Sustainability in Energy and Buildings: Research Advances ISSN 2054-3743
Vol. 6. No. 1 : pp.1-13 : seb17s-003

The Effect of Ambient Temperature on the Power Output of 5kW Photovoltaic Solar Power System

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Abstract: *This paper presents the influence of ambient temperature on 5kW PV-Model depending on recorded data of Dhahran in Saudi Arabia for five months in 2016 and determines the best ambient temperature for the given period according to the power output of the model for each month. Photovoltaic cells are directly affected by temperature, i.e., the power output of the PV cells is dependent on temperature. Its performance is decreased with increase in temperature. This is due to the increase of the electrical circuit resistance with the temperature increase and hence the power output decreases. The study is done using MATLAB/SIMULINK based on KC200GT modified in order to give 5kW output power instead of 200W. Real Data collected from different seasons at Dhahran and applied on the model. The model efficiency is specified according to its performance during the different seasons. Performance of the model showing low efficiency during winter and summer due to the weak radiation and high temperature respectively. Spring season showing the best performance. According to the performance and the power output of the model during different seasons, the best operating temperature is obtained for each month. This will help in cooling process in order to maintain the solar power system working properly during different seasons of the year.*

Index Terms*:** *Renewable Energy, Photovoltaic Cells (PV), Single diode PV cell, PV modules, PV arrays, ambient temperature, Irradiation.**

1. Introduction

Renewable energy sources have been used for many centuries before our time and due to the low price of petroleum, they were abandoned. In recent years, awareness about climate changes and concerns to reduce the fossil energy consumption and carbon dioxide emission has been raised. [1], [2]. Therefore, reverting back to renewable energy sources was one of the most important solutions [3]. Solar energy is considered as one of the most important renewable resources. Each day the earth is provided with 1.4×10^5 TW of energy from sun, 3.6×10^4 TW can be used and the worldwide demand is 1.7 TW, which means that the solar energy could cover the whole planet demand of power [4].

Electricity could be generated from sunlight in several ways; the solar energy could be converted into electricity by using solar thermal power solutions such as steam engines that use solar heat. It can also be converted into electricity by photovoltaic cells [5]. PV cells technology was born of the space age in 1950s for satellites and spacecraft needs. It was emerged in other terrestrial application in 1970s [6]. PV cells are fundamentally semiconductors diodes that its p-n junction should face the sunlight, polycrystalline, silicon, monocrystalline are the most used in manufacturing PV cells. When sunlight hits the surface of PV cells, it charge the carriers that generate electrical current [7].

The ambient temperature plays a key role on the power output of the PV system. The efficiency of the PV cells is mounted around (9-12) % and the PV cells used only 20% of the sun irradiation while the other energy is converted to heat, which affects the power output. The output power decreases by (0.4-0.5) % for each one-Kelvin increase in temperature of PV [8]. For this reason, the ambient temperature affects the power output of the PV system.

In [9], Three PV models where tested in two tropical countries (Singapore and Indonesia) to see the effect of high temperature on the PV performance and notice if the wind speed play a roll in cooling process. Differences among three models were low due to low wind speed. The three models results were equally like with RMSE of 1.5 – 3.8 °C and the power output difference with 0.3 - 1.6 %, respectively. The ambient temperature has a direct impact on the module temperature, hence there is a relation between them but they must be distinguished. [10] is differentiating between the ambient temperature and module temperature and it shows that the module temperature has higher effect on PV modules with 10-20% than ambient temperature.

In [11], two PV modules were tested to see the effect of ambient temperature. One was placed indoor with an ambient temperature of 25 °C and the irradiation is reduced cause to indoor environment and it gives only 27% of its maximum efficiency. The other one was placed outdoor with high temperature and high irradiation, the power output was 78% of its maximum efficiency, the work shows that the ambient temperature effects the power output but it is not the only factor, irradiation also play a key role in performance. In [12], 50W mono-crystalline solar panel model was simulated using MATLAB/SIMULINK to track the effect of ambient temperature on voltage output with different temperatures value ranging between 25-60 °C and the radiation was fixed to 458.2 w/ and they found that the ambient temperature has a great effect on the voltage output which affects the power output consequently. [13] and [14] shows that the power output is decreasing with increasing temperatures, [13] conducted during sunny days of February 2016 at KIIT in India and [14] was taken place during different season of 2013 in Nigeria.

In our work, we use 5kW PV-Model based on MATLAB/SIMULINK. We first chose the suitable way for connecting the PV modules in order to increase power output from 200w to 5kW based on (KC200GT) module. We chose connecting method that is less effected by temperature variation then we applied irradiation and temperature of different months in Dhahran, Saudi Arabia. According to the power output, we obtained the best operating temperature for each month.

The remainder of this paper is organized as follows: second section defined the problem statement. The proposed methodology is described in the third section . Results and discussions of the study are exhibit in section four. Section five represented the conclusion of the work.

2. Problem Statement

Solar PV modules are manufactured at Standard Test Condition (STC) that usually assumes the ambient temperature and irradiation around 25°C and 1000W/m² respectively. However, when they are used in reality, their performance varies depending on the actual location and prevailing environmental conditions. They are affected passively with increase in temperature. Cooling process cannot achieve the nominal temperature of the PV module according to STC especially in hot regions. It is very important to determine the best operating temperature in order to maintain proper operation for PV modules. The problem can be briefly defined as to explore the best operating temperature for solar PV system based on ambient temperature variations during different seasons of the year in order to improve the performance of the solar PV model.

3. Proposed Methodology

As mentioned previously, PV cells are the fundamental unit of the PV system. These cells could be aggregated in a series manner to form a module, and modules could be connected in series, parallel or even both to form what is known as arrays. The ideal photovoltaic cell is represented mathematically by the following equation:

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V + R_S I}{V_t a}\right) - 1\right] - \frac{V + R_S I}{R_p} \qquad (1)$$

where I_{pv} and I_0 represent the photovoltaic and saturation currents of the array respectively. Vt is the thermal voltage of the array and it is equal to $(NskT/q)$ where Ns is cells connected in series. Cells connected in series provide greater output voltages while the cells connected in parallel increase the current. R_s is the equivalent series resistance of the array and Rp is the equivalent parallel resistance.

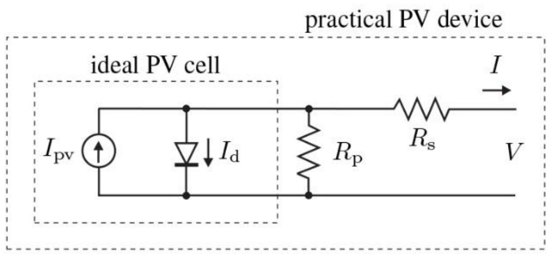

Figure 1: Equivalent circuit of a single diode PV cell.

Equation (1) is used for modeling single panel or module that its output power is low. To increase the output power to a certain value we should model the system as large arrays composed of number of modules that are connected together in special way even in series, parallel or both. The most important change that must be took in account is the value of Rs and Rp.

The light generated current of the PV cell depends linearly on the solar irradiation and effected by the temperature as shown in the following equation:

$$I = \left(I_{pv,n} + K_I \Delta_T\right) \frac{G}{G_n} \qquad (2)$$

where $I_{pv,n}$ [A] is the light-generated current at the nominal condition (usually 25° C and 1000W/m2). Δ_T = T – $\mathrm{T_n}$ (being T and $\mathrm{T_n}$ the actual and nominal temperatures [K]). G [W/m2] is the irradiation on the device surface, and $\mathrm{G_n}$ is the nominal irradiation. I_0 is the diode saturation current and it is directly depending on the temperature and it is calculated as follows:

$$I_0 = I_{0,n} \left(\frac{T_n}{T}\right)^3 exp\left[\frac{qE_g}{ak}\right]\left(\frac{1}{T_n} - \frac{1}{T}\right) \qquad (3)$$

where $E_g$is the semiconductor band gap energy and equal to $E_g \approx 1.12$ eV for the polycrystalline Silicon at temperature of 25° C. $\mathrm{I_{0,n}}$ is the nominal saturation current and it's given by:

$$I_{0,n} = \frac{I_{sc,n}}{\exp\left(\frac{V_{oc,n}}{aV_{t,n}}\right) - 1} \qquad (4)$$

where $V_{t,n}$ being the thermal voltage of series connected cells at the nominal temperature Tn, V = $V_{0c,n}$, I=0, and $I_{pv} \approx I_{sc,n}$

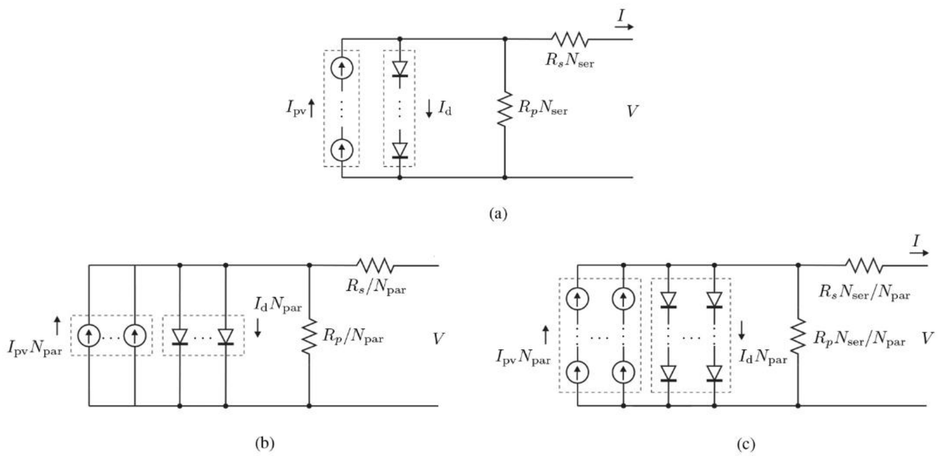

Figure 2: (a) equivalent circuit of an array consists of number of modules connected in series. (b) Equivalent circuit of an array consists of number of modules connected in Parallel. (c) Equivalent circuit of an array consists of number of modules connected in parallel and series.

In the first way of connection as in Fig. 2 (a), there will be no change in current while the voltage will increase. The second way of connection figure (b) the current will increase while the voltage will remain unchanged. The third way of connection as in figure (c) both current and voltage will increase, for this approach, equation (1) became:

$$I = I_{pv}N_{par} - I_0 N_{par}\left[\exp\left(\frac{V + R_S\left(\frac{N_{Ser}}{N_{par}}\right)I}{V_t a N_{Ser}}\right) - 1\right] - \frac{V + R_S\left(\frac{N_{Ser}}{N_{par}}\right)I}{R_p\left(\frac{N_{Ser}}{N_{par}}\right)} \quad (5)$$

Notice that N_{Ser} and N_{par} are the number of series and parallel modules in the array. N_S is the number of series cells in individual module [15]. The model of PV system of this work is done using MATLAB/SIMULINK and depending on the parameters of the KC200GT array that gives 200W power output at ideal condition (ambient temperature at 25°C and irradiation at 1000 W/m^2). To increase the output power up to 5kW we increased the number of modules and built three modules, each one has a different way of connection as explained previously and then we applied different temperature values with a fixed irradiation to determine which one is less effected by temperature variation.

Table 1: Comparison of three PV module configuration

Radiation [1000 w/ m^2]			
Temperature Celsius	Series kW	Parallel kW	Parallel & Series kW
10°	5.671	5.281	5.727
15°	5.688	5.297	5.744
20°	5.701	5.307	5.757
25°	5.708	5.316	5.764
30°	5.703	5.313	5.759
35°	5.682	5.294	5.738
40°	5.634	5.252	5.689
45°	5.547	5.174	5.600
50°	5.402	5.045	5.453
55°	5.180	4.845	5.228
60°	4.858	4.554	4.902

From Table I, the most effective way for connecting the modules is the third way since it is showing the smallest variation in the power output among the three types. Irradiation and temperature data of Dhahran in Saudi Arabia for five months of different season (January, February, April, July and October 2016) was applied on the model to see the influence of ambient temperature on the model. Then we find the best operating ambient temperature for each month.

4. Results and discussions

From Fig. 3 it is noticeable that the power output is low although that the temperature in January is considered to be perfect for the model, but the problem is due to clouds and rains during January at Dhahran, which means weak irradiation during the day. Seven days of this month was excluded due to errors in sensor readings. The best operating temperature is obtained depending on the highest output power days.

In Fig. 4 the days of February was split into two groups for clarification. Except the first two days of the month, the output power was low in the first half. This is due to low radiation, although the temperature is considered reasonable if the radiation was high. The output power was enhanced in the second half due to better irradiation. However, temperature increase will play a major role in the power output amount during next months.

Fig. 5 shows simulation results for twelve days of April the reset was excluded because of clouds and rains. The exhibited days showing perfect irradiation with slight increase in temperature, hence the power output is considered as the best.

Fig. 6 shows the output power of July. The days of the month is divided in two groups depending on the time sampling. In first eleven days, the sensors were taking readings with time sampling slower than the rest days of the month. Regarding to the irradiation, July is very stable; almost shining all the days and the irradiation is very good. The major problem that makes the output power low is high temperature and if we compare fig.6 with fig.4 and fig.5 we will see how does increase in temperature affects the power output of the PV system. Determining the best operating temperature is very important here in order to make the system working properly.

Fig. 7 shows very stable output power during October 2016, however, the output power is around 4kW, this is because the temperature during October is still high in Dhahran. The most notable point is stable irradiation during the whole days of the month.

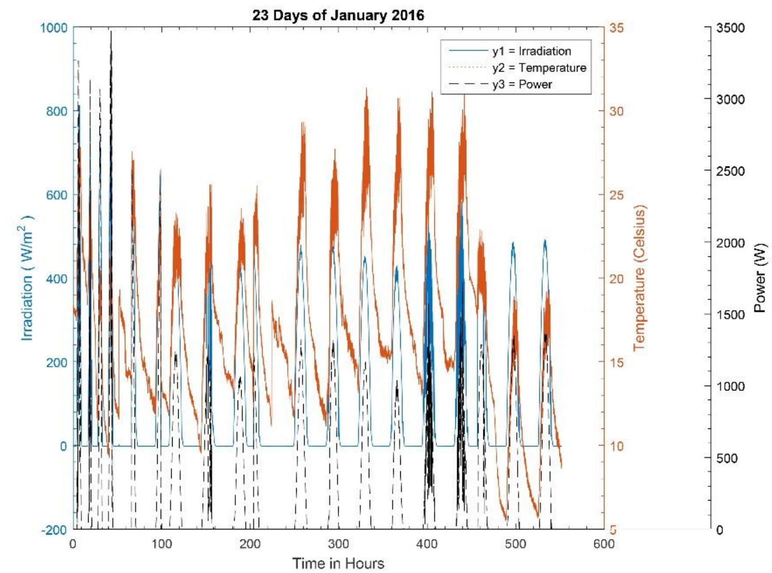

Figure 3: Irradiation, ambient temperature and power output of January 2016

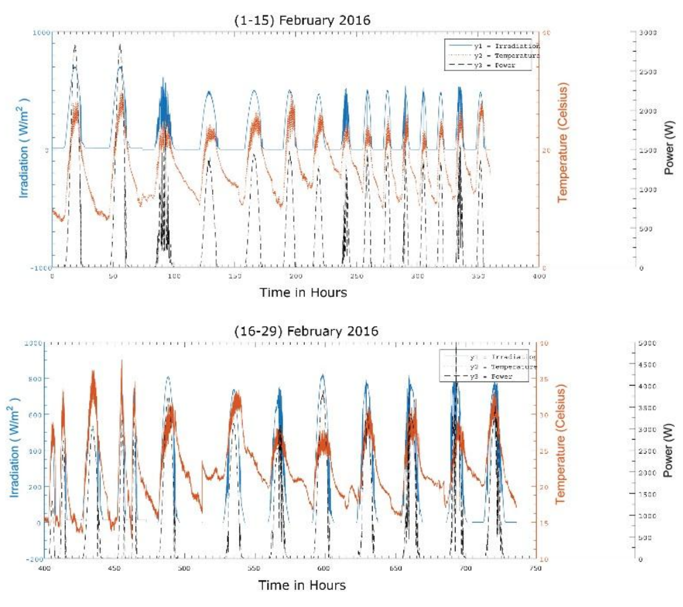

Figure 4: Irradiation, ambient temperature and power output of February 2016

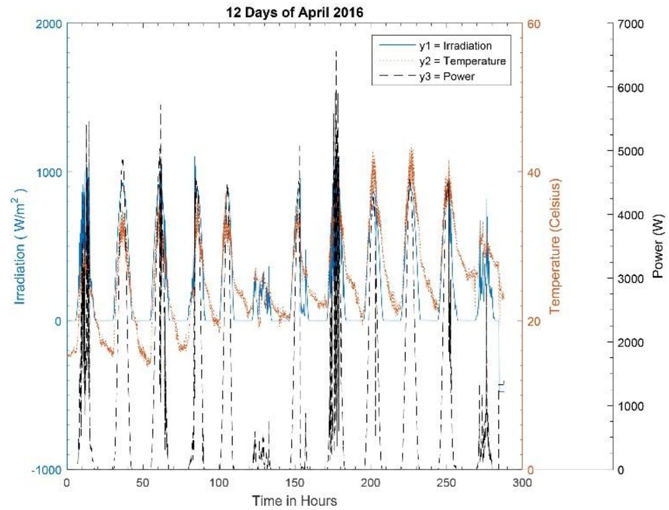

Figure 5 : Irradiation, ambient temperature and power output of April 2016

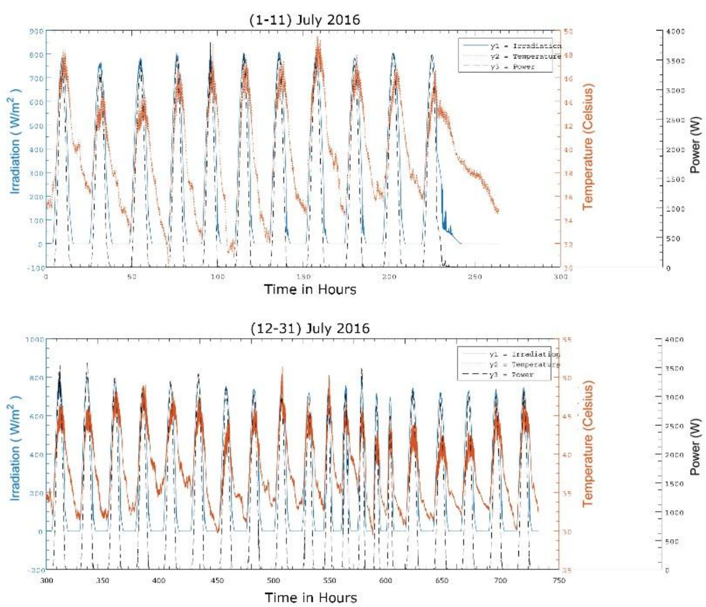

Figure 6: Irradiation, ambient temperature and power output of July 2016

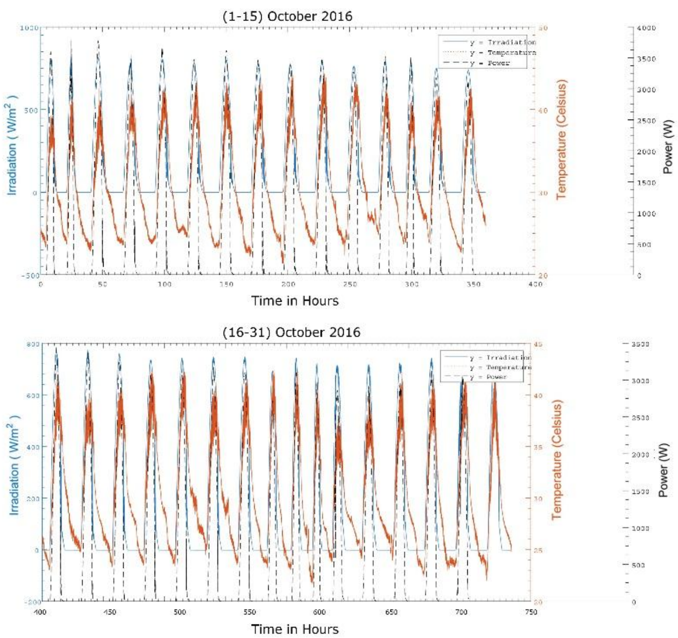

Figure 7: Irradiation, ambient temperature and power output of October 2016

From results of simulation, we can obtain the best operating temperature for each month depending on the highest power output from different days of each month and it could be very useful for cooling process on the PV arrays during different seasons of the year.

Table 2: Best operating temperature for five months in Dhahran 2016

Month	Best Operating Temperature
January	22.5°
February	28.74°
April	33.76°
July	44.8°
October	37.85°

5. Conclusion

This paper has shown the effects of ambient temperature on solar power system. The work is done using 5kW PV model by MATLAB/SIMULINK. The model used in this work based on KC200GT that gives 200kW and we increased it to 5kW by connecting the modules in parallel and series configuration. This configuration has shown the highest effectiveness during high temperature values. Irradiation and temperature for five months from different seasons of year 2016 in Dhahran KSA is applied to the model.

Winter season months showing the smallest efficiency that ranges between (52.6-61.4)%. Summer season months have second lower efficiency; that is around 70%. The most effectiveness performance of the model is obtained in spring season and reaches its optimum value. We conclude that high temperature as in summer affects the performance of PV modules as well as the weak irradiation does in winter season. Depending on the best power output days during the whole months, we obtained the best operating temperature of PV model. This will be very useful for cooling process to maintain the solar power system working properly during different seasons of the year.

6. Acknowledgement

The Authors would like to acknowledge the support and help that have been provided by King Fahd University of Petroleum and Minerals.

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