A COMPARATIVE STUDY OF MPPT METHODS FOR PV ARRAY UNDER PARTIAL SHADING CONDITION IN MATLAB/SIMULINK[1]

MATLAB/SIMULINK'DE KISMİ GÖLGELEME KOŞULLARINDA, PV PANELLERİ İÇİN MPPT METODLARININ KARŞILAŞTIRMALI İNCELENMESİ

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ABSTRACT

Photovoltaic solar power is considered as the most important renewable energy sources which uses solar radiation to generate electricity. The main aim remains to get the maximum power from the photovoltaic (PV) system at different weather cases. The efficiency of the PV array is affected by shading conditions as in partially cloudy, neighboring buildings and towers, and trees. At partially shaded cases characteristics of PV array become more complex, multiple peaks appear on the PV characteristics curve then, it becomes difficult to track the maximum power point this is lead to significant power losses. Maximum power point tracking (MPPT) is a technique employed with photovoltaic (PV) application to increases the output power of the photovoltaic array by tracking the maximum power point (MPP), which depends on atmospheric conditions such as temperature and insolation. Many MPPT methods have been proposed. In this thesis work, four MPPT methods are used the Perturb and Observe (P&O), incremental conductance, neural network and hybrid MPPT method, to make a comparison between them based on performance like percentage tracking efficiency, speed, and time response by using MATLAB /Simulink. So, it's easy for the researcher to choose the best way for practical application.

Key Words: Maximum power point tracking (MPPT), renewable energy, Photovoltaic (PV), Perturb and Observe (P&O), Neural Network, Hybrid MPPT.

ÖZET

Fotovoltaik güneş enerjisi, enerji üretmek için güneş ışınımını kullanan yenilenebilir enerji kaynaklarının en önemlisi olarak kabul edilir. Ana amaç, farklı hava şartlarında, fotovoltaik sistemden maksimum gücü elde etmektir. PV panellerinin verimi, parçalı bulutlu hava, yakındaki komşu binalar, kuleler ve ağaçlar gibi gölge oluşturan durumlarından etkilenir. Kısmen gölgeli durumlarda PV panellerinin karakteristiksel özellikleri daha karmaşık hale gelir, PV karakteristik eğrisinde birden çok tepe görünür ardından maksimum güç noktasını izlemek zorlaşır. Bu durum büyük güç kayıplarına yol açar. Maksimum güç noktası izleme (MGNİ), sıcaklık ve güneşlenme gibi atmosferik koşullara bağlı olan maksimum güç

[1] Aynı başlıklı Yüksek Lisans tezinden üretilmiştir.

noktasını (MGN) izleyerek fotovoltaik dizinin çıkış gücünü artırmak için fotovoltaik uygulamalarında kullanılan bir tekniktir. Literatürde birçok MPPT yöntemi önerilmiştir. Bu tez çalışmasında, “Değiştir ve Gözlemle” metodu, “Artırımlı İletkenlik” metodu, “Sinir Ağları” metodu ve “Hibrit MGNI” metodu olmak üzere dört tane MGNİ metodu kullanılmıştır. Çalışılan metotlar MATLAB/SIMULİNK kullanılarak, izleme verimliliği yüzdesi, hız ve zaman tepkisi gibi performansa dayalı özellikler açısından, birbirleriyle karşılaştırılmıştır.
Anahtar Kelimeler: Maksimum Güç Noktası İzleme (MGNİ), Yenilenebilir Enerji Fotovoltaik, Akıllı Geçiş, Artırımlı İletkenlik, Değiştir ve Gözlemle, Sinir Ağları, Hibrit MGNİ

INTRODUCTION

Solar photovoltaic energy has become more popular because of many factors: minimal wear, low maintenance, sustainable energy, shortage of audible noise and easy to install. Small-scale photovoltaic structure is very common like water pumping and lighting solutions in developing countries, distant villages, and small civil and rural societies (Baba et al., 2014). A photovoltaic solar cell is an electrical instrument based on a semiconductor material which converts a solar energy into useful electricity. When solar power had been dealing with PV system some problems appears such as initial cost, reliability and efficiency of power generation. Therefore, simulation and modeling are an important part in the development and investigate the performances of photovoltaic itself as well to design PV applications (Crocker, 2017). Photovoltaic solar cell has low power so, many cells are linked into parallel or into series, forming a photovoltaic module and PV modules are linked in parallel or into series with the desired values of voltage and current in order to form a PV array (Neupane and Kumar, 2017). Photvoltaic cell has nonlinear characteristics, which changes with the temperature and level of the radiation. If the photovoltaic array is partially shaded, the PV characteristics curve become more complex and more than one peak appears. So, photovoltaic efficiency is decrease (Satyendra, 2017).

There have many causes leads to the PV array get shadowed. For example, neighboring building, trees, chimneys, and the dust on the surface of the panels (Mahammad et al, 2013). To overcome this issue, the maximum power point tracking (MPPT) algorithms is employed to get best efficiency for the photovoltaic at various load operating points. MPPT method is done by a controller for the photovoltaic module’s power converter. In the literature, MPPT techniques have been proposed and plenty of research has been executed to optimize the different algorithms (Baba et al., 2014). However, some of these methods has some disadvantages such as oscillations about MPP and slow tracking speed, this makes it less suitable for rapidly changing weather conditions (Jain, and Agarwal, 2004).

EQUIVALENT CIRCUIT OF PV CELL AND MATHEMATICAL MODEL

The equivalent circuit of a photovoltaic cell is seen in figure 1.

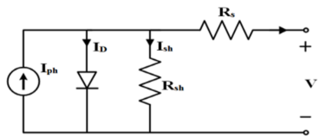


Figure1. The equivalent circuit of a photovoltaic cell

The general equations that describe the I-V characteristic of the photovoltaic module are (Francis et al., 2014; Nguyen, 2015).

$$I = Np * I_{Ph} - Np * I_O * \left[\exp\left(\frac{V/Ns + I * \frac{Rs}{Np}}{n * V_t}\right) - 1\right] - I_{sh} \quad (1)$$

with

$$V_t = \frac{k*T}{q} \quad (2)$$

and

$$I_{sh} = \frac{V*Np/Ns + I*Rs}{Rsh} \quad (3)$$

Where N_P is the number of parallel cells, N_S is the number of series cells, n is the diode ideality factor, V_t is the thermal voltage.

$$I_{ph} = I_{sc} + Ki(T_k - T_{Ref)} * \frac{\lambda}{1000} \quad (4)$$

Where I_{Ph} is the photocurrent current, T_K and T_{Ref} are the actual and reference temperatures in K, λ is the irradiation on the device surface (W/m^2).

$$I_o = I_{rs}[\frac{T}{Tr}]^3 \exp\left[\frac{q*Eg_o}{nk}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \quad (5)$$

$$I_{rs} = I_{sc} / [\exp\left(\frac{qVoc}{NsknT}\right) - 1] \quad (6)$$

Where q is the electron charge, V_{OC} is the open circuit voltage, Ns is the number of cells connected in series, n is diode ideality factor, T is the operating temperature and K is the Boltzmann constant

The equivalent circuit for a photovoltaic array is seen in Figure 2.

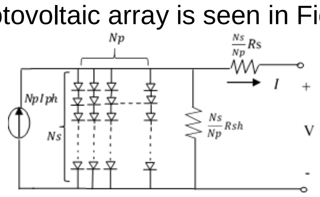


Figure 2. Equivalent circuit of a solar array

MAXIMUM POWER POINT TRACKING

Maximum power point tracking is the main part of a photovoltaic applications due to the MPP of a solar module different with the temperature and irradiation, so the use of MPPT methods to extract the maximum power from a PV array. As such, several MPPT algorithms have been proposed in the literature to improve the efficiency of solar panels (Babaa et al., 2014).

Perturb and Observe (P & O) Method

The photovoltaic panel produces the characteristic of current-voltage curve with a unique point (Maximum Power Point) (Mamatha, 2015). Perturb and Observe algorithm is largely employed in MPPT due to their easy structure and reliability. It is based on the sign of the last increment in the power and the sign of the last perturbation are utilized to decide what should be the next perturbation. At left of the maximum power point increasing voltage of the PV panel leads to power increases while at right of the maximum power decreasing the voltage increases power of a PV panel. Perturbation must be remaining in the same direction, and when the power decreases, then the next perturbation is moved into the opposite direction. The drawback of this technique is it oscillates around MPP and the voltage variation is high. This method also takes a long time for tracking and it has a slow response during rapidly changing conditions (Putri et al., 2015).

Incremental Conductance Method

The incremental conductance technique is based on the truth which the derivative power of the photovoltaic with its voltage equals to zero (Sharma and Purohit, 2014). This technique varying conditions more speedily than the Perturb and observes algorithm. It is producing oscillations in the output power.

This algorithm utilizes the slope of the photovoltaic module power curves to observe a maximum power point. The slope of a power-voltage curve of a photovoltaic module at the maximum power point (MPP) is zero, negative at the left of the MPP, and positive at the right of the MPP. (Subudhi, and Pradhan, 2012; Rezk, and Eltamaly, 2015).

Artificial Neural Network MPPT Method

Artificial neural networks are densely interconnected processing units that employ parallel computation algorithms. Neural networks are contained of easy elements working in parallel (Chekired et al., 2013). This method is similar to biological nervous in human brain (Lippmann, 1987).

ANNs, which utilized to find a suitable solution for the non-linear, consisting of three layers as shown in Figure 3.

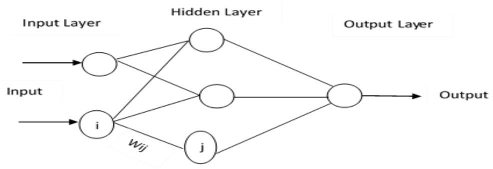


Figure 3. Illustration of a neural network

The input layer is the first layer which receives an external data, the second layer is the hidden layer consist of many hidden neurons which receive a data from the input layer and send it to the output layer (Elgharbi et al., 2012). In each layer, number of nodes, Number of inputs and initial values of weights are depending on the user. The input parameters can be parameters of photovoltaic panel such as voltage and current or atmospheric conditions such as solar radiation and temperature. Parameters of the output can be duty cycle or reference voltage which employed to adjust converters power to work at a maximum power point. (Esram and Chapman, 2007).

The benefits of this MPPT method are their capability to handle big and complex applications with many interrelated parameters (Veerachary and Yadaiah, 2000).

Hybrid MPPT Method

Traditional maximum power point tracking methods are unable to extract maximum power because of global maximum power point (GMPP) occurring at partial shading cases and overall system efficiency is decreased. To overcome this drawback many researchers proposed a hybrid method. The method adjusts the duty cycle to provide load matching and to regulate an input voltage at a maximum power point (MPP) (Rabi, and Kanimozhi, 2016)

A hybrid MPPT is formed by a combination of two MPPT methods or more to improve tracking performance. Jiang and Maskell (2014) proposed a hybrid MPPT method for photovoltaic applications operating during non-uniform insolation cases. This technique combines the artificial neural network algorithm with traditional P&O algorithm for tracking a maximum power.

The P&O method begins searching from an initial value of the boost converter duty cycles for reach to the optimum voltage which corresponds to the maximum power point. Once a sudden variation in irradiance occurs, the ANN technique is then triggered to recognize a new global peak region for a new case of the irradiance (El-Helw et al.2017). This method has a faster convergence speed and a good performance during partial shading condition. However, the hybrid method makes the application more complex and cost of the application may be increased.

SIMULINK MODELING

A complete model of photovoltaic panel has been developed and simulated by MATLAB/Simulink based. Key parameters of PV panel are set as P=100W, Isc= 6.11A, Voc= 21.6 V, Imp =5.5 A, Vmp= 18 V, n=1.2. Four photovoltaic modules connected in series to form a photovoltaic array. Figure 4 shows the PV array.

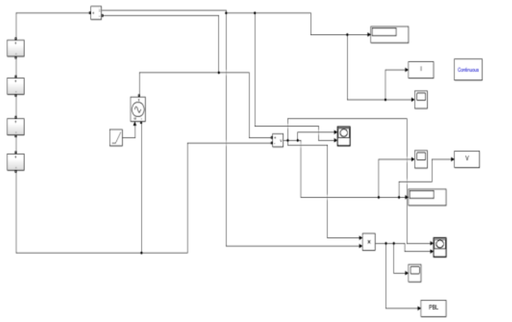


Figure 4. Simulation model of PV array

The photovoltaic system Simulink model with MPPT method is given in Figure 5.

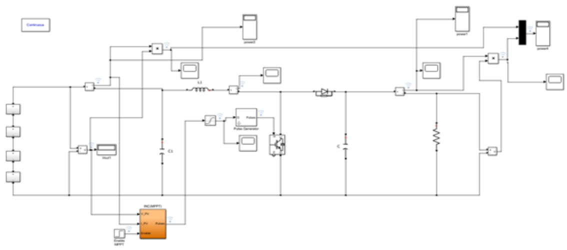


Figure 5. Simulation model of the PV System

The Neural network was defined and designed using ‘MATLAB NNET toolbox’. The developed ANN has two inputs which are the current and voltage of PV array with two layers which are the hidden and the output layer. The hidden layer has ten neurons and the output layer has one neuron which is the duty cycle. The MATLAB software is used to obtain the datasets, 1000 samples that were used for the testing, training, and validation. The datasets are obtained taking values of current, voltage of the photovoltaic array. Generated datasets were splits randomly to 70% for training, 15% for validation, and 15% for testing.

Figure 6. shows simulation model of the hybrid method which combines an ANN method with the P&O method

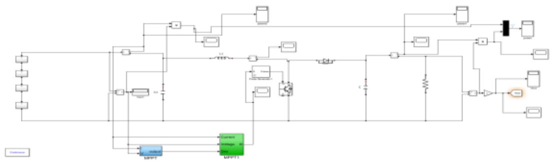
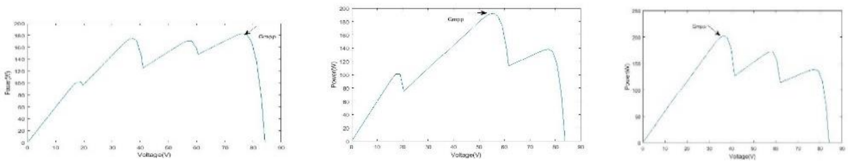


Figure 6. simulation model of PV System with Hybrid Method

5. RESULTS AND CONCLUSION

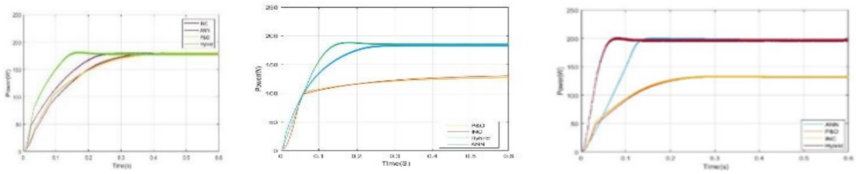
The photovoltaic system was simulated at partial shading conditions. Tracking the global maximum power point (GMPP) by the four MPPT techniques is analyzed under three cases:

Case1- GMPP at the right of power-voltage curve.
Case2- GMPP at the middle of power-voltage curve.
Case3- GMPP at the left of power-voltage curve



(a) (b) (c)

Figure 7. GMPP located at (a) the right of PV curve, (b) the middle of PV curve, (c) the left of PV curve



(a) (b) (c)

Figure 8. Output Power of the PV array with four MPPT methods when GMPP at (a) the right of PV curve, (b) the middle of PV curve, (c) the left of PV curve

From results of the simulation, it is noticed that in case 1 the all MPPT methods are able to track global maximum power point when global maximum power point at the right of the PV curve. Case 2 and case 3 when the global maximum power at the left and middle of the photovoltaic curve. Artificial Neural Network and hybrid methods are able to find the global maximum power point, but the traditional methods Incremental Conductance and Perturb and Observe failed to differentiate between local maximum power and global maximum power point, so always give power around local MPP and in this case a large amount of output power lost. The tracked values of power and time taken to track global maximum power using the four MPPT methods are given in table 2.

Table 2. Performance comparision of four MPPT method under partial shading conditions

		Case1-GMPP at the right of PV curve	Case2-GMPP at the middle of PV curve	Case3-GMPP at the left of PV curve
P_{max} (W)		182	190	200
Hybrid	P_{hybrid} (W)	181	188.5	198
	Time (s)	0.192	0.211	0.109
ANN	P_{ann} (W)	180	187	196.3
	Time (s)	0.223	0.261	0.147
P&O	$P_{P\&O}$ (W)	178.1	134.1	133
	Time (s)	0.399	0.328	0.276
INC	P_{INC} (W)	179.2	135.3	134
	Time (s)	0.389	0.321	0.254

CONCLUSION

Simulation of four maximum power point tracking (MPPT) methods for solar PV array at partial shading condition are presented. Also, a model of the boost converter is designed which is set up the PV's terminal voltage to the suitable voltage to track MPP. The simulation was performed using MATLAB/Simulink environment. A comparative study of four MPPT methods are analyzed under three different partial shading conditions, this comparison is based on the performance of these MPPTs.From the results obtained it is concluded that the ANN and hybrid MPPT methods are able to distinguish between the global maximum power point and local maximum power points with good efficiency and reduces power loss during mismatching conditions, while the conventional methods (P&O and INC) appears worse tracking performance and fails to track the global maximum power point. A comparative study among the four methods has been carried out. The results demonstrate the hybrid method is the best among the other three methods, it is a good solution giving an excellent efficiency and response time in steady state, and under partial shading conditions.

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