Modelling and Simulation of Photovoltaic Systems Using MATLAB / Simulink

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Abstract: - The use of renewable energy sources has increased rapidly today, and the easy availability of solar energy and its abundance in nature are one step ahead of other renewable energy sources. The rapid increase in the technological infrastructure, especially to obtain electricity from solar energy by photovoltaic (PV) method, has also accelerated the process of integrating PV systems into people's daily life. In this study, the solar cell model was obtained by using a solar cell equivalent circuit with Matlab Simulink and a 5.3 kW PV generator was designed using this structure. Also, the performance of the PV module has been analyzed under different temperature and solar irradiation conditions. Thanks to the developed model, it is aimed to use PV model generators with different technical features and different installed power more easily. Methodology in this project study was to create a circuit model of a solar cell in the Matlab Simulink program, modeling this model as a subsystem.

Key-words: Photovoltaic, Modelling, Simulation, System.

1 Introduction

Today, people can obtain electrical energy from the sun by taking advantage of the photovoltaic phenomenon. Photovoltaic (PV) event is a physical event defined as the conversion of sunlight into electrical energy. Semiconductor materials that convert sunlight coming on its surface directly into electrical energy are called solar cells. The solar cell generates voltage at its ends depending on the amount of light falling on it. The voltage generated increases or decreases in direct proportion to the amount of sunlight incident. The reason why many systems working with solar energy take their place in our daily life is the rapid development of PV technology. Obtaining the equivalent model of the solar cell and solar panel is important for the design of photovoltaic systems.

There are many studies of researchers in the literature on obtaining the solar cell model. In these studies, the easiest Matlab program is used to simulate these models. Shen et all obtained the Practice and Theory of solar radiation data processing by modeling the solar cell using Matlab / Simulink. They also simulated the PV module [1]. Chatterjee et all contributed to the production of Power Grid by considering an equivalent PV module in their study called Equivalent of

Photovoltaic Source Models for MPPT and Power Grid Studies [2]. Arrouf et all used the PV generator model in the design of a pump system fed by a PV generator [3]. Carrero et all developed a method of estimating the parameters of PV generators and simulated the PV module [4]. Da Silva et all and Uzunoglu et all have done the modeling of PV modules and hybrid system design. In these studies, equivalent PV module models were used to examine hybrid structures such as fuel cell solar cells [5,6]. Tsai, H.and Pon Vengatesh et all, conducted studies based on solar radiation and investigated the effect of solar radiation on PV module output power [7,8]. Tan, Y. T. et all and Villalva et all studied electrical models of PV arrays by modeling PV generators in systems fed by PV generators [9,10].

In this study, a PV panel block was obtained with Matlab Simulink and a 5.3 kW PV generator was designed. With the designed model, it is aimed to use the PV generator easily and to model PV generators of different powers.

2 Solar Cell Circuit

To study the properties of solar cells, a circuit with known electrical properties and characteristics is

required. Studies have been conducted on various circuits, simple and advanced, for solar cells in the literature. Solar cells are elements that have losses due to their characteristics and work. These losses are covered by resistance. Figure 1 shows the circuit model for the solar cell. Here, Iph stands for photon current, Rsh for leakage current resistance, Rs for voltage resistance, D diode, Rl for load resistance in circuit, Id diode current, Ish for leakage current, Vpv for voltage value in photon circuit. Photovoltaic efficiency detects RS changes, not Rsh variations [11].
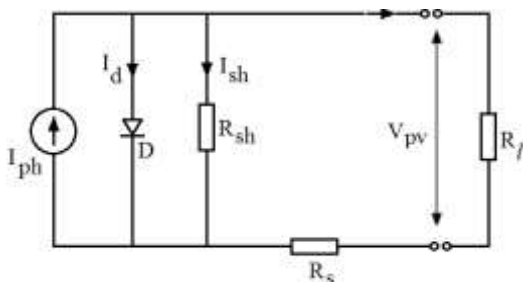

Fig. 1: Solar cell electrical circuit

According to Kirchhoff's law,

$I_{ph} - I_d - I_{sh} = 0$

(1)

I_d , is the total current passing through the circuit, the sum of electrons and currents excited by photons. Net electron current according to Boltzman's law,

$I_e = I_{eo} \cdot \left(\frac{q.V_D}{e^{kbT}} - 1 \right)$

(2)

Space current ,

$Ih = Iho(e^{\frac{qVD}{kbT}} - 1)$

(3)

Diode current,

$I_D = Ie + Ih = Io(e^{\frac{qVD}{mkT}} - 1)$

(4)

Where,

q : electron charges (1.602×10^{-19} C)

V_D : potential difference between the ends of the diode

m : ideality factor (m = 1 in ideal diodes)

k : Boltzman constant (1.381×10^{-23} J/K)

T : Absolute temperature (Kelvin) (ºK= -273.15 ºC)

Dark saturation current

$Io = Ieo + Iho$

(5)

Where,

I_0 current is very sensitive to temperature.

If Kirchoff's law of voltages is applied to the solar cell circuit, equation (6) is obtained.

$I_D = I_0(e^{\frac{qV_D}{mkT}} - 1) = Io(e^{\frac{q(Vpv+I.Rs)}{mkT}} - 1)$

(6)

Here I_D defines the source current.

$I_{sh} = \frac{V_D}{Rsh} = \frac{Vpv+I.Rs}{Rsh}$

(7)

Here I_{sh} defines the leak current.

$Iph = I_0\left(e^{\frac{q(Vpv+I.Rs)}{mkT}} - 1\right) + \frac{Vpv+I.Rs}{Rsh}$

(8)

ISH for mathematical simplification disregarding

$I = I_{ph} - I_0\left(e^{\frac{Vpv}{mVt}} - 1\right)$

(9)

Where I is the output current in the solar cell circuit.

$V_t = \frac{k.T}{q}$

Where Vt is the thermal voltage. Its value at 30ºC is approximately 30.84 v.

3 Solar Panel Circuit

Solar cells generate electrical energy in the range of 1.5-2 W under solar radiation. A current value in the range of 2.5-3 A and a voltage value in the range of 0.6 - 0.7 V are obtained from a single diode. By connecting solar cells in series, modules with a power between 25 - 350 W can be created.

The solar panels are connected with each parallel Npc column module and Nsc row solar cell as can be seen in Fig.2. Therefore, a solar panel was formed. This structure and properties of the solar panel can be obtained from catalogs.
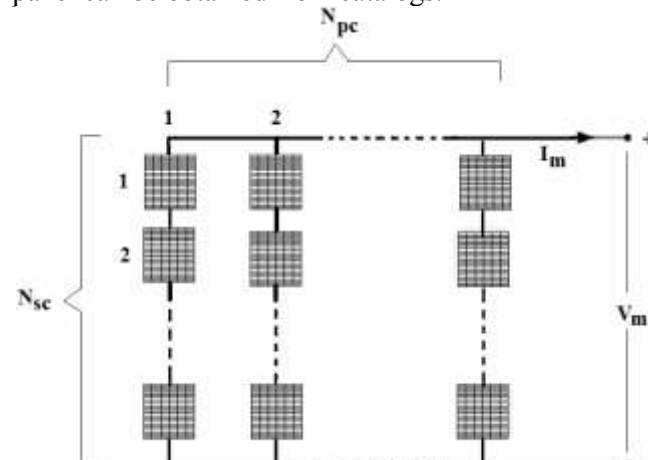

Fig. 2: Solar panel structure

In Fig.2., Im defines the current formed in the panel, the current, the voltage voltage generated in the Vm panel, the number of solar cells forming the Nsc panel, the number of modules forming the Npc panel.

The module current Im and the voltage Vm applied to the module ends are calculated with the equations (10) and (11).

$$V^M = N_{sc} \cdot V_{new}$$
(10)

$$I^M = N_{pc} \cdot I_{new}$$
(11)

Where I_{new} is the new current value and V_{new} is the new voltage value.

The saturation current Io of the PV module in the dark, which is highly affected by temperature,

$$I_0 = I_{0ref}\left(\frac{T_c}{T_{cref}}\right)^3 \cdot exp\left[\left(\frac{qE_g}{nk_b}\right)\left(\frac{1}{T_{cref}} - \frac{1}{T_c}\right)\right]$$
(12)

Here $I_{0\ ref}$ is reference current, Eg is the bandwidth of the material diode. The photone current generated in the PV module according to the irradiation intensity is calculated by equation (13).

$$I_{ph} = [I_{sc} + \alpha(T_c - 25)]\frac{G}{G_{ref}}$$
(13)

Where, for a module G is the current radiation intensity (W / m²), G_{ref} is reference (desired) radiation intensity (W/m²), T is the current module temperature (°K), T_{ref} is the reference (desired) module temperature (°K), A is the temperature coefficient of the module (mA / °K).

In the solar panel, I and V values are calculated by equations (14), (15) and (16).

$$I_{new} = I_{ref} + \left[\alpha\left(\frac{G}{G_{ref}}\right)(T_c - T_{cref}) + \left(\frac{G}{G_{ref}} - 1\right)I_{sc}\right]$$
(14)

$$\Delta I = \left[\alpha\left(\frac{G}{G_{ref}}\right)(T_c - T_{cref}) + \left(\frac{G}{G_{ref}} - 1\right)I_{sc}\right]$$
(15)

$$V_{new} = -\beta(T_c - T_{cref}) - R_s\Delta I + V_{ref}$$
(16)

Here, I_{ref} is the reference current value and V_{ref} is the reference voltage. $\propto$ is the current temperature coefficient, β is the voltage temperature coefficient. The power of the photovoltaic system is directly proportional to the current and voltage. The characteristics of the Solar Module ET Solar ET-M536100 solar panel modeled in Matlab / Simulink are given in Table 1. In this module, whose technical specifications are given in Table 1, 36 polycrystalline silicon solar cells are connected in series and the module has a maximum power of 100W. The module parameters are given by the manufacturers under standard test conditions (1000 W/m² solar radiation and 25 PV module temperature). The output power under these conditions is defined as the largest output power of the solar panel and is expressed in Pmax.

Table 1. Technical specification of Solar Module-M536100

Solar cell type	Mono cristalline silicon
Open circuit voltage (Voc)	22.92 V
Short circuit current (Isc)	6.01 A
Maximum power (Pmax)	100 W (+/-3%)
Maksimum Güç Gerilimi (Vmp)	16.64 V
Efficient (%)	Module (%15.23) - Cell (17.78)
Maximum power current (Imp)	9.16 A
Maximum system voltage	1000 V DC
Size	1480 x 670 x 35 mm
Weight	(19 Kg)
Glass	Tempered and 3.2 mm thickness
Number of cells connected in series (Nsc)	9
Number of line connected in parellel (Npc)	4
Temperature constant of voltage (β)	-0.35
Temperature constant of current (α)	0.038
Maximum temperature	+ 45 °C

4 Simulink Model

The solar panel is modeled in the Matlab Simulink program. This model is made using the technical specification in Table 1. In addition, equations (14) and (16) were used. In the system model, temperature and solar radiation values are used as input parameters, and current, voltage and power values of the solar panel are used as output parameters. Modeled structure of the solar panel, Fig.3. is also seen.
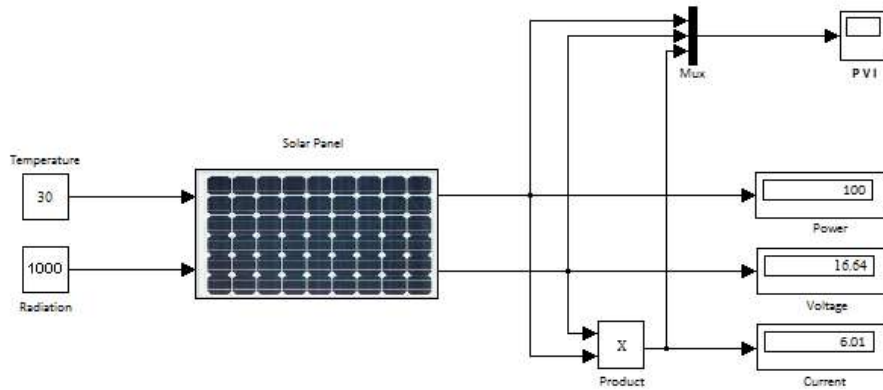
Fig. 3: Simulink model of solar panel

Here the solar panel is modeled as a subsystem. The current (6.01 A), voltage (16.64 V) and power (100 W) parameters obtained from the solar panel for 30 ºC temperature as the input parameter value and 1000 W/m² as the irradiance value are shown in Fig.3.

The Vref and Iref desired values of the solar panel are also the maximum operating point. Parameters such as α , β and Isc are defined in the model. In the solar panel, 9 solar cells are connected in series. This serial structure is connected in parallel to one of the 4 main branches. In other words, Npc = 4 and Nsc = 9 are defined in the system model.

The results in Fig.4 were obtained by running the model in Fig.3. Here, the current of the solar panel is 6.01 A, its voltage is 16.64 V and its output power is approximately 100 W. These values comply with the technical specifications in Table 1. In other words, the solar panel Vref and Iref worked at their desired values. It has reached the maximum point.

The technical specifications of the model designed here are defined by writing the program codes in Matlab. The graphic in Fig.6 was obtained by running this program. Here, the short circuit current of the panel (5.9 A) is the point where the curve intersects the current axis and the open circuit voltage of the panel (22.6 V) is the point where it intersects with the voltage axis. The desired values (Vref = 16.64 and Iref = 6.01) are shown in the graph as the maximum operating point.
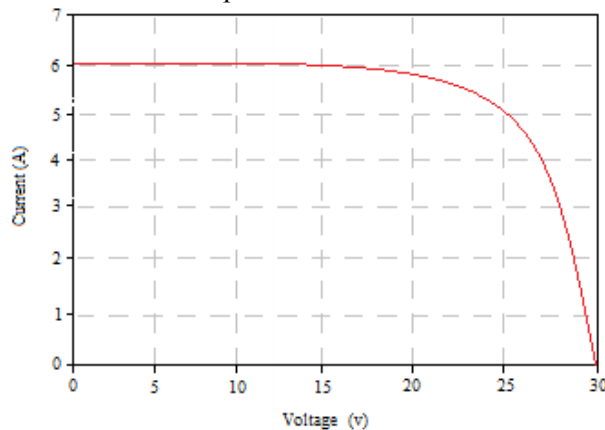
Fig. 4: Solar panel's I-V curve

The model of the solar panel created in Simulink, the effect graph that occurs after different temperature and radiation values Fig.5. and Fig.6. also shown. The increase in PV panel current occurs with the increase of radiation. The increase in the PV panel voltage occurs with the increase of radiation. This situation is shown in Fig.5. is also seen.
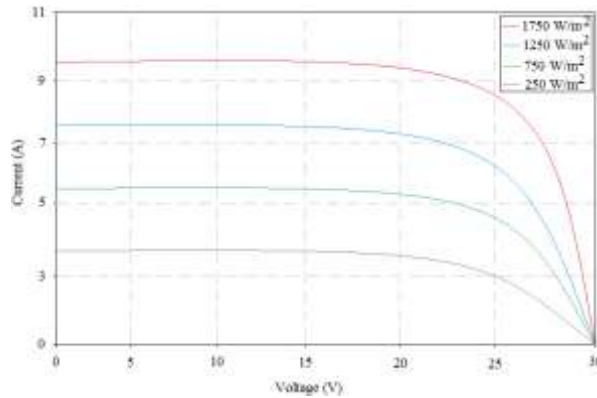

Fig. 5: The effect of radiation on I-V

The increase of PV panel current occurs with the increase of temperature. The increase in PV panel voltage occurs with the increase of temperature. This situation is shown in Fig.6. is also seen.
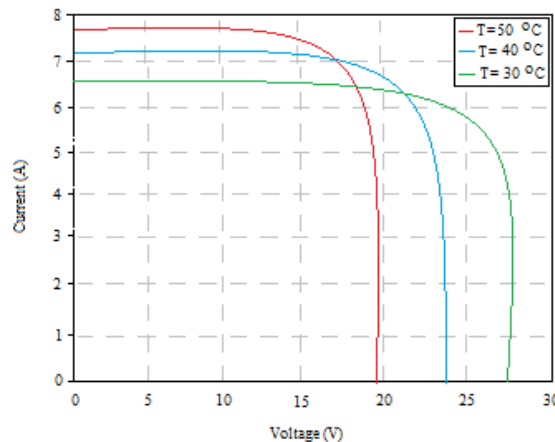

Fig. 6: The effect of temperature on I-V

5 PV Panel Model

A set of solar cells that are electrically interconnected and mounted on a single support structure or frame is called a "photovoltaic module". The modules are designed to supply electricity at a specific voltage, such as a common 12 volt system. The current produced depends directly on the intensity of light reaching the module. Several modules can be linked together to form a sequence. Photovoltaic modules and arrays generate direct current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination. Fig.7. de PV Cell, Module and Array A PV array consists of several PV modules mounted on the same plane and electrically connected to provide the required electrical output for the application. The PV array can be any size between a few hundred watts and hundreds of kilowatts, but larger systems are generally divided into several electrically independent subsets, each fed into its own power conditioning system [12].
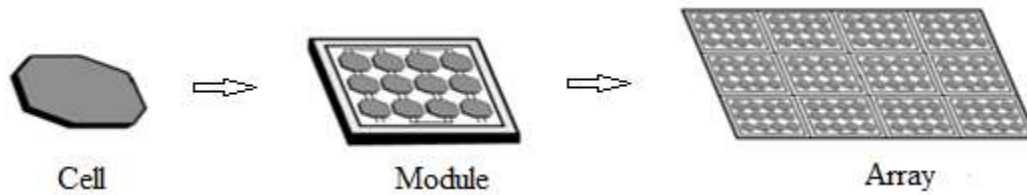
Fig. 7: The formation stages of PV panel

While obtaining solar panels here, the model and block of a panel string is created. By using this block, PV generator model has been obtained. Here, the desired output power is 5.3 kW and the desired output current to be transferred to the load is approximately 22 A. Therefore, it is necessary to use 36 Solar Module-M536100 solar panels, each of which can produce a maximum of 100 W of power. A panel array consisting of 4 main branches must be obtained, in which 9 panels are connected in series and this serial structure is connected in parallel. With this structure, the desired power and current is obtained. Fig.8. The PV generator structure modeled in is shown.

Fig. 8: Simulink Model of solar panel generator

Current, voltage and power information obtained from the generator can be seen in Figure 9. Here, the PV generator voltage is 163.8 V and the PV generator current is 21.92 A. PV generator power was obtained as 3590 W. The PV generator model has been developed in such a way that the desired generator power and generator current can be obtained by connecting the appropriate number of PV panels in series with each other and connecting these series branches as parallel arms. To achieve this, only the number of elements in the serial and parallel branch should be entered into the model in the Matlab program.
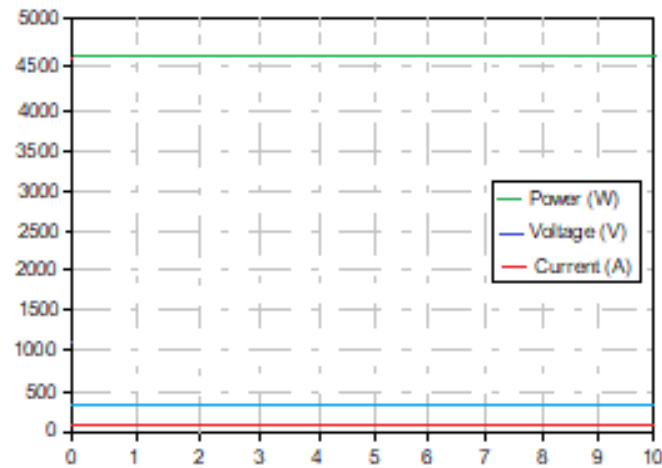
Fig. 9: P, V, I values of Solar PV

It is possible to obtain very different output power in this developed model by connecting the solar panels in series and parallel in an appropriate number and manner. In Figure 10., the output voltage and output current of the PV generator can be seen.
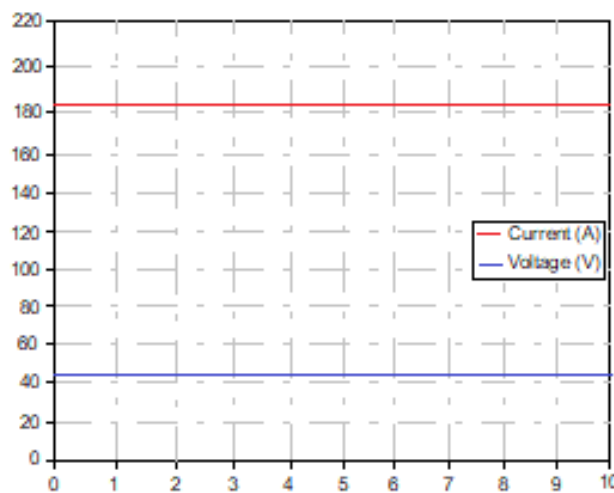

Fig. 10: V and I values of Solar PV

6 Conclusion

Methodology in this project study was to create a circuit model of a solar cell in the Matlab Simulink program, modeling this model as a subsystem, the input parameter being the sun and radiation temperature, the output parameter being current and voltage, the number of panel cells and modules and the determination of the number of strings. As a result of calculating the panel technical specifications and panel output current and voltage, tests were carried out under standard conditions. Different current-voltage values according to different solar radiation and temperature values of the panel were also obtained with graphics.

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