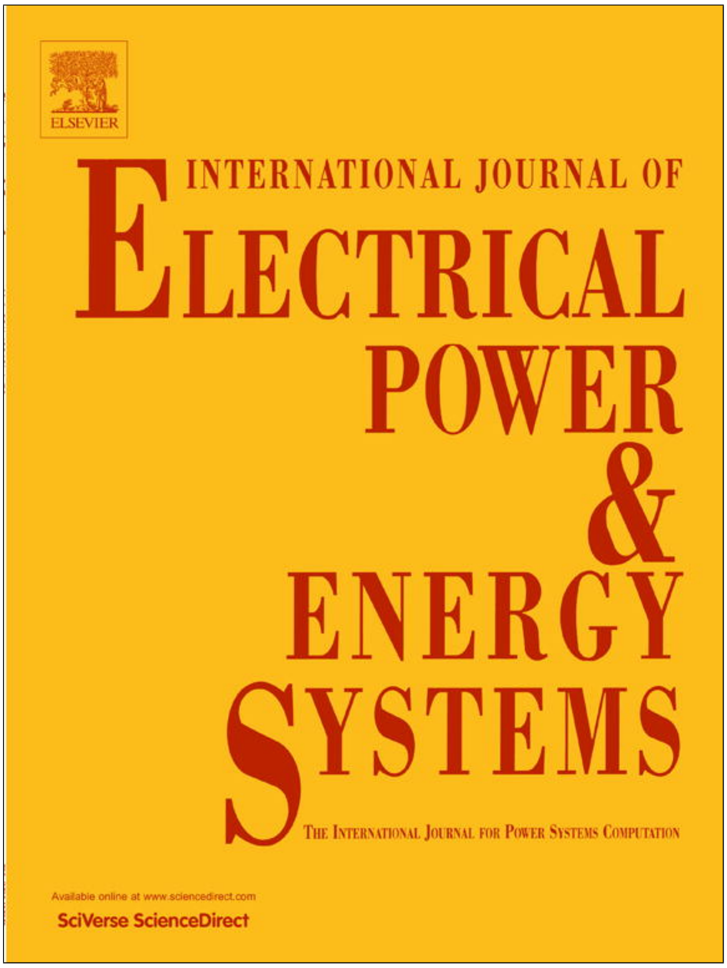

ELSEVIER
INTERNATIONAL JOURNAL OF
ELECTRICAL
POWER
&
ENERGY
SYSTEMS
THE INTERNATIONAL JOURNAL FOR POWER SYSTEMS COMPUTATION
Available online at www.sciencedirect.com
SciVerse ScienceDirect

Electrical Power and Energy Systems 53 (2013) 237–243

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A high performance maximum power point tracker for PV systems

Ali Akbar Ghassami *, Seyed Mohammad Sadeghzadeh, Asma Soleimani

Shahed University, Tehran, Iran

ARTICLE INFO

Article history:
Received 29 September 2012
Received in revised form 25 March 2013
Accepted 17 April 2013

Keywords:
Modified P&O and INC algorithm
MATLAB/SIMULINK
DC/DC converter
Rapidly changing atmospheric
Improving efficiency

ABSTRACT

The solar cell characteristics are non-linear and largely influenced by solar radiation, temperature and load condition. The power output of a PV array changes with varying temperature and irradiation. A maximum power point algorithm is investigated to obtain maximum power from a PV array on varying operating conditions. So far various methods have been proposed to achieve the maximum power from PV module. The incremental conductance (INC) and perturb and observe (P&O) algorithm are more noteworthy. In this paper two high performance and simple maximum power point tracker (MPPT) are proposed. These algorithms are modified P&O and INC algorithms. These modified algorithms are capable to track maximum power under rapidly changing atmospheric conditions with higher accuracy than their conventional methods. They increase the harvested power from PV array and thus improve the efficiency of MPPT algorithm. The algorithms using a high step-up-DC/DC converter are implemented on MATLAB/SIMULINK tool. The results demonstrate a good performance and accurate tracking under rapidly changing atmospheric conditions.

1. Introduction

Due to diminishing deposits of non-renewable energy resources, high oil prices and increasing damages to our environment, the renewable sources of energy have been attained the especial importance. Among several renewable energy sources, the Photovoltaic arrays are is more considerable as renewable sources due to the advantages such as abundance, no noise at all, and no pollution. The PV industry is growing rapidly which the annual growth rate has been more than 40% for the last decade [1]. The development of the solar cells and the power electronics devices has accelerated this growth. However, high cost and low efficiency in energy conversion limit the implementation of photovoltaic systems. On the other hand the price of photovoltaic modules is declining. The PV prices dropping consistently by 22% each time the cumulated global production is doubles and the PV prices have dropped by 40% over the last 2 years and are expected to decrease up to 60% in 2020 [2]. The power output of a photovoltaic cell changes with a varying temperature and irradiation. Therefore a maximum power point algorithm is used to obtain maximum power from a PV array under varying operating conditions. So far various algorithms for tracking maximum power point have been proposed. In reference [3] an overview of these methods has been done. Among several mppt algorithms, the Perturb & Observe (P&O) and Incremental Conductance methods are more considerable than other algorithms due to the advantages such as the implementation simplicity and independence to PV array. The Fuzzy logic and the neural network controllers have the advantages of working with imprecise inputs not needing an accurate mathematical model and handling nonlinearity [4,5]. However, the implementation of these algorithms is limited because of the implementation complexity and dependent to the PV array and periodic tuning. On the other hand, The P&O algorithm can fail under rapidly changing atmospheric conditions. The incremental conductance method is based on the slope of the PV array power curve [6]. This method has partly solved divergence of the P&O algorithm from the MPP under rapidly changing atmospheric conditions and track maximum power point with higher accuracy than the conventional P&O method [7]. In this paper two high performance and simple maximum power point tracker (MPPT) are proposed. These algorithms are modified P&O and INC algorithms. The modified algorithms are capable to track maximum power under rapidly changing atmospheric conditions with higher accuracy than their conventional methods. The MPPT algorithms are simulated in MATLAB software using a high-step-up DC/DC converter. Simulation results describe the good performance of modified algorithms. The reminder of this study is structured as follows. Section 2 explains Model and a characteristic of a PV cell, Section 3 presents the P&O algorithm and its drawback. Section 4 will present the modified P&O algorithm. The INC algorithm and the modified INC algorithm are presented in Sections 5 and 6. The simulation results are presented in Section 7. Finally, the conclusions are presented in Section 8.

* Corresponding author. Tel.: +98 9133414769.
E-mail addresses: ali_ghassami@yahoo.com (AA. Ghassami), sadeghzadeh@shahed.ac.ir (SM. Sadeghzadeh), a10soleimani@yahoo.com (A. Soleimani).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.04.017

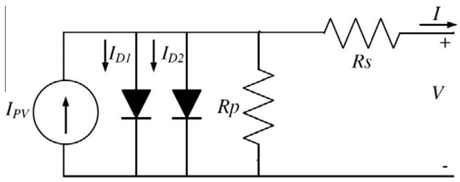


Fig. 1. Electrical model of solar PV module.

2. Model and characteristics of a PV cell

The equivalent electrical circuit of the module applied in this study is shown in Fig. 1. The model utilizes a two diode model to represent the PV cell. The model is known to have more accurate prediction of the PV system performance during partial shading condition [8]. A applied solar panel in this study, is collection of 40 cells of the polycrystalline silicon connected in series with maximum power of 100 W; open circuit voltage of 24.6 V, short-circuit current of 5.3 A; voltage of maximum power 19.6 V.

In this model the cell output current according to the following equation is obtained.

$$I = I_{PV} - I_{o1}\left[\exp\left(\frac{V+IR_s}{\alpha_1 V_{T1}}\right) - 1\right] - I_{o2}\left[\exp\left(\frac{V+IR_s}{\alpha_2 V_{T2}}\right) - 1\right] - \left(\frac{V+IR_s}{R_p}\right) \quad (1)$$

$$I_{PV} = \left(I_{PV-STC} + K_i(T - T_{ref})\right)\frac{G}{G_{STC}} \quad (2)$$

$$I_{o1} = I_{o2} = I_o \ldots = \frac{(I_{PV-STC} + K_i(T - T_{ref}))}{\exp[(V_{oc,STC} + K_v(T - T_{ref}))/((\alpha_1+\alpha_2)/p)V_T] - 1} \quad (3)$$

where I_{PV} is the current generated by the incidence of light. V is the output voltage cell and I is the output current cell. I_{02} and I_{01} are the reverse saturation currents of diode 1 and diode 2 that According to reference of [9], both saturation Currents can be calculated by equation of (3). α_1 and α_2 are diffusion and recombination current component and $p = \alpha_1 + \alpha_2$. The value of α_1, according to Shockley's diffusion theory, must be unity [9]. Due to the best match between the proposed model and the I–V curve on the datasheet, the value of α_2 is choosed with 1.2. $V_{T1,2} = N_s kT/q$ is the thermal voltage of the PV module that N_s is number of cells connected in series, $q = 1.602 \times 10^{-19} c$ and $K = 1.38 \times 10^{-23}$ J/K and T is the cell temperature in Kelvin (K). $I_{PV/STC}$ is generated current in STC, T_{ref} is the reference temperature of PV cell in Kelvin (K), usually 298 K (25). K_i is the temperature coefficient of short circuit current in percent change per degree temperature also given in the datasheet. G is the value of irradiance, which is normally mW/cm^2 and G_{ref} (100 mW/cm^2) is the nominal value of irradiance. The values of R_p and R_s are computed by an efficient iteration method using open-circuit voltage, short-circuit current and voltage–current of maximum power point. The characteristic Eqs. (1)–(3) of the PV module are implemented in MatLab simulink as shown in Fig. 2.

The voltage is considered changing from 0 to open circuit voltage corresponding to the variation in current from short circuit current to 0. Fig. 3 shows the power–voltage and current–voltage characteristic with the variation in solar insolation level at cell various temperatures.

As seen in Fig. 3 with a increasing in temperature and a decreasing in irradiation, the solar power decreases and also there exists a peak power corresponding to a particular voltage and current. Most MPPT techniques attempt to find the PV voltage or PV current that result in the maximum power point under different temperature and irradiance. Also it can be seen, a decrement in the module voltage will decreases the current. In this paper is used this simple fact to improve the efficiency of MPPT algorithm, as it will be explained in Sections 6 and 4.

3. Perturb and observe

The P&O algorithm is based on the perturbation in the operating voltage and then the resulting change of power is observed [10]. This algorithm involves a perturbation in the operating voltage of the PV array, and then if change of power (ΔP) is positive, the future perturbation should be kept the same to reach the MPP and if change of power (ΔP) is negative, direction of perturbation

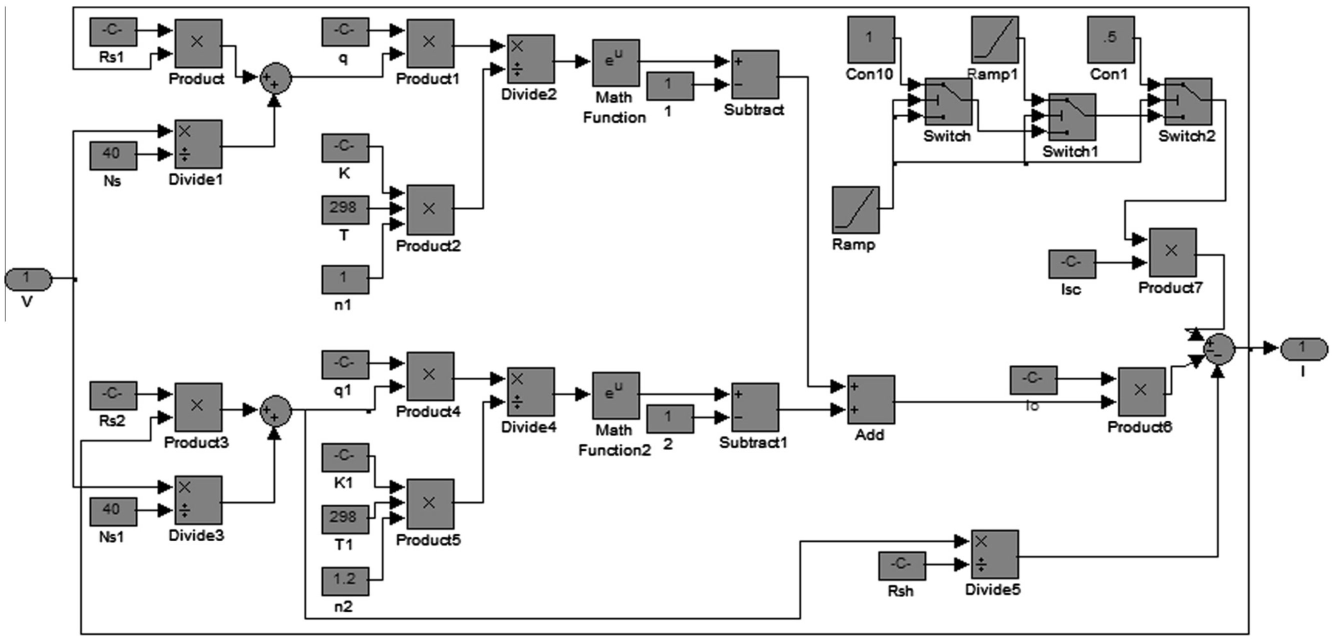


Fig. 2. Simulink of PV module.

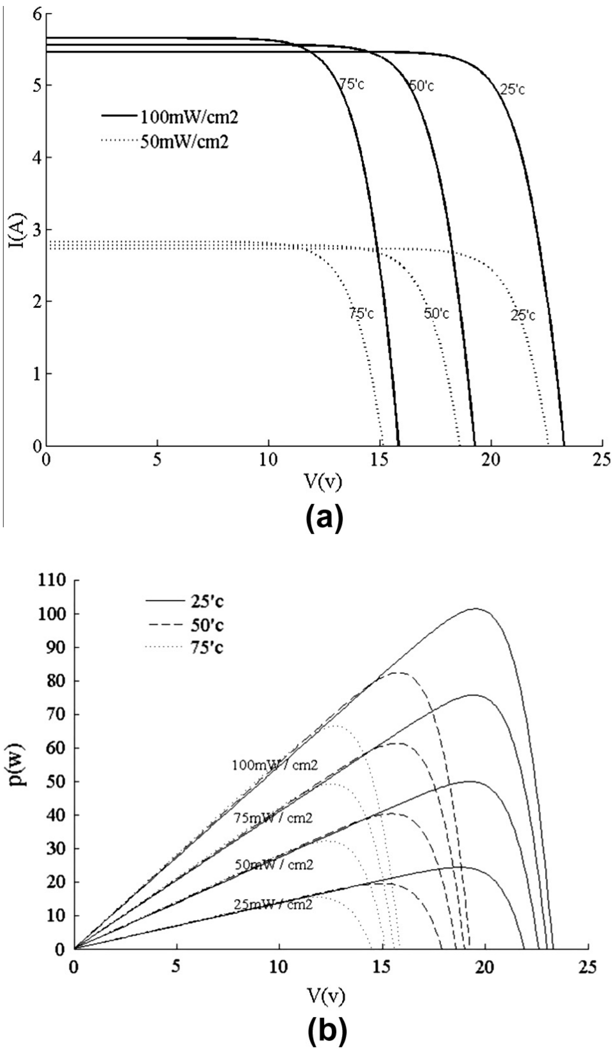


Fig. 3. Characteristics of the PV module for different value of irradiance and temperature.

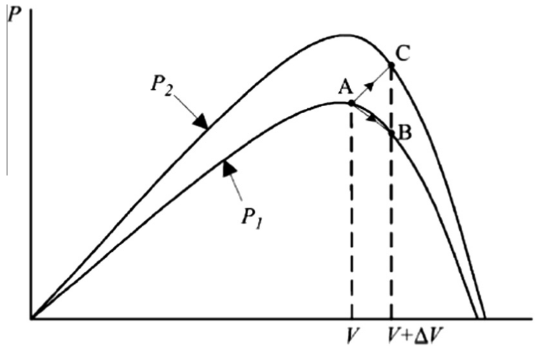


Fig. 5. Divergence of P&O from MPP as shown in [10].

should be reversed to move back toward the MPP. In other words, if with increasing (decrementing) the voltage increases (decreases) the power, the operating point of the PV array is on the left maximum power point and if the power decreases, the operating point is on the rights maximum power point. This process continues until the algorithm reaches the point of maximum power. Then swing around to this point. The flowchart of this algorithm is given in Fig. 4[11].

This algorithm may exhibit erratic behavior in rapidly changing atmospheric conditions as a result of moving clouds. This problem can be explained using Fig. 5 with a two power–voltage curves with varying irradiance [12]. Assume that the operating point is at the point A and is oscillating around the MPP and a perturbation will moves the operating point toward the point B. However, if the irradiance increases rapidly to P_2 power curve within one Sampling period, the operating point will actually moves from the point A toward the point C. This problem happens because the MPPT cannot recognize that power increment is the result of the increasing irradiation and simply assumes that it is the result of moving the operating point to the MPP. If the irradiance is still rapidly increasing, the MPPT continuing to perturb to the right again and the operating point continues to deviate from the actual MPP until the solar radiation change slows. This situation can occur on the partly cloudy days, and the MPP tracking is most difficult because of the frequent movement of the MPP.

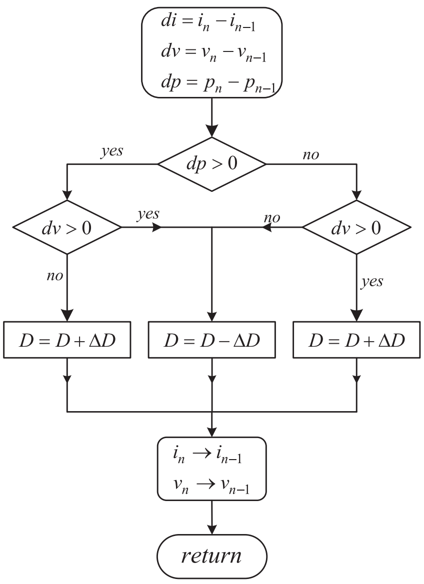


Fig. 4. P&O algorithm.

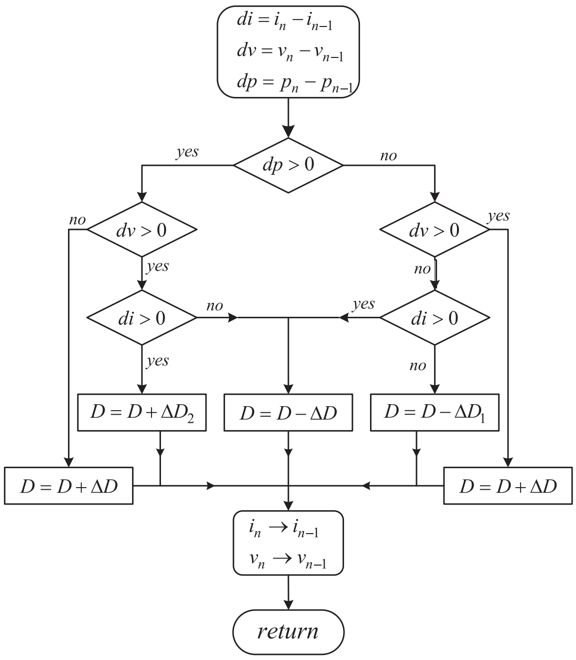


Fig. 6. Flowchart of the modified P&O algorithm.

4. The modified P&O algorithm

The Divergence of the P&O algorithm from the MPP under rapidly changing atmospheric conditions that was described in the previous section can be solved by using the PV current–voltage curve. As seen in this curve, in constant irradiation, when the voltage increases (decreases), the current is decreases (increases). Using this simple fact, can be solved the Divergence from the actual maximum power point in rapidly changing atmospheric conditions, as follow. If the power and the voltage simultaneously increase and the current increases too, the algorithm realizes that it is in rapidly changing atmospheric conditions and decreases the voltage, instead, it increases. When the power and the voltage are increasing simultaneously and the current is decreasing, algorithm is in constant irradiation and increases the voltage. Therefore the MPPT algorithm avoids deviating from the actual MPP. The modified P&O algorithm is presented in Fig. 6.

5. Incremental conductance algorithm

The INC algorithm is based on the slope of power–voltage curve. It calculates the slop of p–v curve. If it is positive, operating point is at the left side of the MPP, thus must be moved to the right by increasing the module voltage. If the slop of curve is negative, algorithm is assumed that the operating point is at the right side of the MPP, thus must be moved to the left by decreasing the module voltage. Finally, when the slop of p–v curve is zero, the operating point is at the MPP and the algorithm stop the voltage adjustment. As given by following equation:

$$\frac{I}{V} + \frac{\Delta I}{\Delta V} > 0 \quad \text{At the left side of the MPP} \tag{4}$$

$$\frac{I}{V} + \frac{\Delta I}{\Delta V} < 0 \quad \text{At the right side of the MPP} \tag{5}$$

$$\frac{I}{V} + \frac{\Delta I}{\Delta V} = 0 \quad \text{At the MPP} \tag{6}$$

The INC algorithm is shown in the flowchart in Fig. 7

6. The modified incremental conductance algorithm

The incremental conductance algorithm is intended to solve the problem of the P&O algorithm under rapidly changing atmospheric conditions [13]. However, in this paper, the performance of the INC algorithm in rapidly changing atmospheric conditions is improved by using the current–voltage curve. If the slop of the p–v curve is positive and the sign of the changing current and voltage are positive simultaneously, the algorithm realizes that the irradiation is in rapidly increasing atmospheric conditions and decreases the voltage. On the other hand, if the slop of the p–v curve is positive, changing voltage and current are in negative simultaneously, the algorithm realize that it is rapidly decreasing atmospheric conditions and increases the voltage. Finally, if changing voltage and current are in opposite directions, the algorithm for tracking maximum power point increases the voltage, as the INC conventional algorithm. So the algorithm avoids divergence from the actual maximum power point in rapidly changing atmospheric conditions. The modified INC algorithm is shown in Fig. 8.

7. Simulation results

In this section the algorithms using the High-step-up DC/DC converter are implemented on MATLAB/SIMULINK tool. The high-step-up dc/dc converter is required to increase voltage gain and satisfy the high bus voltage requirements for dc/ac inverter. Another alternative is used the PV series-connected configuration, but in this method, the output power of the PV arrays is decreased significantly because of module mismatch and partial shading, primarily in urban areas [14,15]. The applied high-step-up dc/dc

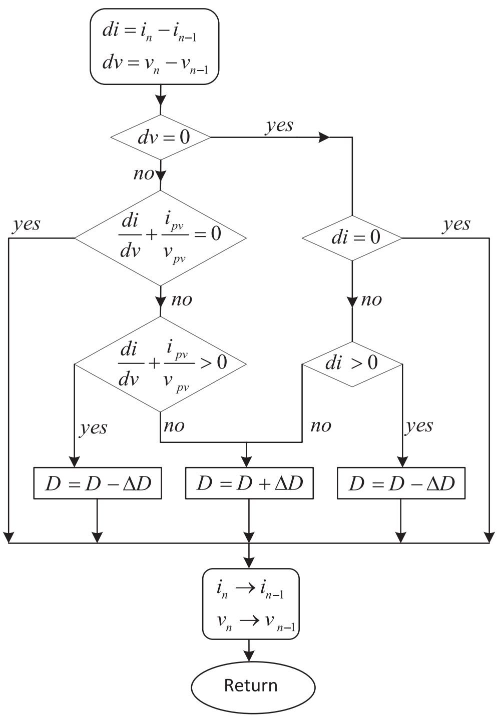


Fig. 7. Flowchart of the INC algorithm.

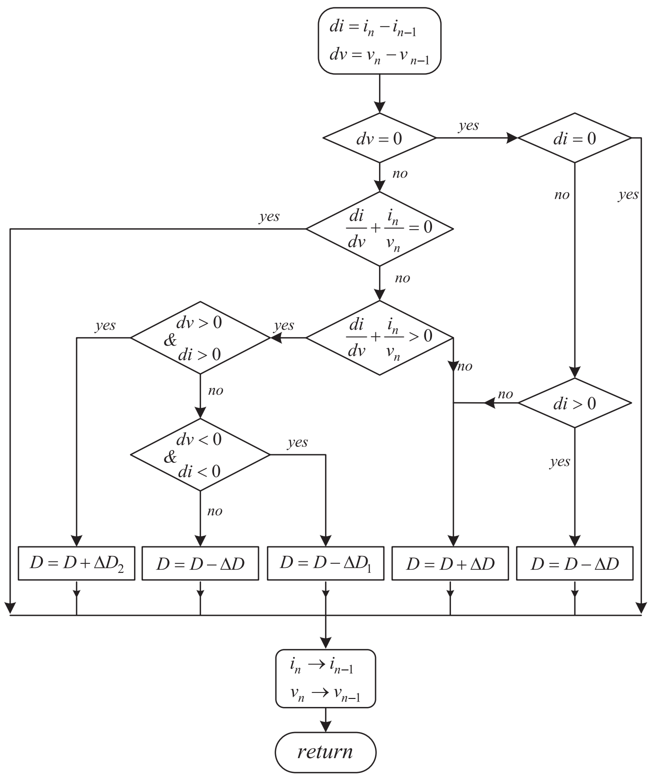


Fig. 8. The modified INC algorithm.

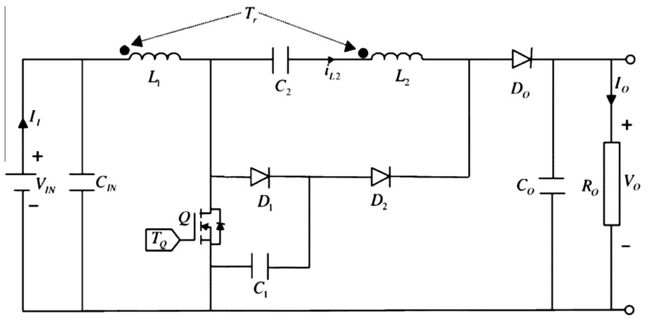


Fig. 9. System configuration of high step-up converter.

converter in this study is able to convert 13–400 V DC and its conversion efficiency is in the range 96–98% [16]. The schematic converter is shown in Fig. 9.

For the simulation of the MPPT system the high-step-up dc/dc converter model is developed in simulink/MAtlab. The values of the components where performed from the design procedures given in [16]. At switching frequency 100 kHz, the value of the components selected are:

$L_1 = 13\mu H \quad n = 1/6 \quad K = 98\% \quad L_2 = 470\mu H \quad C_1 = 5\mu F$
$C_2 = 6.8\mu F$

The switch used was an ideal switch, with low switching and ON state loss. The simulink setup is shown in the Fig. 10.

The MPPT block contains the new algorithms which were explained in the Sections 4 and 6. The temperature is kept fixed and is not varied. The PV block was shown in Fig. 2. A trapezoidal irradiation profile has been used for testing the performance of the new algorithms for tracking the maximum power in under rapidly changing atmospheric conditions. In this test, Radiation reaches from the initial value 500–1000 w/m^2, within 60 ms. Then it is kept constant for 60 ms in the 1000 w/m^2 amount and again reaches the same amount 500 w/m^2, within 60 ms. The behaviors of the basic P&O and INC trackers are simulated and compared in Fig. 11.

It can be seen in Fig. 11 the INC algorithm is track maximum power point better than the P&O algorithm. The modified P&O algorithm has been implemented in simulink software in order to verify performance of new algorithm. In Fig. 12 is compared performance of the modified P&O algorithm and the conventional P&O algorithm under rapidly changing atmospheric conditions.

It can be seen in Fig. 12 the modified P&O algorithm performs better than the basic one and it has the high efficiency under rapidly changing atmospheric conditions. The modified P&O algorithm prevents deviation from the MPP. Also, in order to verify performance of the modified INC algorithm, it has been simulated in simulink and in Fig. 13 is compared with the conventional INC algorithm. As shown in Fig. 13 the modified INC performs slightly

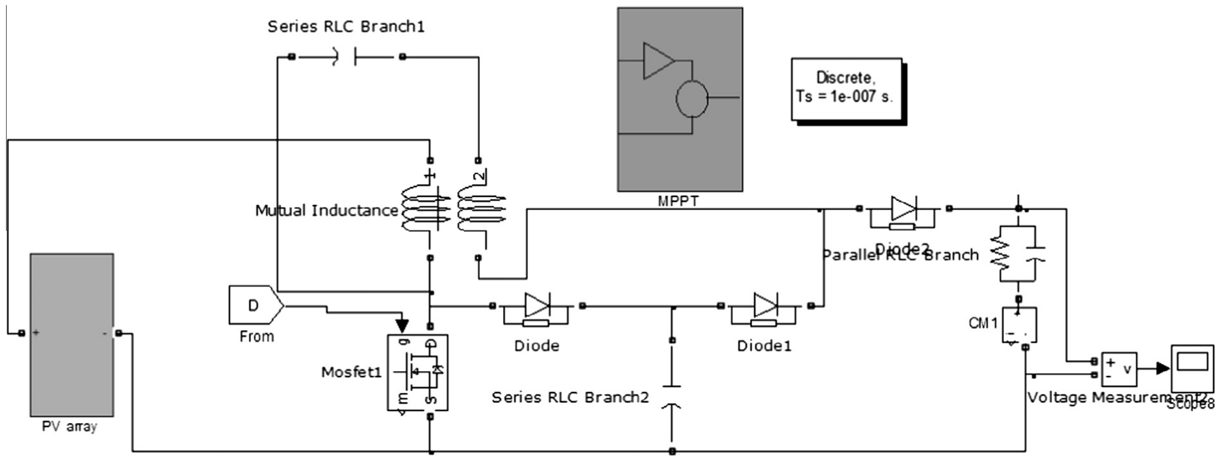


Fig. 10. The simulated model of DC/DC converter.

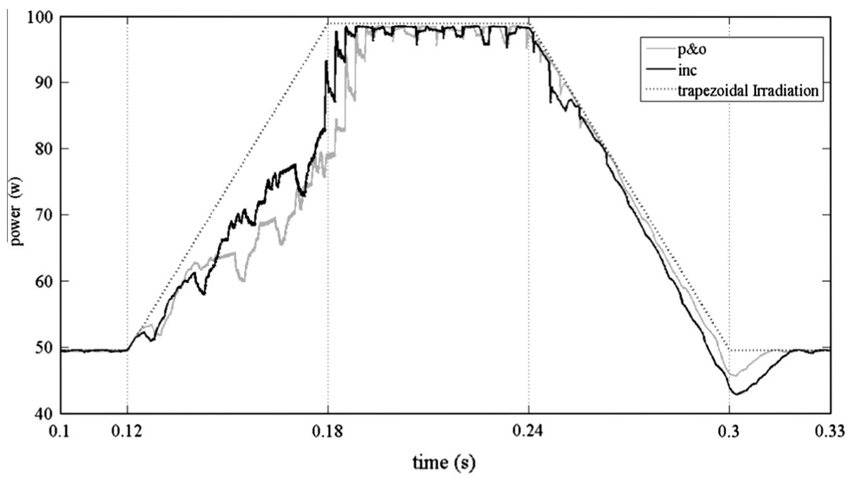


Fig. 11. The comparison of PV array power during a trapezoidal irradiation profile, using the classical P&O and INC method.

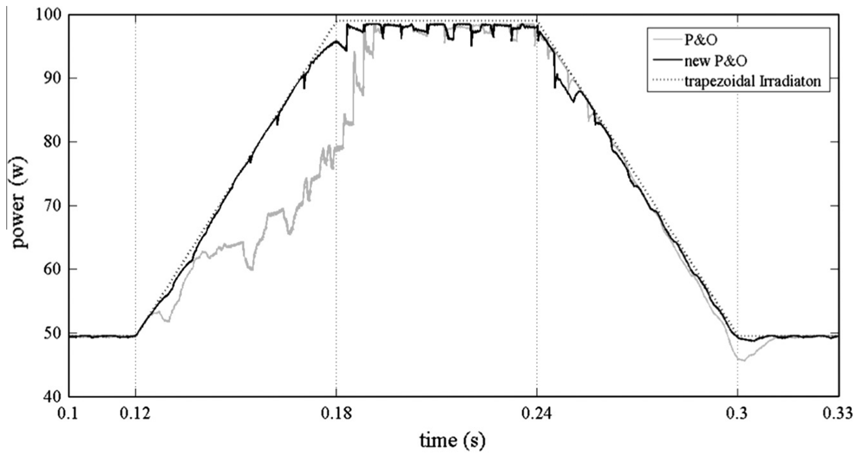


Fig. 12. Comparison of tracking MPP of modified P&O and basic P&O during a trapezoidal. Irradiation profile.

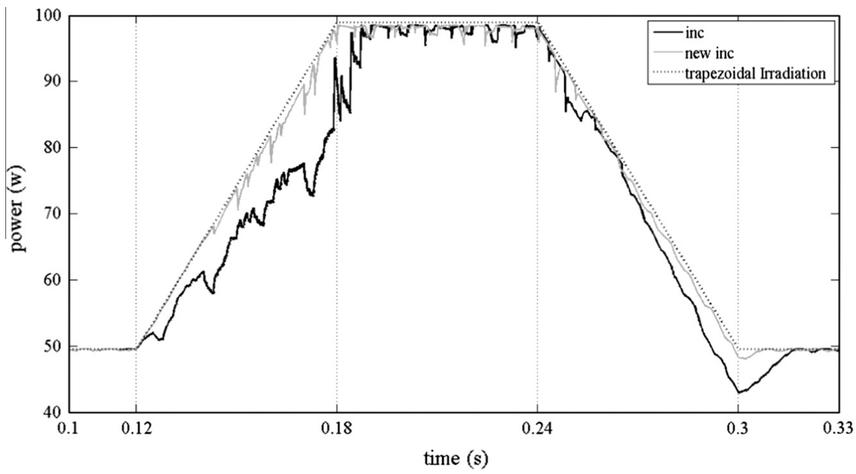


Fig. 13. Comparison of tracking MPP of modified INC and basic INC during a trapezoidal irradiation profile.

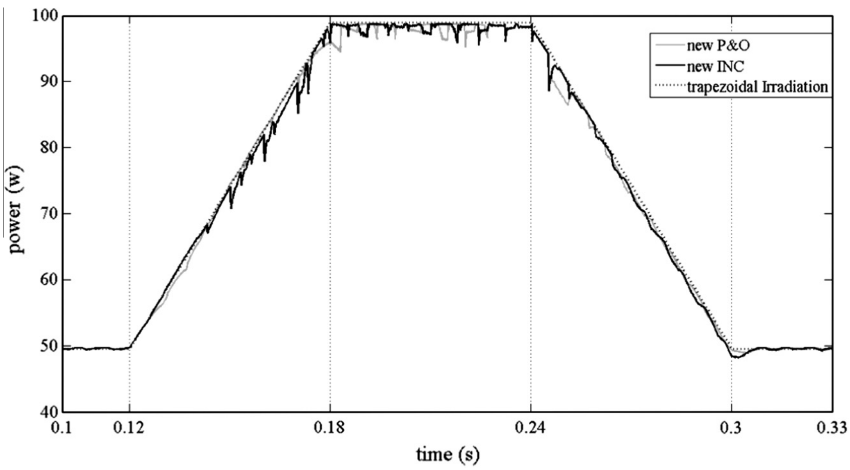


Fig. 14. Comparison of tracking MPP of modified INC and modified P&O during a trapezoidal irradiation profile.

better than the basic one rapidly changing atmospheric conditions and it increases received power from PV module and improves the MPPT efficiency.

Finally, the performance of the modified INC algorithm and the modified P&O algorithm under rapidly changing atmospheric conditions is compared in Fig. 14. It can be seen in Fig. 14, the performance of modified P&O and INC algorithm is improved and they have the high efficiency under rapidly changing atmospheric conditions. The error of these modified algorithms from the trapezoidal irradiation profile is shown in Fig. 15.

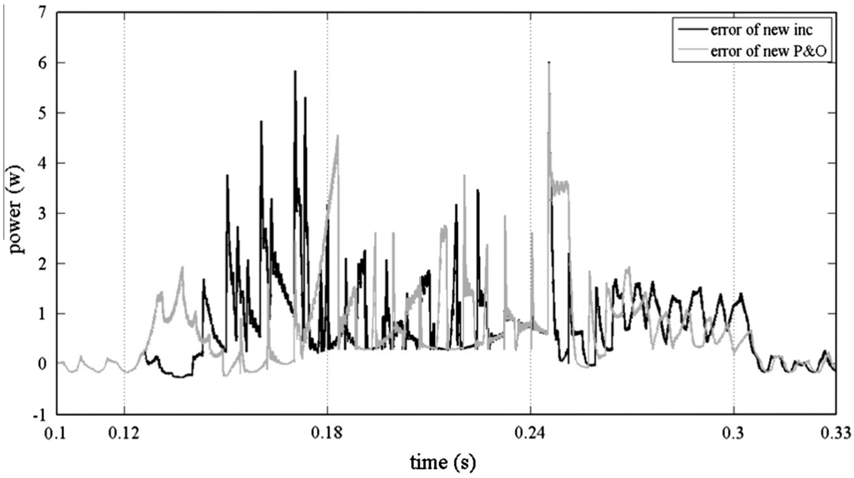


Fig. 15. Comparison of error of modified INC and modified P&O during a trapezoidal irradiation profile.

8. Conclusion

In this paper, a modified maximum power point tracking on P&O algorithm under rapidly changing atmospheric conditions has been investigated. The method uses the current–voltage curve to separate the effects of the environment from the moving the operating point to the MPP in constant irradiation, in most times. Therefore, by identifying the environmental changes, it would prevent the deviation from the MPP. The new method provides an accurate tracking even under rapidly changing atmospheric conditions. The proposed method not only improves the basic P&O algorithm, also improves the basic INC algorithm. In order to verify the performance of the proposed method, the modified P&O and modified INC algorithm have been implemented in simulink software and compared to the conventional P&O and INC algorithm. The results show that both algorithms perform clearly better than them conventional algorithms, by providing accurate tracking under rapidly changing atmospheric conditions.

References

[1] Kroposki B, Margolis R, Ton D. Harnessing the sun an overview of solar technologies. IEEE Power Energy Mag 2009;7(3):22–33.

[2] <http://www.greenpeace.org/seasia/ph/Global/.../SolarGeneration2010.pdf>. October 2010.

[3] Esram Trishan, Chapman Patrick L. Comparison of photovoltaic array maximum power point tracking techniques. IEEE Trans Energy Convers 2007;22(2).

[4] Veerachary M, Senjyu T, Uezato K. Neural-network-based maximum-power-point tracking of coupled-inductor interleaved-boost converter, supplied PV system using fuzzy controller. IEEE Trans Ind Electron 2003;50(4):749–58.

[5] Algazar Mohamed M, AL-monier Hamdy, EL-halim Hamdy Abd, Salem Mohamed Ezzat El Kotb. Maximum power point tracking using fuzzy logic control. Electr Power Energy Syst 2012;39:21–8.

[6] Houssamo Issam, Locment Fabrice, Sechilariu Manuela. Experimental analysis of impact of MPPT methods on energy efficiency for photovoltaic power systems. Electr Power Energy Syst 2013;46:98–107.

[7] Jain S, Agarwal V. A new algorithm for rapid tracking of approximate maximum power point in photovoltaic systems. IEEE Power Electron Lett Mar.2004;2(1):16–9.

[8] Ishaque Kashif, Salam Syafaruddin Zainal. A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model ELSEVIER. Solar Energy 2011;85:2217–27.

[9] Chih-Tang S, Noyce RN, et al. Carrier generation and recombination in P–N junctions and P–N junction characteristics. Proc IRE 1957;45(9):1228–43.

[10] Hohm D, Ropp M. Comparative study of maximum power point tracking algorithms using an experimental, programmable, maximum power point tracking test. In: Proc. 28th IEEE Conf. Rec. Photovoltaic Spec.; 2000. p. 1699–1702.

[11] Irmak Erdal, Güler Naki. Application of a high efficient voltage regulation system with MPPT algorithm. Electr Power Energy Syst 2013;44:703–12.

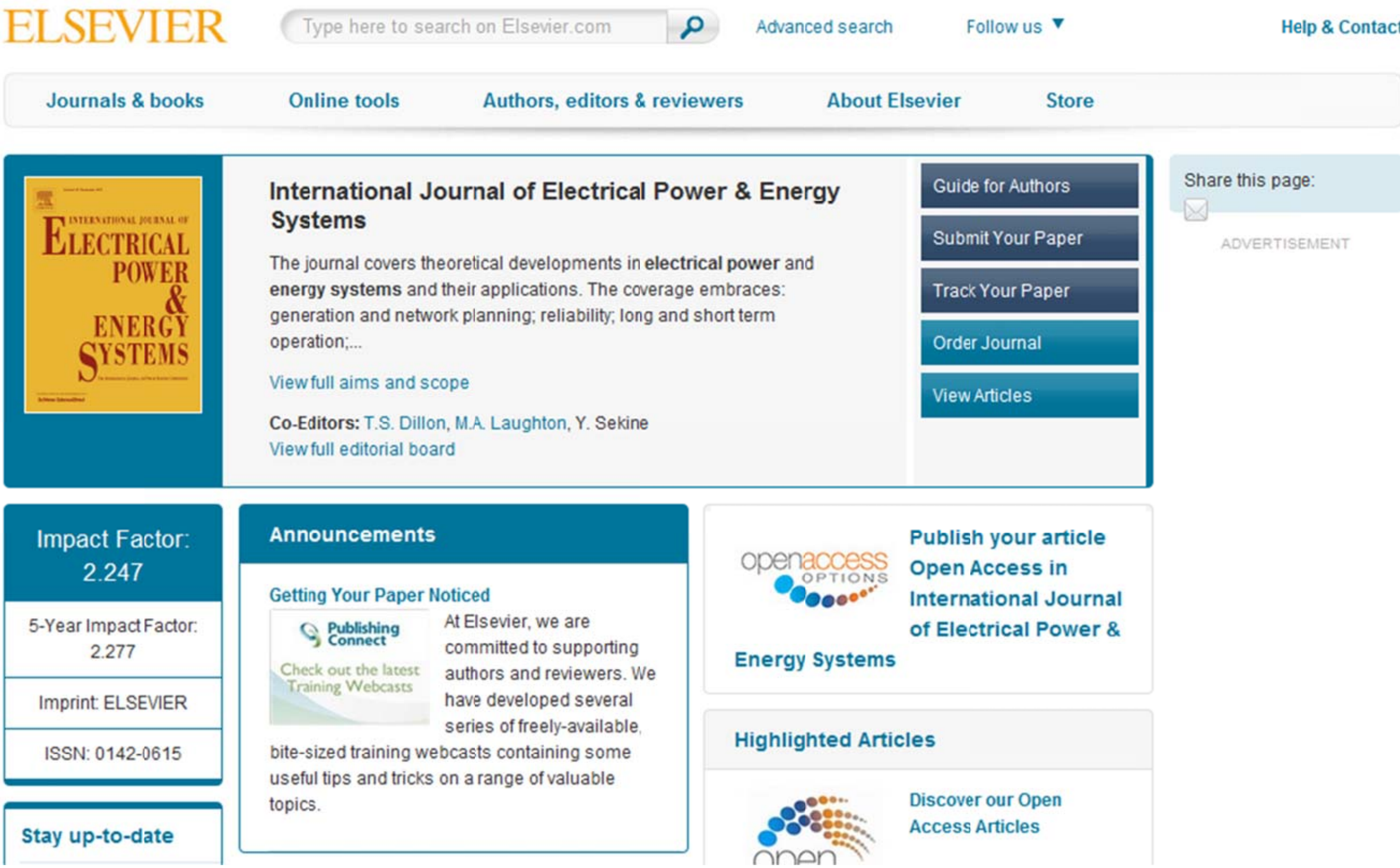
[12] Wasynczuk O. Dynamic behavior of a class of photovoltaic power systems. IEEE Trans Power Appl Syst 1983;102(9):3031–7.

[13] Hussein KH, Muta I, Hoshino T, Osakada M. Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions. IEE Proc – Generat Transm Distrib 1995;142:59–64.

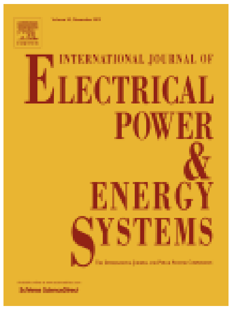
[14] Shimizu T, Hashimoto O, Kimura G. A novel high-performance utility-interactive photovoltaic inverter system. IEEE Trans Power Electron 2003;18(2):704–11.

[15] Wai RJ, Lin CY, Duan RY, Chang YR. High-efficiency dc–dc converter with high voltage gain and reduced switch stress. IEEE Trans Ind Electron 2007;54(1):354–64.

[16] Wai Rong-Jong, Duan Rou-Yong. High step-up converter with coupled-inductor. IEEE Trans Power Electron 2005;20(5):1025–35.



journal homepage: www.elsevier.com/locate/ijepes



International Journal of Electrical Power & Energy Systems

The journal covers theoretical developments in **electrical power** and **energy systems** and their applications. The coverage embraces: generation and network planning; reliability; long and short term operation;...

View full aims and scope

Co-Editors: T.S. Dillon, M.A. Laughton, Y. Sekine
View full editorial board

Guide for Authors

Submit Your Paper

Track Your Paper

Order Journal

View Articles

Impact Factor: 2.247

5-Year Impact Factor: 2.277

Imprint: ELSEVIER

ISSN: 0142-0615

Stay up-to-date

Register your interests and receive email alerts tailored to your needs

Click here to sign up

Follow us

Announcements

Getting Your Paper Noticed

At Elsevier, we are committed to supporting authors and reviewers. We have developed several series of freely-available, bite-sized training webcasts containing some useful tips and tricks on a range of valuable topics.

Most Downloaded Articles

1. **A comprehensive review on the grid integration of doubly fed induction generator**
H.T. Jadhav | Ranjit Roy

2. **Advances and trends of energy storage technology in Microgrid**
Xingguo Tan | Qingmin Li | ...

3. **Energy storage system-based power control for grid-connected wind power farm**
Baoming Ge | Wenliang Wang | ...

VIEW ALL

Most Cited Articles

Dynamic economic emission dispatch using nondominated sorting genetic algorithm-II
Basu, M.

Multi-objective reactive power and voltage control based on fuzzy optimization strategy and fuzzy adaptive particle swarm

Publish your article Open Access in International Journal of Electrical Power & Energy Systems

Highlighted Articles

Discover our Open Access Articles

VIEW ALL

Special Issues

Power Systems Computation Conference (PSCC) 2008
Volume 31, Issue 9 (2009)

Special Issue on Probabilistic Methods Applied to Power Systems
Volume 27, Numbers 9-10 (2005)

14th Power Systems Computation Conference
Volume 25 Number 8 (2003)

VIEW ALL

Latest Energy Jobs from ElsevierJobs.com

Senior Electron Beam Welding Engineer, United Kingdom from TMP/UNIV OF SHEFFIELD
9 May 2013