Modelling the PV System In Order To Obtain Energy Producing Capacity Using Actual System Parameters, Irradiation and Weather Temperature

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Abstract

An electrical energy generation model of a photovoltaic (PV) system is proposed in MATLAB/Simulink environment. This system includes; PV panel, a maximum power point tracker (MPPT), battery system, DC-DC Boost Converter and DC-DC Buck Converter. The PV panel input parameters are ones which can be easily maintained from any PV panel datasheet and this makes the model very useful in the application area. The temperature and irradiation effects are included in the modulation. For the accuracy of the system, real time measurement results and simulation results are compared. The obtained results are satisfying.

Key Words

"Photovoltaic panel, dc-dc boost converter, dc-dc buck converter, maximum power point tracker, modelling"

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1. INTRODUCTION

As the development level increases day by day, it brings the rise in the energy requirement with it. To satisfy the need of this energy, instead of limited sources such as coal and gas, renewable energy sources have come into use **(Razykov**, 2011). Being one of the renewable energy sources, solar energy is mostly preferred due to its extensive practice field and ability to gain without using much effort. Understanding solar energy systems have a big importance in using these systems with efficiency.

The first academic studies in this field have started with obtaining the solar cell characteristics (Picciano, 1969), (Bryant & Glew, 1975) and then continued with modulations of solar systems. With the developing technology, simulations have been done in different environments such as EMTDC/PSCAD (Park , 2001), SPICE (Gow & Manning, 1999)and etc. (Altas & Sharaf, 1992), (Kaushika & Gautam, 2003) but mostly in MATLAB (Tsai & Tsai 2012), (Duman & Altaş, 2014).

Modelling and control of grid connected wind/PV hybrid generation system with MPPT (Kim et al., 2006), PV/battery system modulation and simulation including irradiation and temperature effects (Altaş & Mengi, 2008), obtaining PV characteristics using microprocessor techniques (Locci et al., 1986), grid connected PV system modulation using different converters (Walker & Sernia, 2004), obtaining I-V equation parameters by adjusting the curve at three point (Villalva et al., 2009) and reducing the unknown parameters (Laudani et al., 2014), improving the photovoltaic model with new model structures (Chatterjee et al., 2011), (Salam et al., 2010), (Li et al., 2013) are some of the studies.

Comparisons with experimental results have big importance for the studies to be applicable in the practice field. Some of them can be listed as follows. Experimental study of mismatch and shading effects in the I-V characteristic of a PV module (Alonso-Garcia et al., 2006), MATLAB based modelling and performance study of series connected SPVA under partial shaded conditions (Ramabadran & Mathur, 2009), theoretical and experimental analysis of MPPT algorithms (Houssamo et al., 2010), (Messai et al., 2011), insulation oriented model of photovoltaic module using Matlab/Simulink and verification of this model with measurements through an experimental ring (Tsai, 2010), PV system monitoring and performance of a grid-connected PV power station located in Manchester-UK (Natsheh et al., 2011), improvement and validation of a model for PV array performance with 5 parameter model (De Soto et al., 2006) and many other studies (Sathya & Natarajan, 2013), (Benghanem & Alamri, 2009), (Humada et al., 2016).

In this study, an electrical energy generation model of a photovoltaic system is proposed. The model is simulated in MATLAB/Simulink environment using actual system parameters, solar irradiation and weather temperature, also the simulation system results are compared with experimental system results. The aim of this study is to obtain the power/energy capacity of any solar system using the necessary parameters mentioned above. With this study when the generated power capacity is obtained the energy can be used efficiently. The system includes a PV panel, Maximum power point tracking system, DC-DC Boost Converter, DC-DC Buck Converter and a battery system.

The remaining of this paper is structured as follows. The MATLAB/Simulink model of the PV module and the mathematical expressions are given in section 2. The used converters, MPPT algorithm and PI control are briefly mentioned in section 3. In section 4, the general system design, battery connection and the analysis of the battery connected whole system are presented. The real-time measurements are taken from the solar house used in the 111E292 numbered TUBITAK Project, this experimental system is mentioned in section 5. In section 6, the temperature-irradiation measurement values are used in the simulated system and the obtained results are compared with measured results.

2. MATHEMATICAL MODEL OF A PV MODULE

 PV cells are the main components of solar energy generation. To model a solar energy system, the PV cell modelling should be done first. Solar cells (PV cells) differ by the number of diodes, the series and parallel resistances in the cell. In this paper, the equivalent circuit obtains only one diode and a series resistance (single diode model).

Only one solar cell cannot provide substantial values. When the cells are connected in series and parallel, the output power can be raised up to an acceptable and desired value. The more the cells are connected in series, the more the output voltage increases and the more the cells are connected in parallel, the more the output current increases (Turcek et al., 2011).

For the equivalent circuit used in this paper, the mathematical expressions can be described as below (Nema et al., 2010).

$$I = N_p I_{ph} - N_p I_d \tag{1}$$

$$I = N_p I_{ph} - N_p I_0 \left\{ exp\left[\left(\frac{V}{N_s} + \frac{R_s I}{N_p} \right) \frac{q}{nkT_c} \right] - 1 \right\} \tag{2}$$

$$I_0 = I_{rs} \left(\frac{T_c}{T_{ref}}\right)^3 exp\left[\frac{E_g q}{nk}\left(\frac{1}{T_{ref}} - \frac{1}{Tc}\right)\right] \tag{3}$$

$$I_{rs} = I_{sc} / \left[exp\left(\frac{V_{oc}q}{nkT_cN_s}\right) - 1\right] \tag{4}$$

$$I_{ph} = \left[I_{sc} + \alpha(T_c - T_{ref})\right]\frac{S}{S_{ref}} \tag{5}$$

Where; I(A) is the output current of the cell, V(A) is the output voltage, Id (A) is the diode saturation current, I0 is the temperature dependence of the diode saturation current, Irs(A) is the reverse saturation current, Isc (A) is the short circuit current at reference conditions, Voc (V) is the open circuit voltage at reference conditions, Iph (A) is the photocurrent, n is the diode ideality factor, Tc (˚C) is the cell temperature, Tref (˚C) is the reference temperature, S (W/m^2) is the solar irradiance, S_{ref} (W/m^2) is the reference solar irradiance, Ns stands for the number of cells in series, Np is the number of cells in parallel, Eg is the band gap energy, α (A/˚C) is the temperature coefficient of the short circuit current, q is the electron charge $(1.602 \times 10^{-19}°C)$, k is the Boltzmann's constant $(1.381 \times 10^{-23}J/K)$, and Rs epresents the series resistance. The PV module is modelled in MATLAB/Simulink as shown in Fig. 1. using the equations (1)-(5) (Okumuş & Nuroğlu, 2016).
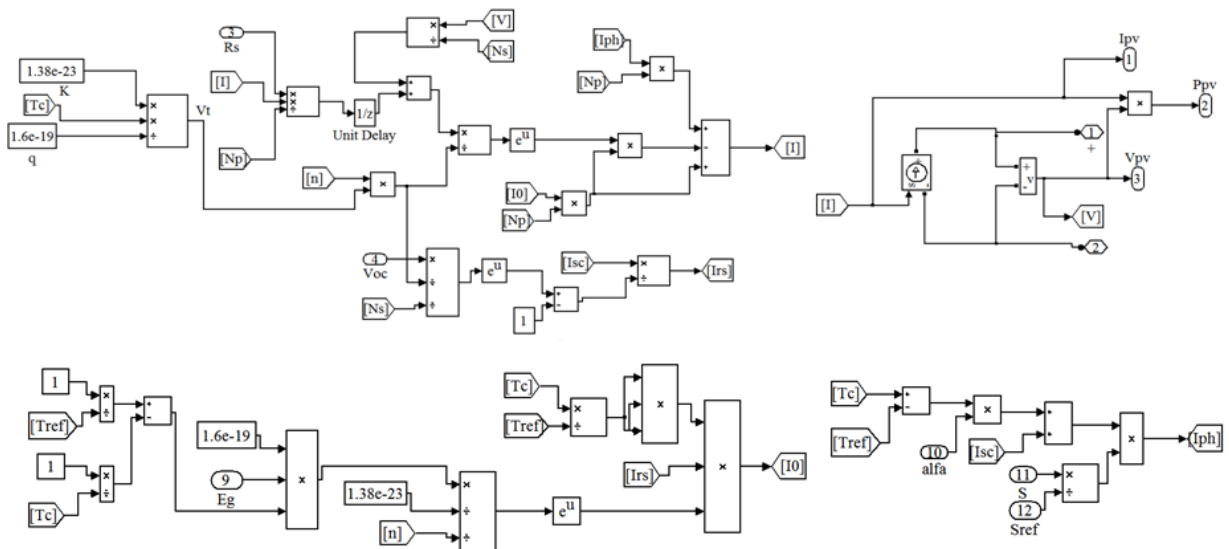

Fig. 1. The simulated PV module

3. CONVERTERS AND CONTROL ALGORITHMS

3.1. Converters

DC-DC converters are systems which can change the input voltage value to the desired output value and they are used in many areas such as renewable energy systems, electrical vehicles and transportation. Converters used in renewable systems are mostly switched mode converters (buck-boost, boost and buck converter). These converters operate in two modes: continuous and discontinuous. The operating mode changes due to the inductance current value. In continuous mode, the inductance current never drops to zero and the inductance is always energized. In discontinuous mode, the inductance current drops to zero and the energy on the inductance is transferred to the load (Davoudi et al., 2006).

In this paper, the used boost and buck converters are operating in continuous mode. The boost converter is used in PV system to regulate the PV module output voltage while the buck converter helps the load to be fed continuously. When the buck converter power is not enough for the load, the battery system takes part (Mohan, 1989).

3.2. Control Algorithms

The MPPT controls the boost converter to obtain maximum power from the PV module. Having an easy application P&O algorithm is one of the most preferred MPPT algorithms. This algorithm deals with the change in the PV power brought out by the PV current and voltage (Sankarganesh & Thangavel, 2012). The PV output voltage and current values are measured and then the power is obtained. According to the positivity and negativity of the change in the output power (ΔP) and voltage (ΔV), the maximum power point is tracked. The algorithm adjusts the duty cycle value which generates the maximum power. Many different control methods are used for converters. Being one of these control methods PID control is mostly used due to its easy application, noncomplex structure and low cost. In this paper, PI controller is used to control the buck converter. This controller is used mostly when the offset value can't be reduced. The control signal is compared with the sawtooth signal and the switching signal is gained. This signal is applied to the buck converter and the output voltage is obtained. The feedback control continues until the output reaches the reference value (Alagöz et al., 2013). The parameter values used in the PI control is given in Table 1.

Table 1. The parameter values used in PI control.

Parameters	Values
Proportional gain, Kp	1
Integrative gain , KI	10
Switching frequency	31 kHz

4. SYSTEM DESIGN

The MATLAB/Simulink model of the proposed PV system is shown in Fig. 2. The system includes a boost converter, buck converter, an MPPT and a battery with battery control system.

The boost converter is used in the system to regulate the PV output voltage. This converter is controlled by the MPPT to obtain maximum power from the PV module. The buck converter uses the boost output voltage and with PI controller it provides the intended voltage value for the load. The buck converter uses the boost output voltage and with the PI controller it provides the intended voltage value for the load. The battery takes part in the system when the buck converter output is not at the desired value. With the battery control, the load is always powered either by the PV module or the battery.
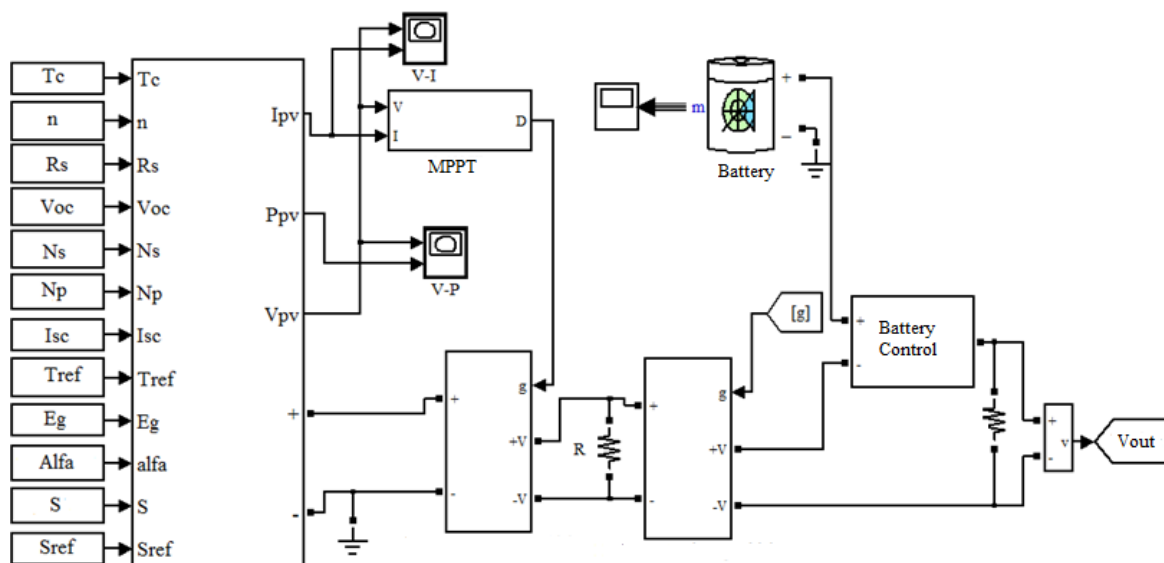
Fig. 2. The MATLAB/Simulink model of the proposed PV system.

4.1. Battery Control System

The simulink modulation of the battery control system connected to the buck converter is given in Fig. 3.
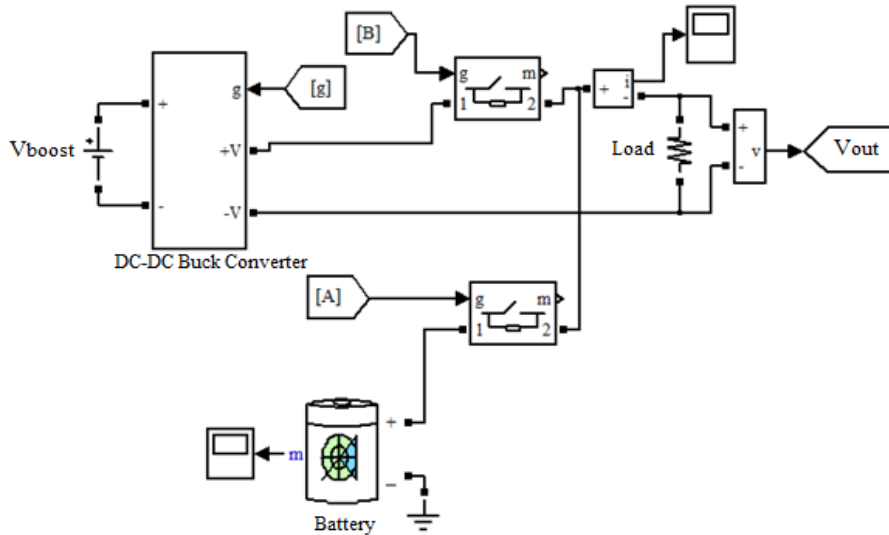

Fig. 3. The simulink modulation of the battery control system connected to the buck converter.

The addition of the battery to the system is done by the switches as in [12]. If the signal coming to the B point is 1, the load is fed by the buck converter but if the A point is 1, the load is fed by the battery. The control system of A and B points are given in Fig. 4.
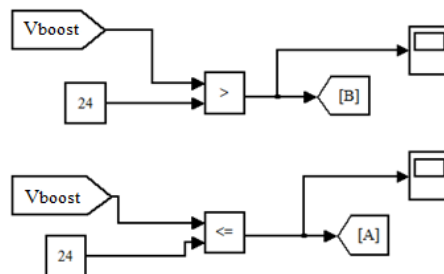
Fig. 4. The control system of A and B points.

The decision is made by comparing the reference voltage with the output voltage coming from the boost converter. In this study, the load reference voltage is 24 V, so if the boost output voltage is higher than 24 V the buck converter can reduce it to the reference value and B point signal becomes 1. But if the output voltage of the boost converter is less than 24 V the A point signal becomes 1 and the load gets fed by the battery.

The state of the battery connected system is investigated by applying different temperature and irradiation values as inputs and analyzing the load.

The temperature values are shown in Fig. 5. The values change every minute and are 0 ˚C, 25 ˚C and 40 ˚C respectively.
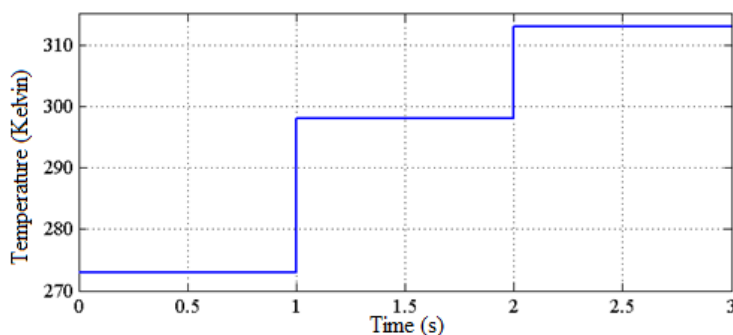

Fig. 5. The temperature values.

The irradiation values also change at the same minutes as shown in Fig. 6. The values are 500 W/m^2, 1000 W/m^2 and 100 W/m^2 respectively.
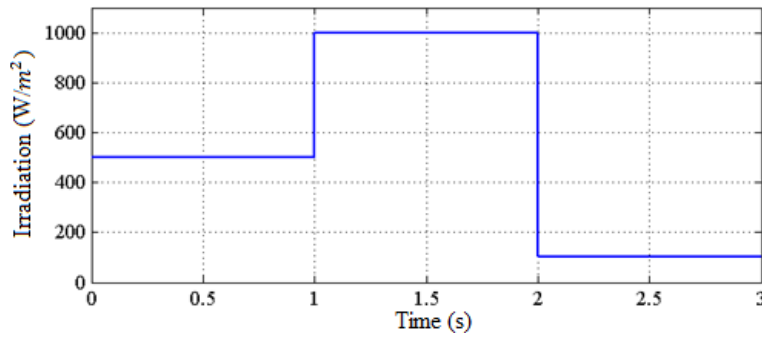

Fig. 6. The irradiation values.

In Fig. 7, the change in buck converter input voltage and load voltage are shown according to the temperature and irradiation values. As it is seen, while the buck converter input voltage changes the load voltage is constant at the reference value.
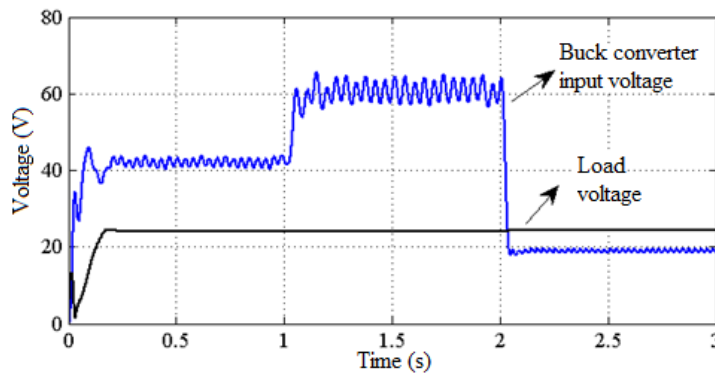

Fig. 7. The change in buck converter input voltage and load voltage according to the temperature and irradiation values.

In Fig. 8, the time intervals of the connection of the battery and buck converter are shown. As mentioned before if the A point signal is 1 the load is fed by the battery and if the B point signal is 1 the load is fed by the buck converter.
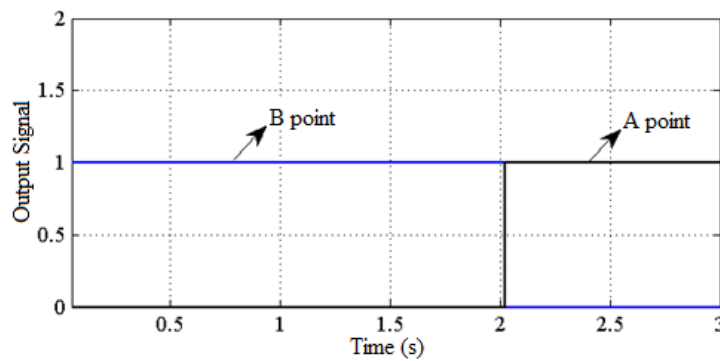

Fig. 8. The time intervals of the connection of the battery and buck converter.

The power change of the load is also given in Fig. 9. As it is seen, the power is nearly constant at all times.
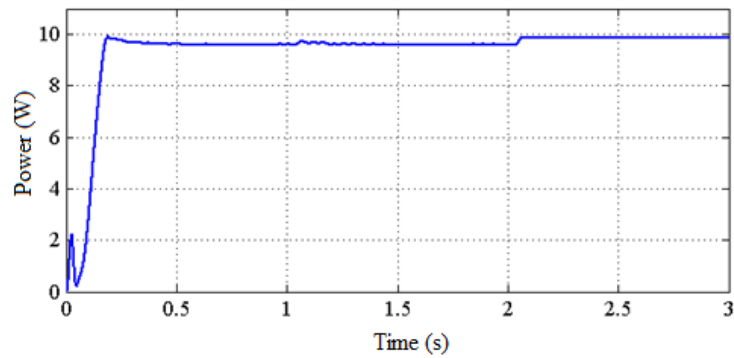
Fig. 9. The power change of the load.

5. EXPERIMENTAL SYSTEM

In order to see the comparability of the model, real-time measurements are taken from the solar house which is used in the 11E292 numbered TUBITAK project. The used panel models are SR-M50100. There are 4 panels on the solar house but for this study only two of them are used. The two panels are connected in parallel and a rheostat is connected to the output as a load.

All the measurements are real- time measurements which are taken on 26.04.2016 starting at 7:30 until 16:34. The output power is measured with C.A. 8220 Power Analyzer which can record immediate data and transfer it to the computer at the same time. The power analyzer can also measure immediate current and voltage. For the current measurement, an additional probe should be used and so E3N model current probe is connected to the analyzer.

Because in the modulation the temperature and irradiation effects were considered, the real-time measurements of these parameters should also be taken. For the irradiation measurement, the PCE-SPM1 device is used and is located on the solar house with the same angle as the PV panels. Also, this device measures the data every minute immediately and transfers it to the computer synchronously. For the temperature measurement PCE-330 device is used and along with the other devices, it can measure immediate data.

6. RESULTS

6.1. Experimental Results

The temperature measurement results are given in Fig. 10. In the early hours, the temperature value is around 16 ˚C rising to 30 ˚C in the middle of the day and then again down to around 22 ˚C.
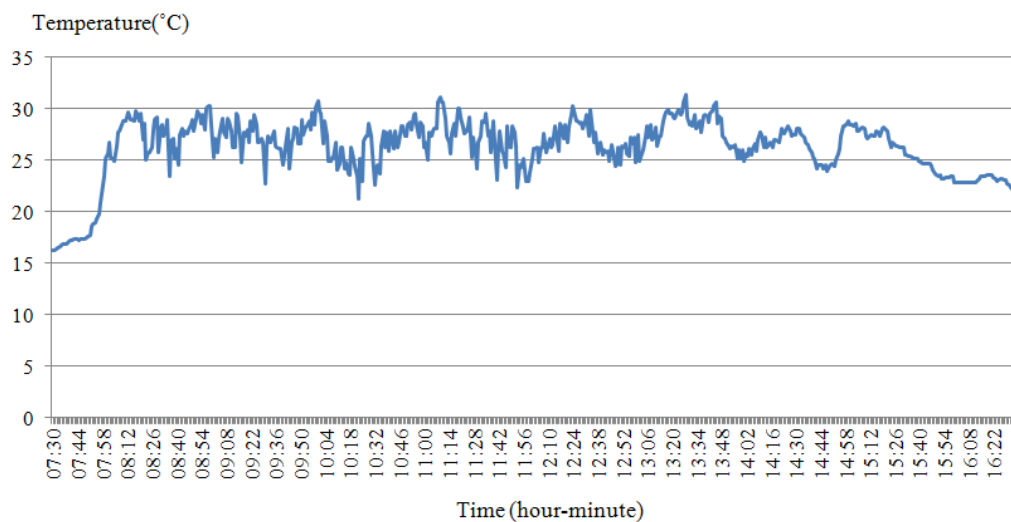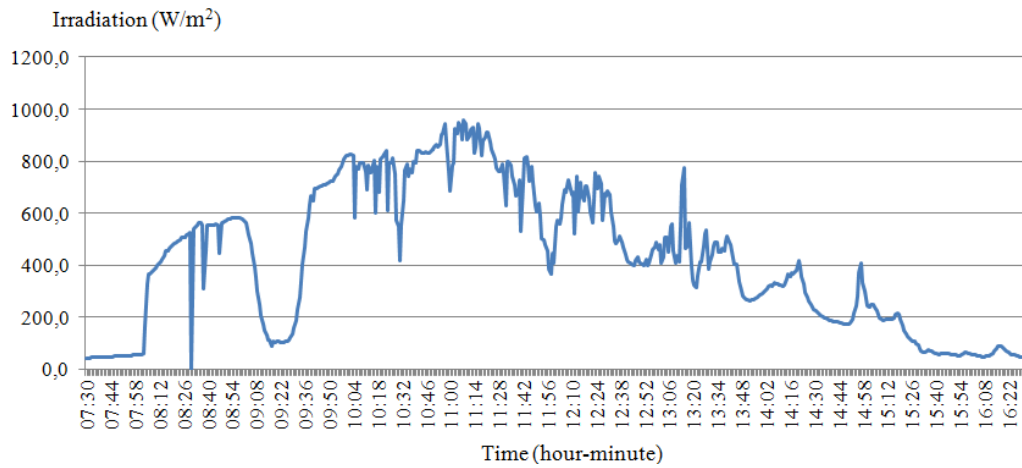


Fig. 10. The real time measured temperature values.

The irradiation measurement results are shown in Fig. 11. The irradiation is 420 W/m^2 in the morning and then up to 950 W/m^2 in the afternoon and 34 W/m^2 in the evening.

Fig. 11. The real time measured irradiation values.

As seen from the figure, the irradiation value drops to a very low value at a significant point. The measurement results are taken directly from the irradiation measurement device as mentioned before so the reason for the low irradiation value is mostly because of the shade of the nearby structure and this will also lead to obtaining low voltage, current and power values from the simulation at that significant point.

Also, the measured power results are given in Fig. 12. The power value changes between 38-59-48 W.
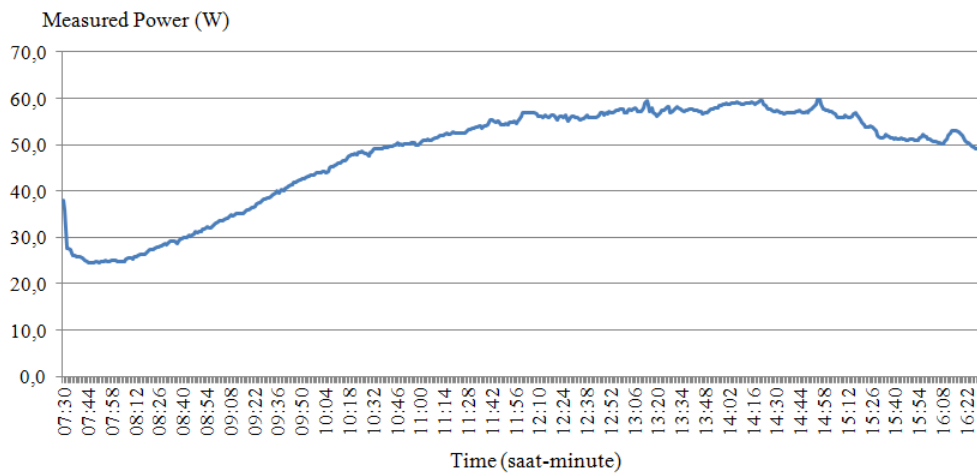
Fig. 12. The real time measured power values.

6.2. Simulation Results

As mentioned before two of the panels are used in this study and the panels are connected in parallel. For the results to be realistic the simulation should match with the real system. So the simulation of two panels connected in parallel is done as shown in Fig. 13.
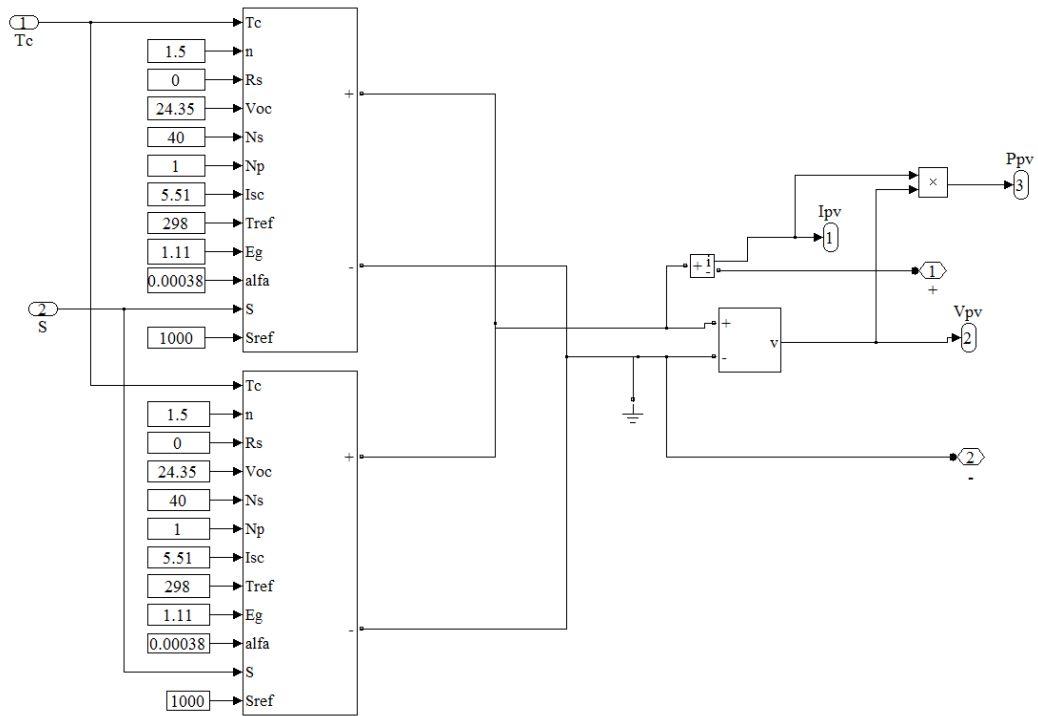
Fig. 13. The two panel connected in parallel simulation.

Because of excessive values, the real-time measurement irradiation and temperature values between 08:05-14:55 are applied to the simulation and results are obtained. The voltage values change between 16-24 V as in Fig. 14.
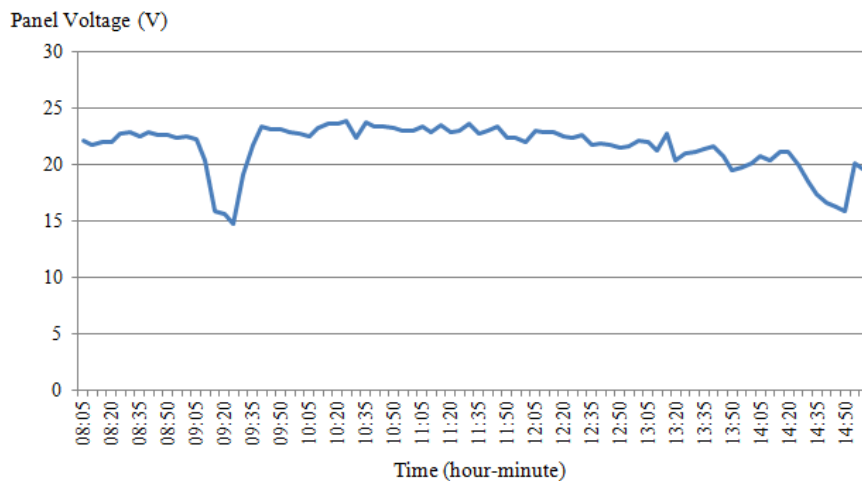

Fig. 14. The simulation voltage values.

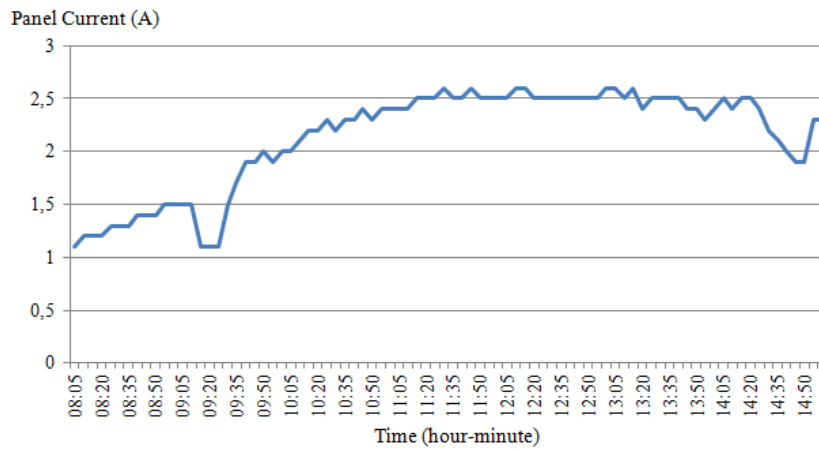The current change is shown in Fig.15 and it is 1.1-1.6 A.

Fig. 15. The simulation current values.

The power values change between 17-60 W as shown in Fig. 16.
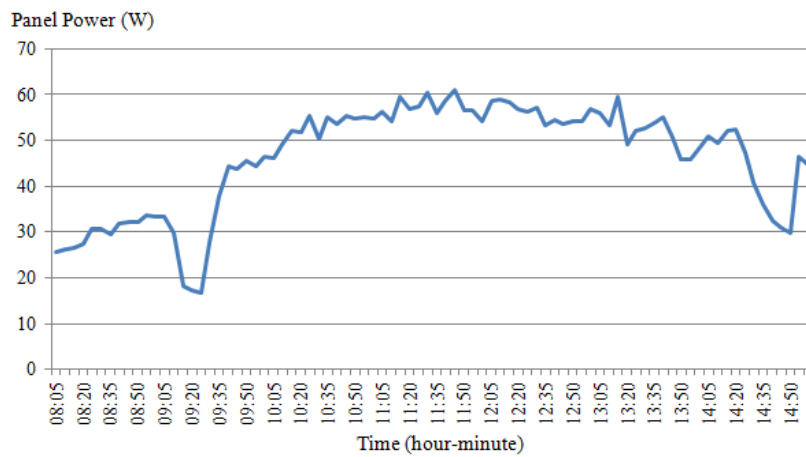

Fig. 16. The simulation power values.

6.3. Comparison Results

The simulation and experimental results are analyzed to see the compatibility of the proposed system. In Fig. 17, the measured and simulation voltage values are compared and approximately 93% compatibility is seen. As mentioned before due to the change in the irradiation values, a voltage drop is seen in the simulation voltage values around 09:20 and 14:50. But the irradiation effect is not seen clearly in the measured values as it is in the simulation.
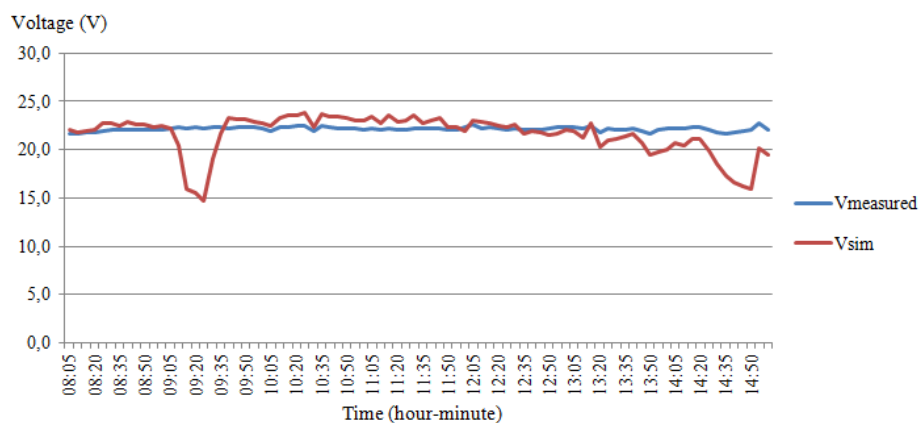

Fig. 17. The comparison of measured and simulated voltage values.

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In Fig. 18, the measured and simulation current values are compared and the accuracy is close to 94%. As it was in the simulation voltage values, the current values also have a value drop at that significant time.
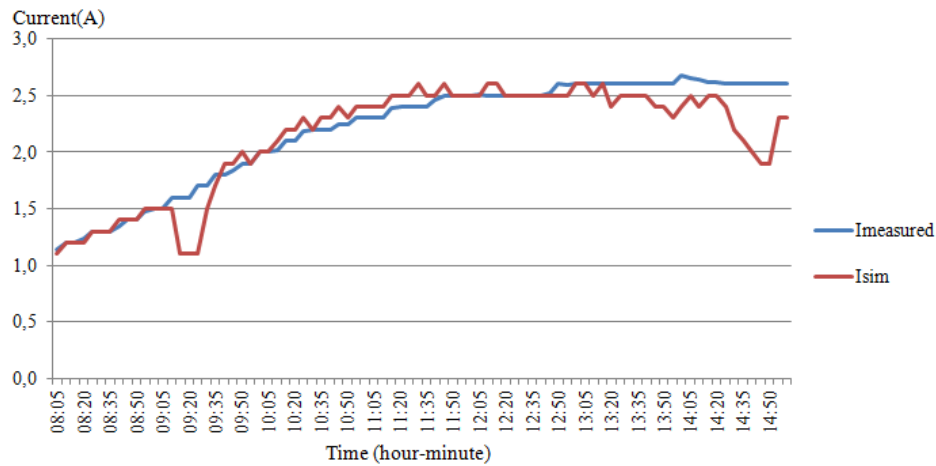

Fig. 18. The comparison of measured and simulated current values.

Also in Fig. 19, the measured and simulation power values are compared. The results show an 89 % matching.
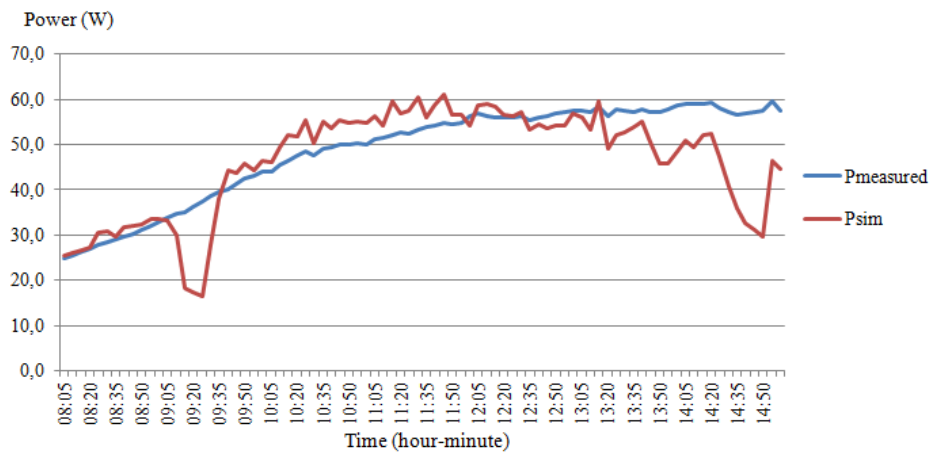

Fig. 19. The comparison of measured and simulated voltage values.

7. CONCLUSION

In this paper, an electrical energy model of PV system is proposed. The model includes a PV panel, DC-DC Boost Converter, DC-DC Buck Converter, an MPPT and a battery system. The model is designed so that it can easily be used in the application field. The PV input parameters are ones which can be found in every panel datasheet.

For the MPPT algorithm, P&O is used because of its easy application. For the accuracy of the model, experimental studies have been done in a solar house. The panels are simulated as they are connected in the solar house and the temperature, irradiation; panel generated voltage, current and power are measured. The experimental results are compared with the simulated results and an 89% high accuracy value is obtained for the power comparison.

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