel and 2 series 2 parallel. For the simulation, the parameters of photovoltaics were Pmax = 100 W, Imp = 5,62 A, Vmp = 17,8 V, Voc = 21,8 V, Isc = 6,05 A. The components for the design of Interleaved Boost Converter in simulation were chosen as Vin = 17,13 Volt, Vout = 48 Volt, L = 244,205 μH, C = 20,979 μF, the frequency switching was 40 kHz, and the voltage ripple was ≤ 1%.

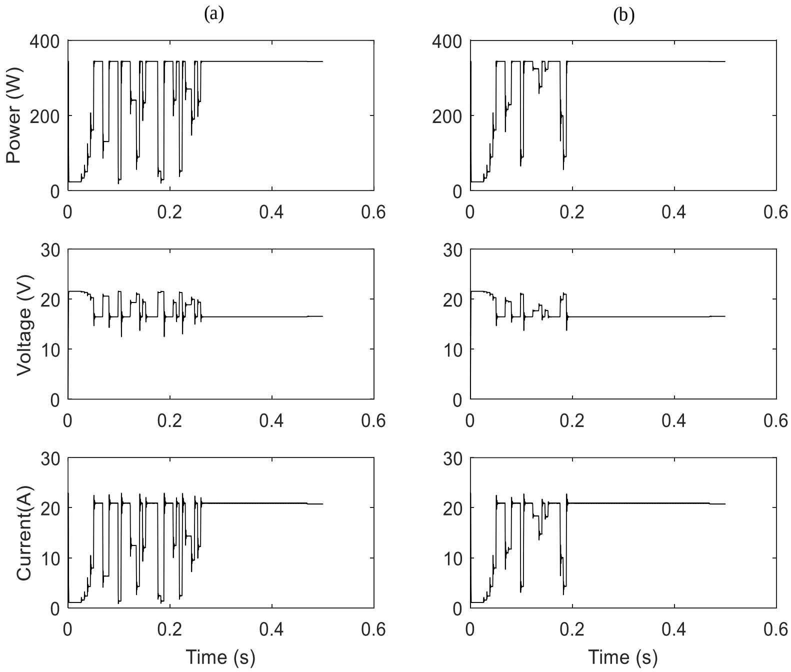

Figure 7a. Simulation Result of GWO for MPPT in combination of Photovoltaic is 4 parallel
b. Simulation Result of MGWO for MPPT in combination of Photovoltaic is 4

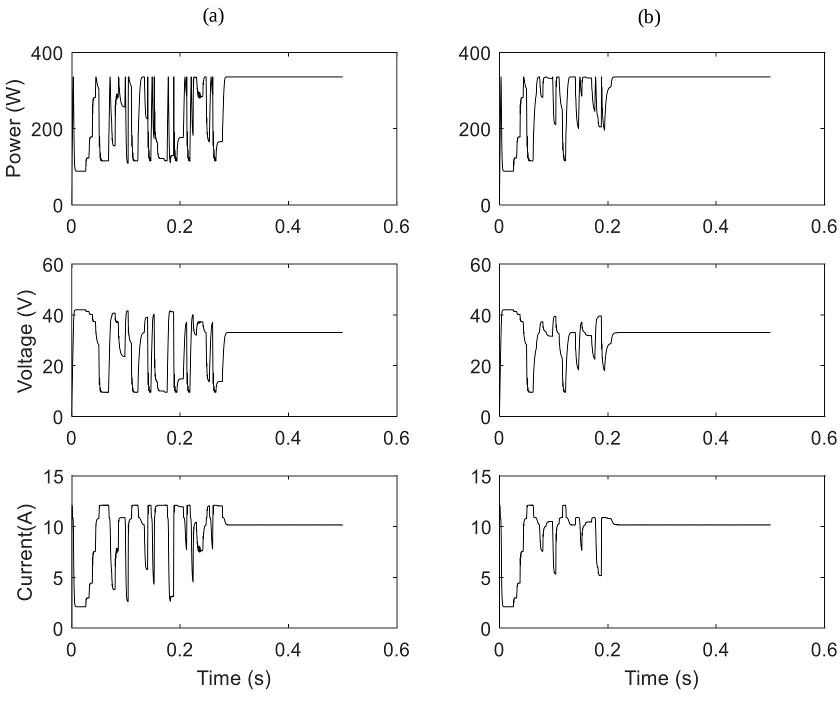

Figure 8a. Simulation Result of GWO for MPPT in combination of Photovoltaic is 2 series 2 parallel
b. Simulation Result of MGWO for MPPT in combination of Photovoltaic is 2 series 2 parallel

Table 1. Table Comparison about Non-MPPT and MGWO Algorithm in partial shading condition

Various Conditions	Tracking Methods	Power (W)	Voltage (V)	Current (A)	Tracking Speed (s)
4 parallel	GWO	343.61	15.873	21.647	0.261
	MGWO	344.65	16.238	21.225	0.189
2 series 2 parallel	GWO	335.56	33.02	10.16	0.284
	MGWO	335.76	32.98	10.18	0.21

Figure 7 shows the simulation result of GWO and MGWO for MPPT in combination with Photovoltaic in 4 parallel. The simulation result of GWO obtains MPP of 343.61 Watt. Moreover, the speed of GWO for achieveing MPP is 0.261 s. The simulation result of MGWO obtains MPP of 344.65 Watt. Moreover, the speed of GWO for achieveing MPP is 0.189 s.

Figure 8 shows the simulation result of GWO and MGWO for MPPT in combination with Photovoltaic in 2 series 2 parallel. The simulation result of GWO obtains MPP of 335.56. Watt. Moreover, the speed of GWO for achieveing MPP is 0.284 s. The simulation result of MGWO obtains MPP of 335.76 Watt. Moreover, the speed of MGWO for achieveing MPP is 0.21 s.

The simulation result shows that the proposed algorithm increases the tracking speed when it is compared to GWO. The proposed algorithm has the faster tracking speed because the value of α decreases exponentially during the iteration. In term of MPP accuracy, the proposed algorithm has good accuracy for MPP tracking. Moreover, the proposed algorithm has better MPP accuracy when it is compared to GWO.

B. Experiment Result

The experiment is conducted to verify the performance of the proposed MGWO Algorithm in partial shading condition. Figure 9 shows that the PV configuration of 4 parallel and 2 series 2 parallel is used to conduct the experiment. The power of PV configuration in this experiment is 400 WP. The PV configuration is integrated with converter, microcontroller system, and DC lamp load. Personal computer is used to receive data from microcontroller sent from Bluetooth to know the changes of voltage, current, and power. Irradiance meter is used to measure the irradiance, while thermogun is used to measure the temperature of PV System. The prototype is shown in Figure 9.

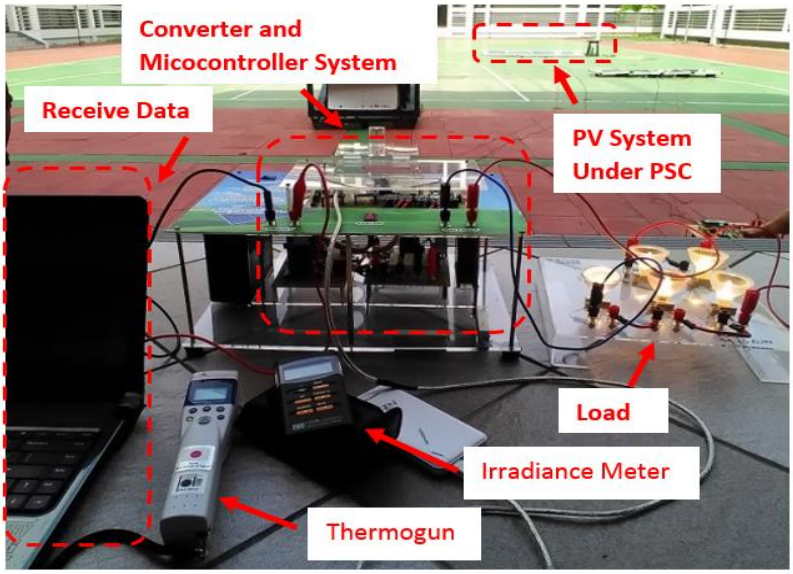

Figure 9. Prototype for experimental testing of the proposed algorithm

Figure 10 shows that the proposed algorithm for MPPT can achieve the convergence of MPP. Moreover, MPP can quickly be achieved by the proposed algorithm. As the proposed algorithm has small oscillations around MPP, the performance of MGWO demonstrates good accuracy and fast tracking for MPPT in partial shading condition.

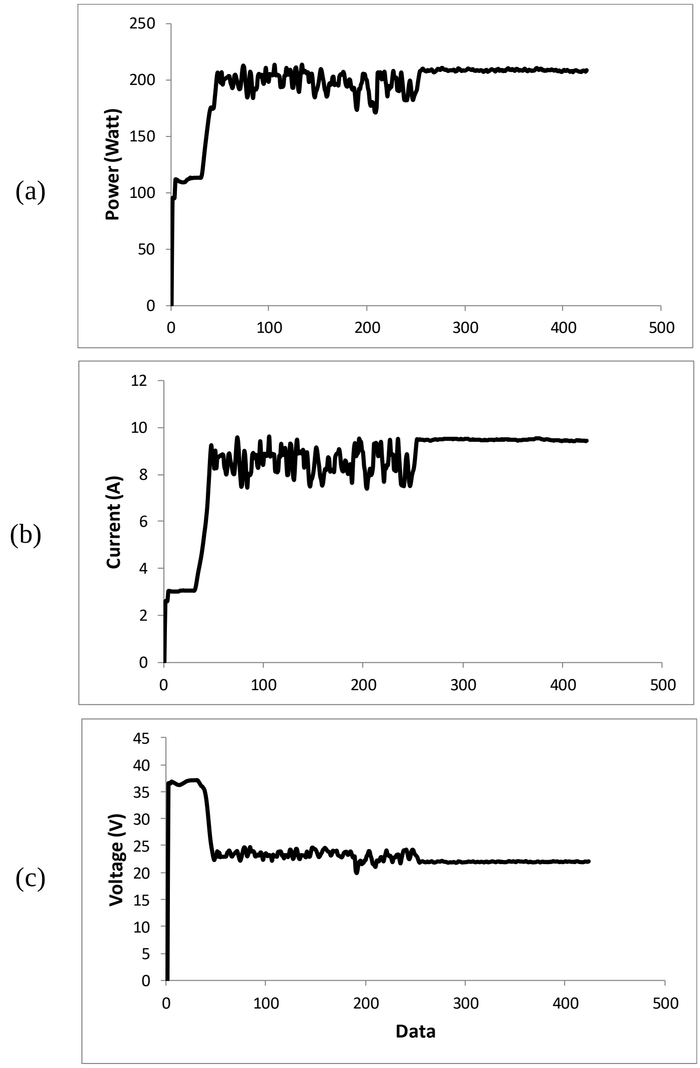

Figure 10. (a) the experiment result of power using MGWO for MPPT in partial shading condition, (b) the experiment result of current using MWGO for MPPT in partial shading condition, (c) the experiment result of voltage using MWGO for MPPT in partial shading condition

7. Conclusion

This paper has discussed the MGWO to track the MPP in PV system under partial shading condition. The performance of the proposed algorithm is evaluated using the simulation and experimental cases in 400 W prototype PV system under partial shading condition. In the experimental case, the proposed algorithm is implemented by interleaved boost converter and low-cost microcontroller. The simulation result show that the proposed algorithm has time for tracking speed of 0.189 s and 0.21 s more speed compared by GWO in various of PV system conditions. For maximum power tracking is obtained of 344, 65 W and 335,76 W more accurate compared by GWO in various of PV system conditions. The result shows that the proposed algorithm is superior when it is compared with GWO method in terms of tracking accuracy and speed. Moreover, the proposed algorithm has small oscillations around MPP.

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