Performance Optimization of Photovoltaic Pumping System Based Maximum Power Point Tracking Algorithm

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***Abstract*—The optimization of a standalone photovoltaic pumping system with integrated maximum power point tracking (MPPT) to reach an optimum power transfer is addressed in this paper. Due to the low efficiency of the solar photovoltaic, some MPPT methods are proposed to continuously deliver the highest power to the load under different weather condition. In the present work we present a comparative study between two maximum power point tracking that are perturb-and-observe method and incremental conductance method. The induction motor driven pump that is powered by a solar array is controlled by the field oriented control.**

***Index Terms*—renewable energy, photovoltaic pumping, maximum power point tracking (MPPT), induction motor**

I. Introduction

At present, efficient generation of green energy is the prime challenge for there searcher of this field. With the explosion of world population and rapid industrialization, energy demand is increasing drastically. But the natural sources of energy like coal, oil, and natural gas are limited. As a result, the only way to overcome the challenge is the development of renewable and inexhaustible energy. Among the renewable sources, solar energy is the pioneer. The features such as nontoxic, harmless, inexhaustible, and carbon dioxide emission free conversion have made this topic very interesting. But the energy conversion efficiency of solar system has not reached a satisfactory level yet, so the researches in this field continue. The recent trends on which research concentrates most are fabrication of effective PV cell, modification of cell arrangement and array configuration, implementation of maximum power point tracking algorithm, and so forth. Among the aforementioned, technology application of MPPT technique is the most popular because it improves the PV efficiency significantly. But the initial installment cost of a PV system with MPPT technique is very high. So, it is very important to carry out a reliable simulation before going for practical implementation [1]-[8].

The use of photovoltaic energy has been paying more attention and it is one of the most rapidly growing and the cleanest energy sources [9]. The electrical energy produced by photovoltaic energy can be exploited in different ways as it is inexhaustible nature, pollution free, distributed over the earth, maintenance free and continuous cost reduction, the most important advantage is the reduction of carbon dioxide emissions [10]-[13].

Moreover, it is possible to track the maximum power point tracking that's one of the key functions that every photovoltaic should have to optimize the energy captured [14]-[16]. The most popular applications of photovoltaic energy are the pumping system driven by electrical motors [17]-[20] that have become a favorable solution for water supply [21]. The directly connected P_v -Load offers a low cost implementation but it reduces the energy utilization efficiency system. However a Dc motor was already using but it suffer from maintenance problem and expensive price, the Induction motor is preferred since it requires less maintenance and cost. Furthermore, it is necessary to transfer the energy with minimum loss and obtain the best performance at all operating point, a significant improvement in energy utilization can be achieved by a maximum power point tracking controller to search the optimum power output of the Photovoltaic P_v array. Many of the research used a DC/DC converter to maximize the P_v cell by acting the converter's switching duty cycle [22]-[24]. Hence a pumping photovoltaic system described in this paper comprises the following components: P_v panel that converts sunlight into direct current (DC) electricity, which is fed to the induction motor via an inverter controlled by an MPPT algorithm, can be an attractive proposal. In addition, we choose store the water in the reservoir and consumed to demand to avoid the use of batteries. This brief is mainly organized as follows. The modeling of P_v pumping system is described in Section II. Section III discussed the control of the system. In Section IV the simulation results are given. Finally conclusion is presented in Section V.

II. Modeling of the Photovoltaic Pumping System

The power configuration of the studied photovoltaic pumping system is depicted in Fig. 1.

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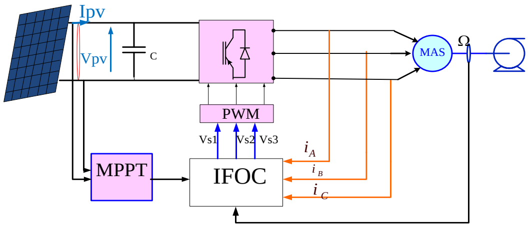

Figure 1. Bloc diagram of Pv pumping system

A. Modeling of Photovoltaic Array

The Photovoltaic module used in this system is a 36 multi-crystalline solar cell in series able to provide 53.32W of maximum power. A mathematical model of a solar cell can be treated as a current source parallel with a diode, the model is completed by a parallel resistor R_{sh} and a series resistor R_s as shown in Fig. 2.

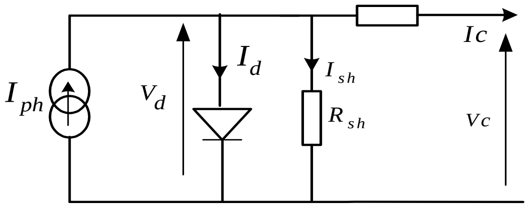

Figure 2. Equivalent circuit of a solar cell

Thus, to achieve the desired current and voltage, an association of N_s modules in series and in parallel N_p connected modules gives rise to a P_v generator, its output current voltage characteristic is given by (1) as in [11].

$$I_{pv} = N_p I_{ph} - N_p I_0 \left(\exp\left(\frac{\frac{V_{pv}}{N_s} + \frac{R_s I_{pv}}{N_p}}{a V_T} \right) - 1 \right) - \left(\frac{V_{pv} + \frac{N_s R_s I_{pv}}{N_p}}{\frac{R_{sh} N_s}{N_p}} \right) \quad (1)$$

With:

$$V_T = \frac{nKT}{q}$$

B. Modeling Motor-Pump

The electrical model of the induction machine in the d-q referential axis can be written as follows: The stator and rotor voltages are governed by the following differential equations:

$$\begin{cases} v_{sd} = R_s . i_{sd} + \frac{d\Phi_{sd}}{dt} - w_s . \Phi_{sq} \\ v_{sq} = R_s . i_{sq} + \frac{d\Phi_{sq}}{dt} + w_s . \Phi_{sd} \\ 0 = R_r . i_{rd} + \frac{d\Phi_{rd}}{dt} - w_r . \Phi_{rq} \\ 0 = R_r . i_{rq} + \frac{d\Phi_{rq}}{dt} + w_r . \Phi_{rd} \end{cases} \quad (2)$$

The flux of the induction machine is given by:

$$\begin{cases} \Phi_{sd} = L_s . i_{sd} + M . i_{rd} \\ \Phi_{sq} = L_s . i_{sq} + M . i_{rq} \\ \Phi_{rd} = L_r . i_{rd} + M . i_{sd} \\ \Phi_{rq} = L_r . i_{rq} + M . i_{sq} \end{cases} \quad (3)$$

The electromagnetic torque produced can be expressed by:

$$Cem = \frac{3}{2} \frac{pM}{L_r} (\phi_{rd} i_{sq} - \phi_{rq} i_{sd}) \quad (4)$$

Assuming ideal power switches, the output voltage (V_A, V_B, V_C) of the inverter is given by:

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \frac{V_p}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} \quad (5)$$

where $C1$, $C2$, $C3$ are the controller signals applied to the switches and V_{pv} was the array voltage.

The water pump chosen is a centrifugal pump applies a load torque proportional to the square of the rotor speed.

$$C_r = K\Omega^2$$

III. Control System

The photovoltaic array is regulated at the optimum power point that it can provide to obtain best performance from the system.

A. MPPT Control Algorithm

The aim of the maximum power point tracking is to extract the maximum output power, The MPPT used in this paper based on two algorithms that are perturb and observe algorithm and Incremental conductance.

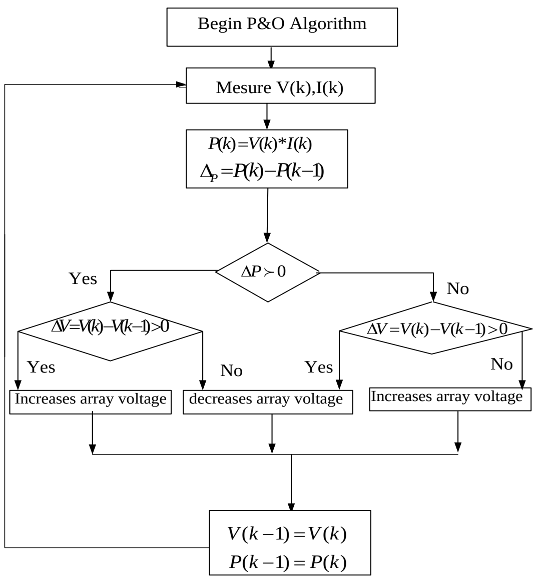

Figure 3. Flowchart for P&O

1) Perturb and observe

Perturb and observe algorithm is very popular and widely used in control of MPPT because of its law-cost, simplicity and ease of implementation [12]. The MPPT is continuously subjected to two excitation source, the first originating from the weather condition and the other from the perturbation of the tracking algorithm [18]. Basically, it is based on the following criterion: the module voltage is perturbed by a small increment, and the resulting change in the power is observed. If the change in power is positive, the voltage is adjusted by the same increment, and the power is again observed. This continues until the change in power is negative, at which point the direction of the change in voltage is reversed [13].

Fig. 3 shows the flowchart that corresponds to the P&O implemented algorithm [14], [15].

2) Incremental conduction algorithm

The Incremental Conductance method offers good performance under rapidly changing atmospheric conditions. The derivative of output power P with respective to panel voltage V_{Pv} is equal to zero at Maximum Power Point (MPP). The slope of the PV array power curve is zero at the MPP, increasing on the left of the MPP and decreasing on the right-hand side of the MPP. The basic equations of this method are as follows [16], [17]:

$$\begin{cases} \dfrac{dI_{pv}}{dV_{pv}} = -\dfrac{I_{pv}}{V_{pv}} & \text{for } V = V_{mp} \\ \dfrac{dI_{pv}}{dV_{pv}} > -\dfrac{I_{pv}}{V_{pv}} & \text{for } V < V_{mp} \\ \dfrac{dI_{pv}}{dV_{pv}} < -\dfrac{I_{pv}}{V_{pv}} & \text{for } V > V_{mp} \end{cases} \quad (6)$$

Fig. 4 shows the flowchart that corresponds to the IC implemented algorithm [16].

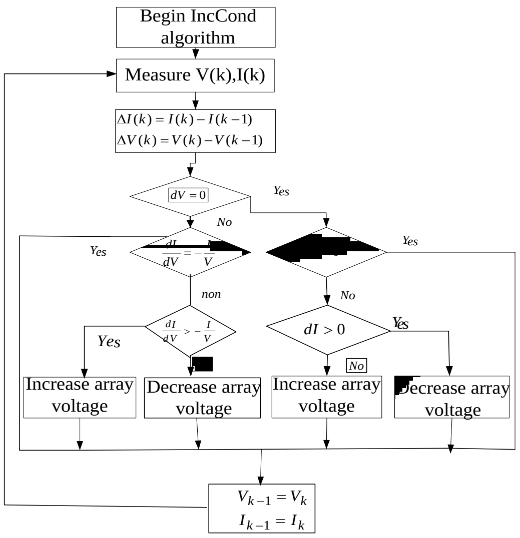

Figure 4. Flowchart of the IC method

The disadvantage of this algorithm is increased complexity compared to perturb and observe algorithm.

B. Control of the Induction Machine

The IFOC control ensures the decoupling between the flux and the torque in order to control the rotor flux, the speed and the two stator currents. The electromagnetic torque becomes proportional to the stator quadrature current as a similar to a DC machine. The field oriented control is obtained by (7).

$$\begin{cases} \phi_{dr} = \phi_r \\ \phi_{qr} = 0 \end{cases} \quad (7)$$

Thus the equations (2) and (4) become:

$$\begin{cases} \dfrac{di_{ds}}{dt} = \dfrac{1}{\sigma L_s}\left[-R_s i_{ds} - w_s \sigma L_s i_{qs} + \dfrac{M}{L_r}\dfrac{d\phi_r}{dt} + V_{ds}\right] \\ \dfrac{di_{qs}}{dt} = \dfrac{1}{\sigma L_s}\left[-R_s i_{qs} - w_s \sigma L_s i_{ds} - \dfrac{M}{L_r} w_s \phi_r + V_{qs}\right] \\ \dfrac{d\phi_r}{dt} = \dfrac{M}{\tau_r} i_{ds} - \dfrac{1}{\tau_r}\varphi_r \\ w_s = \dfrac{M}{\tau_r}\dfrac{i_{qs}}{\phi_r} + p\Omega \\ Cem = \dfrac{3pM}{2L_r}\phi_r iqs \end{cases} \quad (8)$$

IV. Simulation Results of the System

A. MPPT Simulation

The simulation result obtained of the proposed control technique applied to the photovoltaic pumping system using parameters given in Appendix are the following. Fig 5 and Fig. 6 present the evolution of Power voltage and current voltage characteristic by P&O algorithm during a variation transient in solar radiation, the irradiation varies from 200W/m² to 1000w/m² assuming constant temperature 298K. It can be seen that the increase of the illumination explained by an increase of the maximum power available and the system track the new maximum power point tracking very quickly when the weather change suddenly but the operating point oscillates around The MPP, resulting loss in power system. These oscillations would reduce the effectiveness of the photovoltaic power.

1) P_v Panel simulation with P&O controller

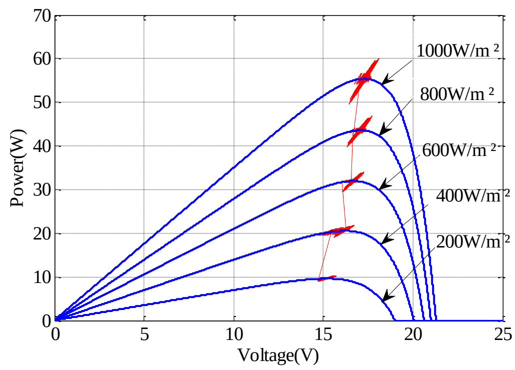

Figure 5. Power-Voltage characteristics

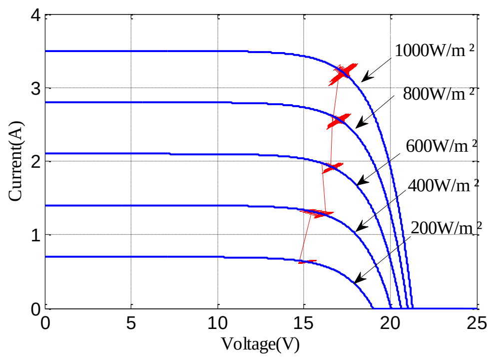

Figure 6. Current-Voltage characteristics

Fig. 7 and Fig. 8 show the IC algorithm efficiencies that the MPP has reached without perturb the operating point from begin to end of the simulation.

2) P_V Panel simulation with IC controller

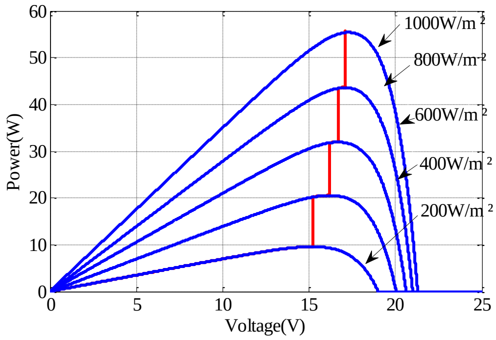

Figure 7. Power-Voltage characteristics

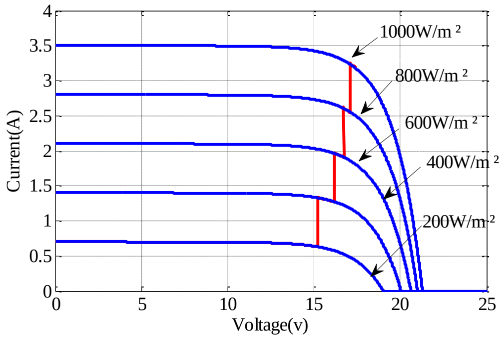

Figure 8. Current-Voltage characteristics

Comparison of P&O controller and IC, in this system shows that incremental conductance given better results than perturb and observe, it improved stability and offered higher energy utilization efficiencies compared to P&O algorithm, The MPPT without oscillations is desirable, for this reason we choose using the IC employed in our standalone P_V pumping system to further reduce the power loss. For the pumping photovoltaic Simulation, initially, we considered a fixed illumination E=1000W/m ²and a variable temperature Fig. 9 to see its impact on the power generator photovoltaic. Then we can show a good convergence of the power generator P_V to its optimum value.

3) Variation of the temperature value T

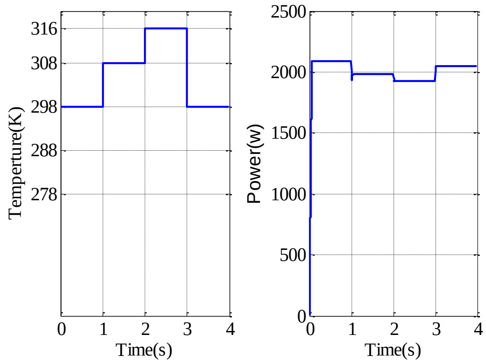

Figure 9. Profile of the Temperature and the power produced by G_{Pv}

4) Variation of the solar illumination value E

In order to test the continuation of the P_{max} , we choose to vary the solar illumination value E as it is shown in Fig. 10, and to see its impact on the performances of the photovoltaic pumping.

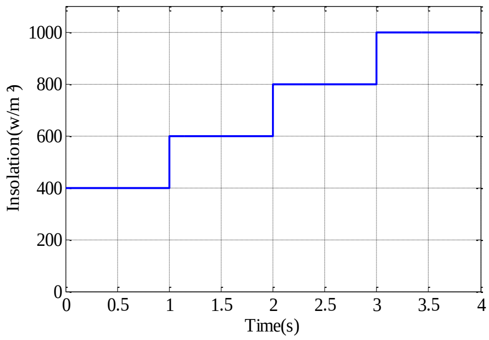

Figure 10. Variation in solar radiation

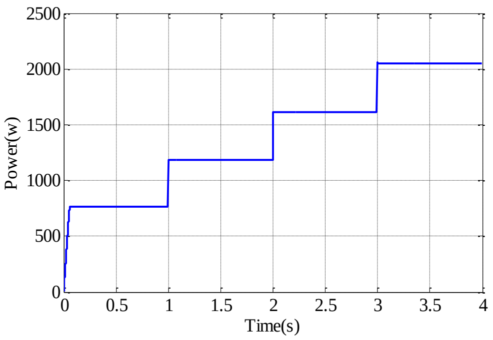

Figure 11. P_V array power for sudden increase in illumination

The simulation results (Fig. 9, Fig. 11) showed the excellent performance of the P_V control in response to serve change in temperature and solar intensity condition. The output power of the generator photovoltaic system was substantially change with the weather condition.

Fig. 12, Fig. 13 and Fig. 14 illustrates the pump flow, the waveform of the mechanical speed (N), and the electromagnetic torque wave form of the induction motor, there are a small transitory on the tracking to their reference which are stabilize at their reference value during a time of 0.1s and closed to their optimal value for different value of insulation.

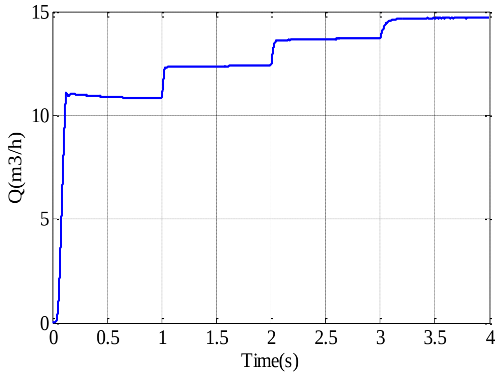

Figure 12. Evolution of the pump flow

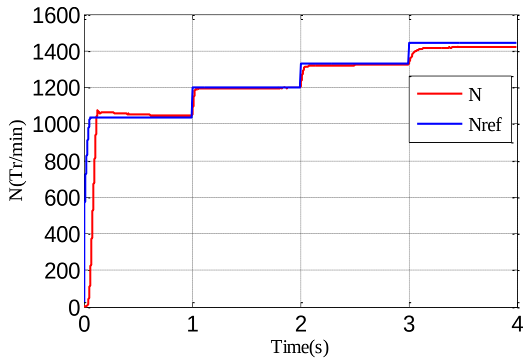

Figure 13. Evolution of the mechanical speed

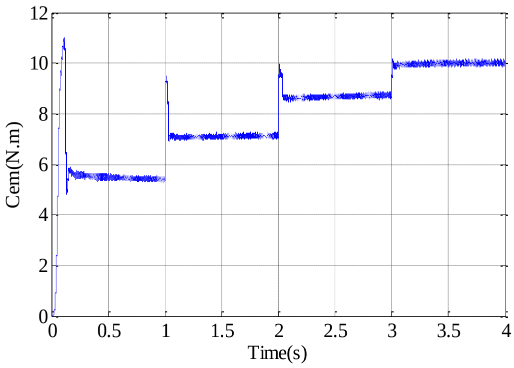

Figure 14. Evolution of the torque

V. Conclusion

The proposed system was simulated, we introduced an approach of modeling and control of a photovoltaic pumping system. From the results acquired during the simulations, we show clearly the benefits of the MPPT algorithm which can significantly increase the efficiency of energy production and assure better tracking performance under different weather condition. Results presented in this paper demonstrate that the proposed system has a faster response to transient temperature and irradiation.

Control and analysis of hybrid system will follow in future work.

Acknowledgements

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References

[1] K. Ishaque, Z. Salam, M. Amjad, and S. Mekhilef, "An improved particle swarm optimization (PSO)-based MPPT for PV with reduced steady-state oscillation," *IEEE Transactions on Power Electronics*, vol. 27, no. 8, pp. 3627-3638, 2012.

[2] J. Hernandez, W. Vallejo, and G. Gordillo, "Practical method for estimating the power and energy delivered by photovoltaic modules operating undernon-standard conditions," *Progress in Photovoltaic: Research and Applications*, vol. 21, pp. 867-875, 2012.

[3] D. Sera, L. Mathe, T. Kerekes, S. V. Spataru, and R. Teodorescu, "On the perturb-and-observe and incremental conductance MPPT methods for PV systems," *IEEE Journal of Photovoltaics*, vol. 3, no. 3, pp. 1070-1078, 2013.

[4] M. Chergui and M. Bourahla, "Contribution to improve the direct torque control in the photovoltaic pumping," in *Proc. IEEE Conference on Developments in E-Systems Engineering*, 2011, pp. 602-607.

[5] S. K. Kollimalla and M. K. Mishra, "Adaptive perturb & observe MPPT algorithm for photovoltaic system," in *Proc. IEEE on Power and Energy Conference at Illinois*, 2013, pp. 42-47.

[6] A. Khiareddine, C. Ben Salah, and M. F. Mimouni, "Determination of the target speed corresponding to the optimum functioning of a photovoltaic system pumping and regulation of the water level," in *Proc. International Conference on Electrical Engineering and Software Applications (ICEESA)*, 2013, pp. 1-5.

[7] A. Acakpovi, F. F. Xavier, and R. Awuah-Baffour, "Analytical method of sizing photovoltaic water pumping system," in *Proc. International Conference on Adaptive Science & Technology (ICAST)*, 2012, pp. 65-69.

[8] N. N. Singh, S. P. Singh, D. Singh, B. Singh, and R. P. Vishvakarma, "An efficient control on photovoltaic energy conversion system using modified perturb and observe technique for stand alone applications," in *Proc. IEEE Student's Conf. on Electrical, Electronics and Computer Science (SCEECS)*, 2012, pp. 1-4.

[9] S. G. Malla, C. N. Bhende, and S. Mishra, "Photovoltaic based water pumping system," in *Proc. IEEE Conference on Energy, Automation, and Signal (ICEAS)*, 2011, pp. 1-4.

[10] S. Umashankar, D. Vijayakumar, and D. P. Kothari, "Perturb and observe MPPT algorithm for solar PV systems-modeling and simulation," in *Proc. IEEE on India Conference (INDICON)*, 2011, pp. 1-6.

[11] M. Khelif, A. M'raoui, and A. Malek, "Simulation, optimization and performance analysis of an analog, easy to implement, perturb and observe MPPT technique to be used in a 1.5KWp photovoltaic system," in *Proc. IEEE on Renewable and Sustainable Energy Conference (IRSEC)*, 2013, pp. 10-17.

[12] L. Piegari and R. Rizzo, "Adaptive perturb and observe algorithm for photovoltaic maximum power point tracking," *IET Journals and Magazines on Renewable Power Generation*, vol. 4, no. 4, pp. 317-328, 2010.

[13] S. Bal and B. C. Babu, "Comparative study between P&O and current compensation method for MPPT of PV energy system," in *Proc. IEEE Conference on Engineering and Systems (SCES)*, 2012, pp. 1-6.

[14] J. Chauhan, P. Chauhan, T. Maniar, and A. Joshi, "Comparison of MPPT algorithms for DC-DC converters based photovoltaic systems," in *Proc. IEEE Conference on Energy Efficient Technologies for Sustainability (ICEETS)*, 2013, pp. 476-481.

[15] R. Roshan, Y. Yadav, S. Umashankar, D. Vijayakumar, and D. P. Kothari, "Modeling and simulation of incremental conductance MPPT algorithm based solar photo voltaic system using CUK converter," in *Proc. IEEE Conference on Energy Efficient Technologies for Sustainability (ICEETS)*, 2013, pp. 584-589.

[16] A. Safari and S. Mekhilef, "Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter," *IEEE Transaction on Industrial Electronics*, vol. 58, no. 4, pp. 1154-1161, 2011.

[17] M. A. Elgendy, B. Zahawi, and D. J. Atkinson, "Assessment of perturb and observe MPPT algorithm implementation techniques for PV pumping applications," *IEEE Transactions on Sustainable Energy*, vol. 3, no. 1, 2012.

[18] K. Ishaque, Z. Salam, and S. Syafaruddin, "A comprehensive MATLAB simulink PV system simulator with partial shading

capability base don two-diode model," *Solar Energy*, vol. 85, no. 9, pp. 2217-2227, 2011.
[19] K. Ishaque, Z. Salam, A. Shamsudin, and M. Amjad, "A direct control based maximum power point tracking method for photo voltaic system under partial shading conditions using particle swarm optimization algorithm," *Applied Energy*, vol. 99, pp. 414-422, 2012.
[20] K. Ishaque, Z. Salam, H. Taheri, and S. Syafaruddin, "Modeling and simulation of photovoltaic (PV) system during partial shading based on a two-diode model," *Simulation Modelling Practice and Theory*, vol. 19, no. 7, pp. 1613-1626, 2011.
[21] B. Liuand and S. Duan, "Energy efficiency evaluation of building integrated photovoltaic systems with different power configurations," *Simulation Modelling Practice and Theory*, vol. 29, pp. 93-108, 2012.
[22] K. Ishaque, Z. Salam, S. Mekhilef, and A. Shamsudin, "Parameter extraction of solar cell using penalty based differential evolution," *Applied Energy*, vol. 99, pp. 297-308, 2012.
[23] A. Jusoh, H. Baamodi, and S. Mekhilef, "Active damping network in DC distributed power system driven by photovoltaic system," *Solar Energy*, vol. 87, pp. 254-267, 2013.
[24] S. M. Mehdi, M. Saad, R. Rasoul, R. Yusof, and E. T. Renani, "Analytical modelling of partially shaded photovoltaic systems," *Energies*, vol. 6, no.1, pp. 128-144, 2013.

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