HYBRID GENETIC ALGORITHM VERSUS PSO FOR TRACKING THE MPP OF PV MODULE

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Abstract: *Classical algorithms for maximum power point tracking (MPPT) are not difficult to implement and provide accurate enough results and speed under normal conditions. Under partial shading or other multiple local maximum power point (MPP) conditions they are missing the global MPP. This paper proposes a hybrid genetic algorithm (HGA) for tracking the maximum power point when multiple local maximum power points can be found and a comparison with a biological algorithm for tracking the maximum power point: Particle Swarm Optimization (PSO).*

Keywords*: photovoltaic system, MPPT, optimization method, hybrid genetic algorithm*

1. Introduction

The increased oil and gas prices since the 1970's, the finite nature of conventional energy sources and the need of cleaner energy have lead more and more countries to discover the true potential of renewable energy sources. The most widely used renewable energy resources are hydro, wind and solar. The most suitable for generating massive amounts of power is solar energy, mostly because of its better predictibility among the above. ([1], [2], [3])

The P-V and I-V characteristics of a photovoltaic (PV) module are nonlinear and the output of the PV module varies with changing weather conditions, like temperature and solar irradiance. In order to be able to tap the PV power source close to its full potential, a Maximum Power Point Tracking (MPPT) algorithm needs to be used. Among the several techniques that can currently be used for designing and implementing an MPPT algorithm, the most used are the Perturb and Observe (PnO) or Hill-Climbing and INC MPPT algorithm. ([4], [5], [6])

These classical algorithms have the advantage of being easy to implement and providing good tracking speed [7] but also possess the disadvantage of stopping after reaching one local maximum power point, and therefore missing the global maximum power point (MPP). This usually happens when operating large PV arrays, where the solar irradiance varies geographically from module to module because of partial shading or when, because of aging or deterioration, the modules or panels have different P-V and I-V characteristics. ([8], [9])

In [7], [8] and [9] have also been presented some MPPT algorithms that are tracking the global maximum power point of a PV system, the most effective being Particle Swarm Optimization (PSO), which is inspired by the movement of large groups of biological individuals, like a swarm of insects or a flock of birds.

This paper proposes a new hybrid genetic algorithm (HGA) for tracking the global MPP of a PV module in terms of multiple local MPPs in order to increase the efficiency, the accuracy and the speed of the PSO algorithm mentioned above.

2. Characteristics of PV Modules and Maximum Power Point Tracking

PV systems consist of multiple PV modules connected in series and parallel for providing a desired operating voltage and output power [10]. The models of solar cells are used for deducing the models of the PV generators. Several studies propose using one diode, two diodes (more precise) or three diodes (very complex) models. In this paper, the conventional single diode model presented in Fig. 1 has been used.

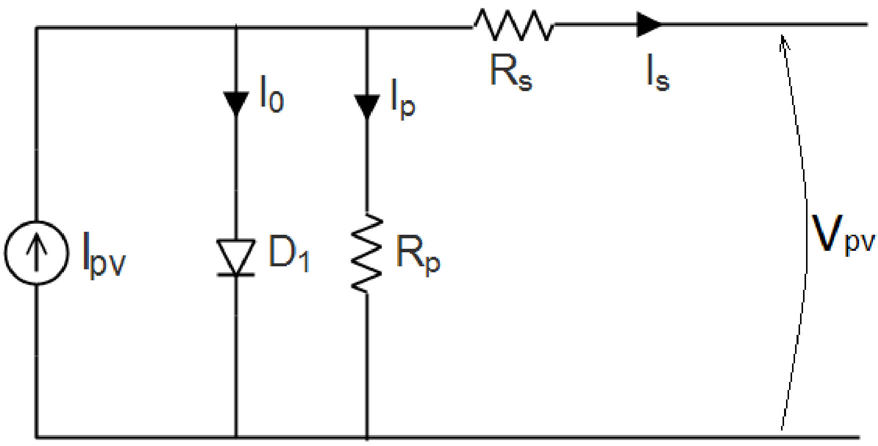


Fig. 1 Conventional Single Diode Model of the PV Cell

I_{pv} is the photogenerated current based on the irradiance level, I_d the diode current, R_s and R_p are the series and parallel (shunt) resistances, respectively. Based on **Error! Reference source not found.**, the relation between the output voltage and current can be written as

$$I_S = I_{pv} - I_0 \left[e^{\frac{q(V_{pv}+I_S R_S)}{KTA}} - 1 \right] - \left(\frac{V_{pv} + I_S R_S}{R_P} \right) \tag{1}$$

where I_0 is the dark current ([11]).

For simulating the PV cell in Simulink, the model presented in **Error! Reference source not found.**, has been used. Thus the influence of the solar irradiance (Fig. 2) and that of the operating temperature on the MPPT (Fig. 3) have been identified.

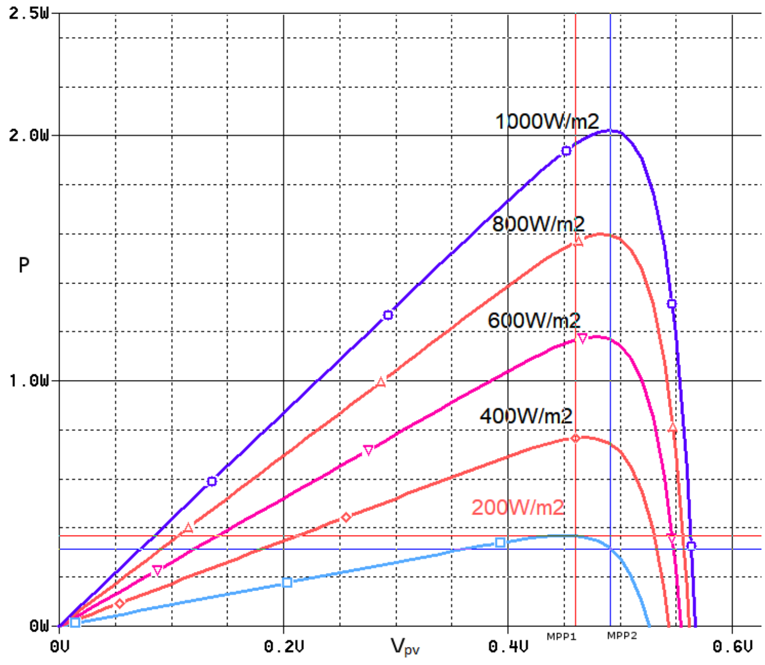


Fig. 2 Irradiance effect on the P-V curve

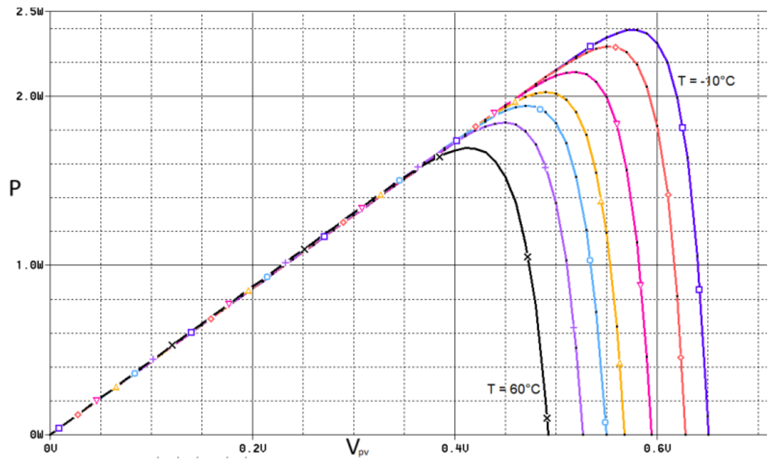


Fig. 3 Temperature dependence of P-V characteristics

The MPP has a significant dependence on the change of ambient temperature and a small dependence on the level of radiation, as presented in Fig. 2 and Fig. 3, respectively ([12], [13], [14]).

Tracking the MPP is not a simple task, esentially because the P-V and I-V curves depend on both operating temperature and incident radiance, which, in turn, can change very fast over short periods of time.

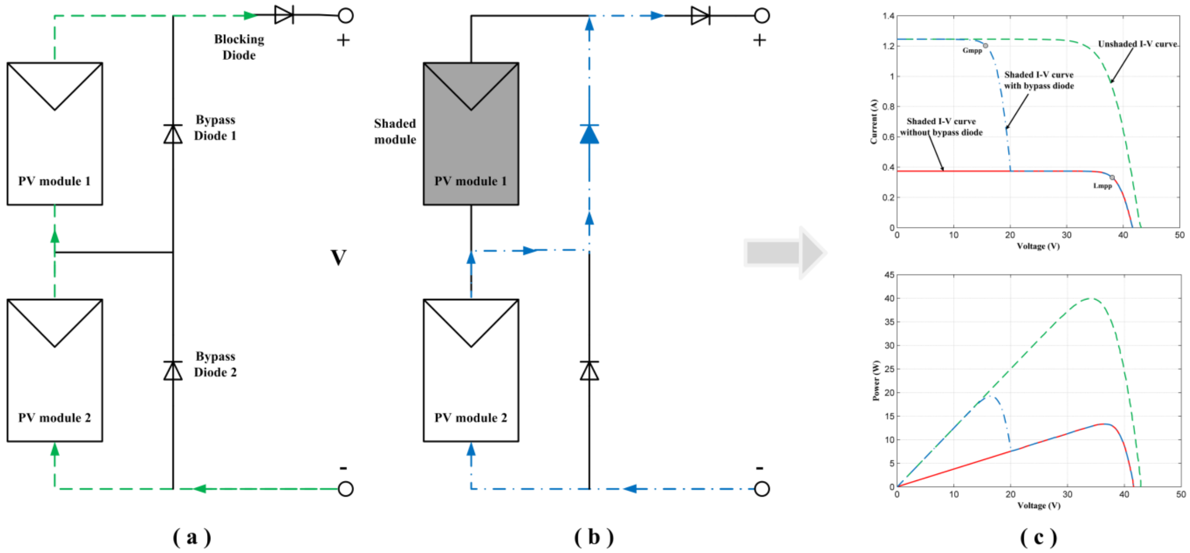
Over time, several methods have been proposed for tracking maximum power points for PV arrays ([15], [16]). The most used one seems to be Perturb and Observe (PnO), an iterative method that perturbs the output photovoltage V_{pv} and analyses the resulted power compared to the previous one. The method provides fairly good tracking speed and accuracy under normal working conditions, but usually misses the global maximum power point when several local maximum power points can be reached.

By using a PnO algorithm with a variable step, proportional to the slope of the P-V characteristic ([17], [18], [19], [20]), the trade-off between response time and efficiency loss due to oscillations can be reduced, but the problem of missing the global MPP still remains unsolved.

3. Photovoltaic Systems Working under Partial Shading Conditions and Particle Swarm Optimization Algorithm

The P-V and I-V characteristics of a PV system consisting of parallel and series connected modules can be obtained by the composition of the characteristic of each module. Under uniform radiance conditions, in parallel connection, the I-V characteristic is obtained by adding the current for the same voltages, while in series connection, it is obtained by adding the voltages for the same currents. However, the partial shading condition causes steps in the I-V characteristic of a group of PV modules that are serially connected, because of the activation of the bypass diodes. The purpose of the bypass diodes is to prevent the shaded cells from reverse biasing and overheating [21].

These steps in the I-V characteristics lead to multiple maximum power points in the P-V characteristic. The local maximum power points lead to the failure of the MPPT control with classical algorithms. In Fig. 4 it is illustrated the total power reduction of a PV system consisting of two modules connected in series with one module partially shaded, compared to the case of uniform irradiation.



(a) (b) (c)

Fig. 4 Operation of PV systems: (a) under uniform irradiation, (b) under partial shading condition, (c) the resulting P-V and I-V curves for (a) and (b)

It is clearly shown that the optimal energy harvesting from a PV system under partial shading condition is achieved only by operating at the global maximum power point (GMPP), which, in turn, requires an efficient MPPT method.

Particle swarm optimization (PSO) is a population based stochastic optimization technique used to determine the required parameters by maximizing the objective function in a given search space. PSO has two primary operators: the velocity update and the position update. The PSO method uses several agents (particles) to search for the maximum values of a predefined objective function. Each agent moves in the search space with a velocity, $v_{i,k}$. In each iteration, a new velocity value is calculated for each agent, based on the global best position, the current best position and the current velocity for each iteration [22]. Then, the new position is updated by using the new velocity value and the previous position.

4. A Hybrid Genetic Algorithm for Tracking the MPP

One other possible method for finding a maximum point is using a genetic algorithm (GA).

Generally speaking, a genetic algorithm represents a heuristic search that is inspired by Charles Darwin's theory of natural evolution. The algorithm reflects the natural selection process, where the fittest individuals are selected for producing offspring of the next generation.

The process begins with selecting the fittest individuals from a population, they produce offspring which inherit the characteristics of the parents and will then be added to the next generation. This process keeps on iterating and at the end, a generation with the fittest individuals will be found. ([24])

This notion can be applied for a search problem. We consider a set of solutions for a problem and select the set of best ones out of them.

Five phases are considered in genetic algorithms which are presented in Fig. 5:

1.Initial population
2.Fitness function
3.Selection
4.Crossover
5.Mutation

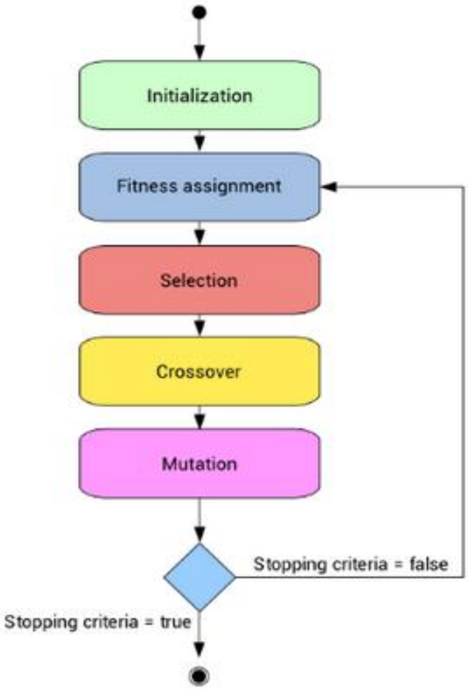


Fig. 5 Phases of a genetic algorithm

When implementing a GA for a specific problem, one must define the size of the chromosome, the size of the initial population, the fitness function, the crossover function, the mutation formula and the stopping criteria.

While the initial population and the size of the chromosome are self-explanatory, the fitness function is usually the function whose maximum needs to be found.

The crossover function recombines the selected individuals for generating a new population.

Since the crossover might generate offspring that are very similar to the parents, a new generation with low diversity may appear. The mutation operator solves this problem by changing the value of some features in the offspring at random.

The stopping criteria is usually a predefined number of iterations that don't produce a new maximum.

Generally, the chromosomes of the GA are a set of genes or inputs, but in finding the MPP of a PV there's only one input, the output voltage of the PV system, thus in this paper a pseudo-genetic algorithm has been proposed, where the chromosome only has one gene, the mutation is a movement of the selected individuals within a given interval and the crossover is replaced by randomly generating new individuals for filling the population in the current step.

Furthermore, after reaching the stopping criteria, the best solution may be different that the global maximum power point, but situated in the vicinity of it. For ensuring that the global maximum power point is tracked, the method continues by using the improved Perturb and Observe algorithm presented in [18], which increases the accuracy of the method. This way a hybrid genetic algorithm has been created.

The performance of the method can be improved by changing the size of the population and the parameters of the crossover and mutation functions.

5. Simulation Results and Discussion

MatLab and Simulink software tools have been used for modelling the PV system and simulating the MPPT algorithms under various changes of the weather conditions. The Simulink model is presented in **Error! Reference source not found.**.

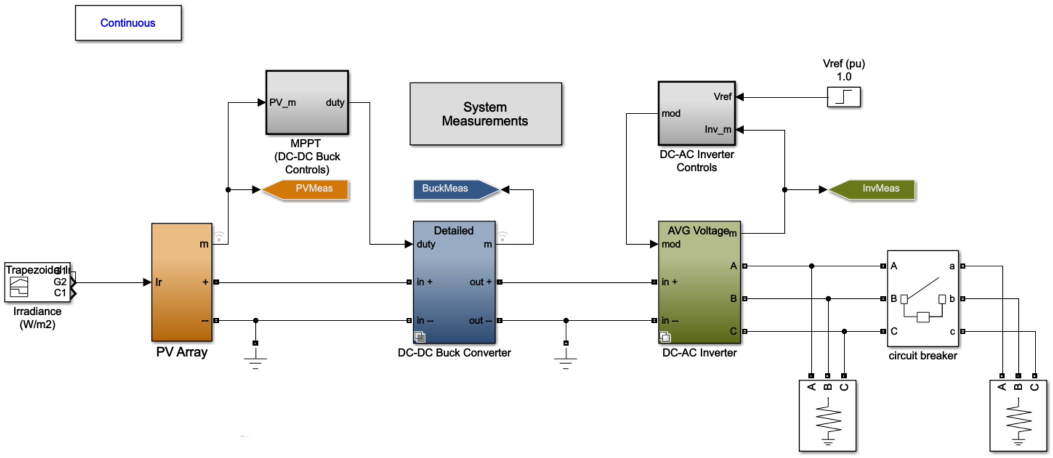


Fig. 6 Simulink model for simulating the MPPT algorithms

The studied PV system consists of two PV cells connected in series, the irradiance is 1000 W/m^2 for one of the cells, also called base irradiance in this paper, and 600W/m^2 or 60% of the base irradiance for the second cell, respectively, and the P-V characteristic of the system is drawn in **Fig. 7**.

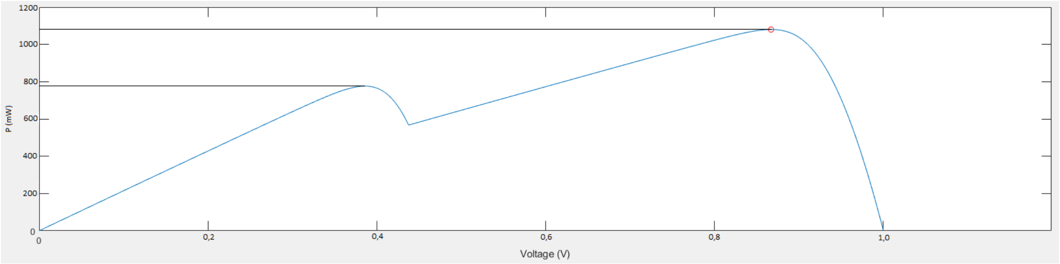


Fig. 7 Characteristic of a PV system with two cells in series, one with partial shading (60%)

The MatLab and Simulink simulations were performed with the proposed HGA algorithm and the PSO algorithm, and by comparing the simulation results, a good accuracy of the proposed HGA method was obtained, in a sense that the MPP is reached with an error defined by the relation

$$\varepsilon'_{HGA} = \frac{\left|P_{MPP,meas} - P_{MPP,HGA}\right|}{P_{MPP,meas}} = \frac{1{,}144 - 1{,}138}{1{,}144} = 0{,}5245\% \qquad (2)$$

respectively for the PSO algorithm

$$\varepsilon'_{PSO} = \frac{\left|P_{MPP,meas} - P_{MPP,PSO}\right|}{P_{MPP,meas}} = \frac{1{,}144 - 1{,}122}{1{,}144} = 0{,}9415\% \qquad (3)$$

In relations (2) and (3), $P_{MPP,meas}$ represents the measured maximum power, $P_{MPP,HGA}$ and $P_{MPP,PSO}$ represent the maximum power obtained using the HGA and respectively PSO algorithm.

On the other hand, the Simulink calculation time for reaching the MPP using GA is better than the time needed to reach the MPP when the simulation procedure used PnO, t_{HGA} = 0,045s < t_{PSO} = 0,065.

In order to compare the HGA proposed algorithm and the PSO algorithm, in Table 1 are presented the two performance indicators accuracy (error) and calculation time. Both indicators show good performance of the proposed HGA algorithm.

Table 1 Performance Indicators for PV with Partial Shading

Algorithm	Proposed HGA	PSO
accuracy (errors)	0,5245%	0,9415%
time (s)	0,045	0,065

The simulation was repeated with variable irradiance values over a predefined period of time. The used input signals are a trapezoidal signal (Fig. 8) and pulse signal (Fig. 9) for simulating slow and rapid changes in the irradiance, respectively.

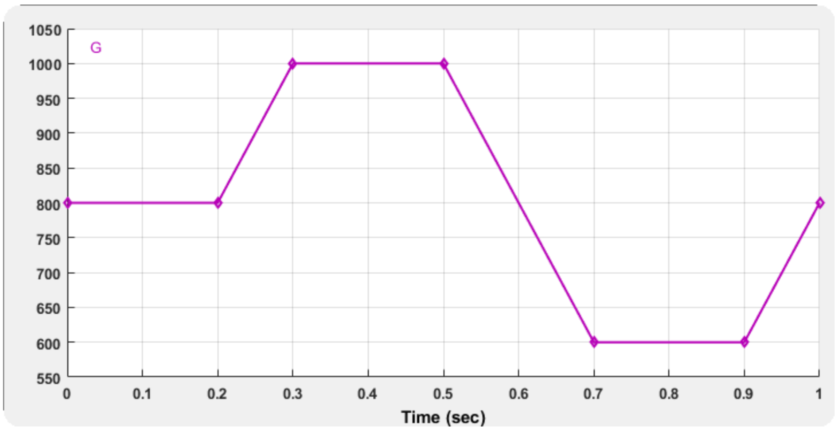


Fig. 8 Trapezoidal Signal

When using the trapoezoidal signal as imput signal, the average power obtained by tracking the MPP with the HGA method was $P_{med,HGA1}$ = 0,8850W and the average power obtained by tracking the MPP using the PSO algorithm was $P_{med,PSO1}$ = 0,8804W.

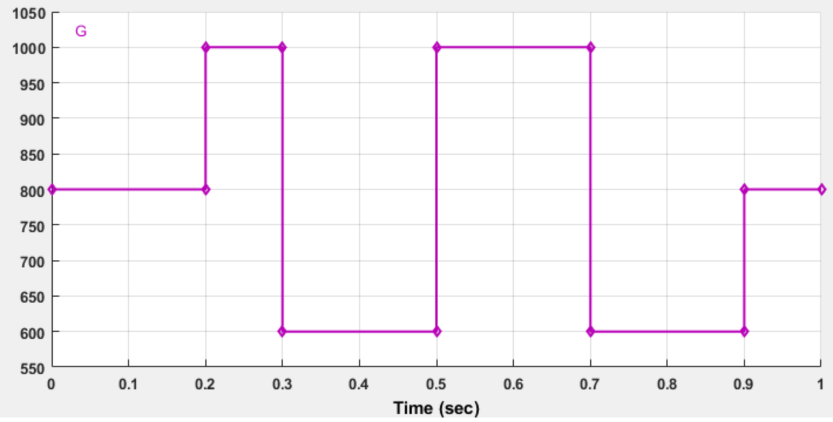


Fig. 9 Pulse Signal

In the case of the pulse signal, the average power obtained by tracking the MPP using the HGA method was $P_{med,HGA2}$ = 0,8587W, while the average power obtained when the tracking was done using the PSO algorithm was $P_{med,PSO2}$ = 0,8432W.

It can be observed that in both situations the HGA performs better, but under conditions of rapidly changing irradiance, the difference between the average power extracted using the two methods

$$P_{med1} = P_{med,HGA1} - P_{med,PSO1} = 0{,}0046W \qquad (4)$$

is lower than the difference between the average extracted power under conditions of slower changing irradiance

$$P_{med2} = P_{med,HGA2} - P_{med,PSO2} = 0{,}0145W \tag{4}$$

6. Conclusions

The efficiency of MPP search algorithms for PV systems is measured by 2 performance indicators: the accuracy with which the MPP is determined and the average power generated over a period of time for each algorithm. In this paper a hybrid genetic algorithm was proposed, whose efficiency, based on the above indicators, is proved by comparing its performances with the ones obtained by using the PSO method.

The results were validated by using a MatLab/Simulink application on the same PV system in two situations: constant base irradiance and variable base irradiance over a period of time. In both situations, the HGA algorithm provided good performance indicators.

In control and monitoring systems for PV panels, the advantages of the proposed HGA algorithm are extremely useful considering the response time and the accuracy.

References

[1]. **T. Esram and P.L. Chapman**, Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, Energy Conversion, IEEE Transactions on, **vol. 22**, no. 3, June 2007, pp. 439-449

[2]. **H. Abouobaida and M. Cherkaoui**, Comparative study of Maximum Power Point trackers for fast changing environmental conditions, Multimedia Computing and Systems (ICMCS), 2012 International Conference on

[3]. **D.T.R. Challa and I. Raghavendar**, Implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter, International Journal of Modern Engineering Research (IJMER), **vol. 2**, no. 6, 2012, pp. 4491-4496

[4]. **M.A. Elgendy, B. Zahawi and D.J. Atkinson**, Assessment of the Incremental Conductance Maximum Power Point Tracking Algorithm, Sustainable Energy, IEEE Transactions on, **vol. 4**, no. 1, 2013, pp. 108-117

[5]. **H.J. El-Khozondar, R.J. El-Khozondar, K. Matter and T. Suntio**, A review study of photovoltaic array maximum power tracking algorithms, Springer Open Journal, 2016

[6]. **R.K. Kharb, S. L. Shimi and S. Chatterji**, Improved Maximum Power Point Tracking for Solar PV Module using ANFIS, International Journal of Current Engineering and Technology, **vol. 3**, no. 5, 2013, pp. 1878-1885

[7]. B. Subudhi and Raseswari Pradhan, A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems, Sustainable Energy, IEEE Transactions on, **vol. 4**, no.1, 2013, pp. 89-98

[8]. **J. Ma, K.L. Man, T.O. Ting, N. Zhang, S.U. Guan, P.W.H. Wong, E.G. Lim, T. Krilavicius, 4, J. Kapociute-Dzikiene, C.U. Lei**, *Improving Power-Conversion Efficiency via a Hybrid MPPT Approach for Photovoltaic Systems*, Elektronika ir Elektroteknika, vol. 19, no. 7, 2013, pp. 57-60

[9]. **A. Dolara, R. Faranda, and S. Leva**, *Energy Comparison of Seven MPPT Techniques for PV Systems*, J. Electromagnetic Analysis and Applications, vol. 1, no.3, 2009, pp. 152-162

[10]. **D. Bonkoungou, Z. Koagala and D. Njomo**, *Modeling and simulation of photovoltaic*

module considering single-diode equivalent circuit in Matlab, International Journal of Engineering and Technology and Advanced Engineering, vol.3, no. 2, 2013, pp. 493-499

[11]. **L. Castañer, S. Silvestre**, *Modelling Photovoltaic Systems Using PSpice,* John Wiley & Sons, Ltd., London, U.K., 2002

[12]. **J. Nelson**, *The Physics of solar Cells,* London, Imperial College Press, 2003

[13]. **R. Messenger and J. Ventre**, *Photovoltaic System Engineering*, CRC Press, Boca Raton, Fla, USA, 2000

[14]. **T. Markvart and L. Castañer**, *Practical Handbook of Photovoltaics: Fundamentals and Applications*, Elsevier, Oxford U.K., 2003

[15]. **E. Klugmann, E. Radziemska, and W.M. Lewandowski**, *Effect of temperature on conversion efficiency of solar module*, Proc. of the 16th European Photovoltaic Solar Energy Conference, Glasgow, 2000, pp. 2406-2409

[16]. **H. Andrei, C. Cepisca, S. D. Grigorescu, T. Ivanovici, and P. Andrei**, *Modelling of the PV Panels Circuit Parameters Using 4-Terminals Equations and Brune's Conditions*, Scientific Bulletin of Electrical Engineering Faculty, vol. 12, no. 1, 2010, pp. 63-67

[17]. **H. Andrei, T. Ivanovici, G. Predusca, E.Diaconu, P.C. Andrei**, *Curve Fitting Method for Modeling and Analysis of Photovoltaic Cells Characteristics*, Automation Quality and Testing Robotics (AQTR), IEEE International Conference on, 2012

[18]. **S. Popescu**, *An Improved PnO Algorithm with Variable Step*, The Scientific Bulletin of the Electrical Engineering Faculty (SBEEF), Nr.1, 2018

[19]. **J.I. Rosell and M. Ibáňez**, *Modelling power output in photovoltaic modules for outdoor operating conditions*, Energy Convers Managem. **vol. 47**, 2006, pp. 2424–2430

[20]. **A. Belkaid, I. Colak and K. Kaysli**, *Implementation of a Modified P&O-MPPT Algorithm Adapted for Varying Solar Radiation Conditions*, Electrical Engineering, 2017, vol. 3, no. 99, pp. 839-849

[21]. **A. S. Benyoucef, Aissa Chouder, K. Kara, S. Silvestre, O. A. Sahed**, *DSP Implementation of a novel Artificial Bee Colony Optimization-Based MPPT for Photovoltaic Systems*, Applied Soft Computing, vol. 32, July 2015

[22]. **Q. Bai**, *Analysis of Particle Swarm Optimization Algorithm*, Computer and Information Science, 2010. 3(1): p. 180-184.

[23]. **M. S. Ngan, C. W. Tan**, *Multiple Peaks Tracking Algorithm using Particle Swarm Optimization Incorporated with Artificial Neural Network*, World Academy of Science, Engineering and Technology International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:5, No:10, 2011

[24]. **S. Popescu**, *Tracking the MPP of a PV Module Using a Genetic Algorithm*, University POLITEHNICA of Bucharest Scientific Bulletin, ISSN 1223-7027 (under review)