Analysis and Modeling of Photo-Voltaic (PV) Cell Power Generation System using Simulink

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Abstract—In recent years the renewable energy sources have become a much popular alternative to electrical energy sources in which the power generation through conventional techniques is inappropriate. Currently, the use of photovoltaic (PV) cells in the power generation systems has been growing significantly. In this paper, we have modeled a PV energy system which is an alternative to the conventional energy source of electric power unlike thermal power system. The brief description along with detailed modeling of PV system is presented. The simulation results have been presented analyzed in term of V-I and P-V characteristics. The effect of variation in irradiation and system temperature is also presented and discussed. The complete PV system is described through extensive simulation results that unearth the suitability of the presented system. A software simulation model is evolved in MATLAB/Simulink.

Keywords—Renewable energy; Photo-voltaic; MATLAB; Simulink;

I. INTRODUCTION

Due to the crucial condition of commercial fuels that embody oil, gas, and others, the development of renewable energy sources is endlessly rising now days. Due to this reason the renewable energy sources became very necessary. The main advantages of these renewable energy sources include plenty of availability in nature, eco-friendly and recyclable. There are many renewable energy sources such as wind energy, solar energy, hydro energy, and least but not last tidal energy. These are the world’s fastest growing renewable energy sources. The energy conversion from these renewable energy sources can be carried out with wind turbine and photo-voltaic (PV) cells. These energy conversion plants can be installed at low cost and has no emission of the pollutants. Currently the energy demand has steep rise in the industry and due to the limited availability of conventional energy sources, nonconventional energy sources have attracted the much attention of the researchers worldwide. Due to excessive requirement of energy and restricted accessibility of conventional power systems, the nonconventional energy sources are more favorable among the researchers. A lot of efforts had been made within the literature to decorate the electricity efficiency of non-traditional sources to make it extra reliable and beneficial.

PV power generation system uses many PV cells in series or parallel arrangement, in order to extract the energy from all of the cells on the identical time which complements the system potential and performance as well. In [2], [3], [4] authors discussed the specified working of PV. In [1], [2], [4] and [5] fundamental information of photo-voltaic cell, photo-voltaic array, photo-voltaic module, and modeling of the same were studied. Also, the behavior of photo-voltaic modules under environmental conditions like different temperature, solar radiation, and shading effect has been studied in [4]- [7]. Behavior of PV module all through partial shading conditions and minimization of these affects has been discussed in [6]- [8]. Different maximum power point tracking (MPPT) techniques and their advantages and disadvantages with their importance is described [9]- [14].
This paper presents the analysis and modelling of the PV cell power generation system. The brief study of the PV module is carried out. This work presents the modeling of the PV power generation system using Simulink. The effect of the number of cells and the temperature is analyzed and presented.

Following the introduction, the remainder of this paper is organized as under. Section II introduce the PV energy system model with it overview. Section III presents modeling of PV module. Section IV represents the modeling results followed by a discussion on the results. Section V described the concluding remarks.

II. PHOTOVOLTAIC ENERGY SYSTEM

A French Physicist E. Becquerel stated that, some materials have a tendency to generate the electricity if sunlight is exposed on them. Lately in 1905, Albert Einstein described the phenomenon of photoelectric effect and nature of light. As per the Photoelectric effect when photons or sunlight strikes to a metal surface, the electrons will flow through it. Thereafter the photoelectric effect has been adopted as the principle technology for photovoltaic power generation system. Figure 1, shows the photo electric effect and PV array. The first PV module became manufactured through Bell Laboratories in 1954.

2.1. PV power system

The PV power system is mostly operated by solar energy. The labeled block diagram of PV system is represented in Figure 2. It can be seen form the block diagram the PV power system consist a modules or arrays (depends on the size of PV power system) of PV cells. These arrays convert the solar energy in to electric energy in the form of solar irradiation. Maximum power point tracing (MPPT) obtained the maximum power from the PV system. The DC-DC converter regulates the voltage level of the PV system to match it with the voltage level of the appliances (load) connected to the system. These converters may be either buck or boost or buck-boost, which is depends on the requirement and available voltage level. DC bus connects the PV power system to the load (electric appliances). The battery and bi-directional converter are able to supply the power on both the directions. When there is less power generated from PV system the bi-directional converters allow the battery power to the DC bus. On the other side if the power generated from PV module is sufficient the converter stores the extra power in the batteries to use it further in case of power deficiency.

![Figure 1. Photo electric effect and PV cell, module, array](image-url)
The photovoltaic system converts daylight directly to power while not having any disastrous effect on our environment. The primary phase of PV array is PV cell, that’s only an easy p-n junction device. Figure 2 shows the equivalent circuit diagram of the solar cell [1]. The circuit is a power source a parallel diode, a resistance in the set, which describes an internal resistance to the current and a shunt resistor, which describes a leakage current. The current provided to the load can be represented as:

$$I = I_{PV} - I_0 \left[ \exp \left( \frac{V + IR_S}{aV_T} \right) - 1 \right] - \left( \frac{V + IR_S}{R_P} \right)$$

Where $I_{PV}$ is the photocurrent, $I_0$ is the diode’s reverse saturation current. $a$, is termed as identity factor, $V_T$ is thermal voltage, $V$ is the voltage across the diode. $R_S$, is the series resistance and $R_P$ is the shunt resistance. PV cell’s photocurrent relies upon on the radiation and temperature can be denoted as:

$$I_{PV} = (I_{PV,STC} + K_i \Delta T) \frac{G}{G_{STC}}$$

Where $I_{PV,STC}$ is the light generated current under standard condition, $K_i$ is called cell’s short circuit current temperature coefficient, $G$ is the solar irradiation represented in W/m$^2$, and $G_{STC}$ is the nominal solar irradiation represented in W/m$^2$. The reverse saturation current is proportional to a cubic function of temperature, which can be denoted as:

$$I_0 = I_{0,STC} \left( \frac{T_{STC}}{T} \right)^3 \exp \left[ \frac{qE_g}{aK \left( \frac{1}{T_{STC}} - \frac{1}{T} \right)} \right]$$

Where $T_{STC}$ is the temperature at standard test condition, $E_g$ energy band gap of semiconductor, $q$ charge of electrons, and $I_{0,STC}$ is the nominal saturation current. The reverse saturation current as a function of temperature can be represented by:

$$I_0 = \frac{(I_{SC,STC} + K_i \Delta T)}{\left( \frac{V_{OC,STC} + K_i \Delta T}{aV_T} \right)} - 1$$
Where $I_{SC,STC}$ is the short circuit current at standard test condition, $V_{OC,STC}$ is the short circuit voltage at standard test condition, and $K_V$ is the temperature coefficient of open circuit voltage.

As the full power generated with the aid of a single PV mobile is very low, the combination of the PV cells was used to satisfied our requirements. Hence this grid of the PV cells is better known as photo voltaic array. The equations of the PV array can be given as:

$$I = I_{PVT} - I_0 \frac{\exp \left( \frac{V + IR_S (\frac{N_S}{N_P})}{\alpha V_T N_S} \right) - 1}{R_P (\frac{N_S}{N_P})} - \frac{V + IR_S (\frac{N_S}{N_P})}{R_P (\frac{N_S}{N_P})}$$  \hspace{1cm} 5.

Where $N_S$ denotes the number of series cells and $N_P$ denotes the number of parallel cells. A small variation in series resistance can have large effect on the efficiency of a PV cells on the other side the variation in shunt resistance does not have much effect. For a very small leakage current, the shunt resistance is assumed to be infinity and can be treated as open circuit. After the above consideration, the mathematical expression of the model can be represented as:

$$I = I_{PVT} - I_0 \frac{\exp \left( \frac{V + IR_S (\frac{N_S}{N_P})}{\alpha V_T N_S} \right) - 1}{R_P (\frac{N_S}{N_P})}$$  \hspace{1cm} 6.

The maximum power of the PV system can be given by:

$$P_{max} = V_{max} I_{max}$$  \hspace{1cm} 7.

IV. NUMERICAL RESULTS AND DISCUSSION

The modelling of PV system was evaluated through Simulink. The simulations have been completed by the use of Simulink/MATLAB software. The system hardware includes of an Intel i3-2100 CPU having a 3.1 GHz clock and 4 cores, 4 GB of RAM running in Window 8.1, 64-bit, operating system. The parameters and their values were used in the modeling of PV system through Simulink is presented in Table 1.

Table 1. Modeling of parameters at 25°C and $G = 1000 \text{ w/m}^2$

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power, $P_{max}$</td>
<td>200.143 W</td>
</tr>
<tr>
<td>Voltage at maximum power, $V_{mp}$</td>
<td>26.3 V</td>
</tr>
<tr>
<td>Current at maximum power, $I_{mp}$</td>
<td>7.61 A</td>
</tr>
<tr>
<td>Short circuit current, $I_{SC}$</td>
<td>8.21 A</td>
</tr>
<tr>
<td>Open - circuit voltage, $V_{DC}$</td>
<td>32.9 V</td>
</tr>
<tr>
<td>Temprature coefficient of open circuit voltage, $K_V$</td>
<td>-0.1230 V/K</td>
</tr>
<tr>
<td>Cell’s short circuit current temperature coefficient, $K_I$</td>
<td>0.0032 A/K</td>
</tr>
<tr>
<td>Number of parallel cells, $N_P$</td>
<td>4</td>
</tr>
<tr>
<td>Number of series cells, $N_S$</td>
<td>54</td>
</tr>
</tbody>
</table>

Figure 3, represents the P-V curve of the PV module under consideration. From the Figure it can deduce that power in PV system is increased at certain point with the voltage. After a certain value of V, the power of the PV system started to fall. This point at which the power is maximum, termed as
maximum power point tracing (MPPT) point. Figure 3 shows that at MPPT the maximum power is around 200 W, which occurs at 26.3 V of voltage and 7.61 A of current.

![Figure 2. Power-voltage (P-V) curve of PV system](image1)

Figure 2. Power-voltage (P-V) curve of PV system

Figure 4, shows the V-I characteristics of PV system. From the figure we can again verify that for given parameters the short circuit current of PV module is around 8.2A, and open circuit voltage is 32.9V. It can be also found that at MPPT the current and voltage is around 7.61A and 26.3V respectively.

![Figure 4. Voltage-current (V-I) curve of PV system](image2)

Figure 4. Voltage-current (V-I) curve of PV system

Figure 5, represents the effect of variation in irradiation in PV system. It can be observed from the figure the short circuit current is larger with greater the value of irradiation. Hence for the highest value of irradiation (1000 w/m^2) the short circuit current is 8.2 A and for smallest value of irradiation (700 w/m^2) the short circuit current is 8.2 A.
w/m²) short circuit current is around 5.8 A. While on the other side, open circuit voltage has a less effect of irradiation.

Figure 6, demonstrated the effect of irradiation on P-V characteristics of the PV module. From the figure is can be find that the system power increase with increasing irradiation. Hence larger the irradiation larger the system power and smaller the irradiation results in small power generated in PV module. The interesting fact can be noticed here the irradiation has less effect on open circuit voltage in both the V-I and P-V curves.
The authors already observed and demonstrated the effect of irradiation in PV module. Figure 7, represent the effect of temperature in PV module with the help of V-I characteristics. From the Figure 7, it can be observed that for all the values of temperature (°) short circuit current remains almost constant. After MPPT there is a steep fall in system current. Larger variation in the temperature results in steep fall in the system current which cause a slight shift in MPPT. This deduction in the system current and shift of MPPT reduced the open circuit voltage of the PV module. Similarly, Figure 8, shows the effect of temperature on P-V curve of PV module. The same effect of temperature can be analyzed in this figure. When the PV system is short circuited the temperature has no effect on system power at certain point (MPPT). After this, power with highest temperature decreases fast. This produced the difference in open circuit current of the PV system.
V. CONCLUSION

A basic framework of PV system has been efficiently modeled on MATLAB/Simulink and presented in this paper. The PV system model utilized the Simulink to analyze the various effects of the environmental conditions on the modeled PV system. The various environmental conditions like irradiation and temperature has been analyzed and presented. The complete PV system performance is observed using V-I and P-V curves of the modeled PV system. It is concluded from the modeling of the PV system that irradiation has large effect on short circuit current of the PV system which results in same effect on system power. Higher the irradiation resulted in large system power. Besides this the system temperature has large effect on open circuit voltage, hence negligible effect on short circuit current and system power. The larger the system temperature results in lower open circuit voltage which results steep fall in the system power.

On the basis of this result, our future research work would include PV system based implementation of renewable energy systems. The PV system can be embedded with wind energy system to model the hybrid stand-alone power generation system.

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