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Effect of High Temperature on the Efficiency of Grid-Connected PV System

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***Abstract*—This paper describes a method of modeling and simulation photovoltaic (PV) module that implemented in MATLAB. Each solar cell technology comes with unique temperature coefficients. These temperature coefficients are important and the temperature of the solar cell has a direct influence on the output power of a solar PV module and inverter. Once the temperature of a solar module increases, the output power of the solar module and inverter will decrease. Crystalline solar cells are the main cell technology and usually come with a temperature coefficient of the maximum output power of about -0.5% / degree Celsius. The rated power as generally indicated on the module's label is measured at 25 degrees Celsius, and with any temperature increase above 25°C you have to take into account power losses of 1% for every 2°C increase. Most installed solar modules in sunny countries especially reach higher temperatures than 25°C. In fact, temperatures of 40°C and above are easily reached. Solar cell performance decreases with increasing temperature, fundamentally owing to increased internal carrier recombination rates, caused by increased carrier concentrations. The operating temperature plays a key role in the photovoltaic conversion process which includes the inverter side in grid connected applications.**

***Index Terms*— Photovoltaic, MATLAB, Modeling, temperature coefficient, efficiency, PV module, PV characteristic**

I. INTRODUCTION

The development of solar cell technology begins with the 1839 research of French physicist. The first genuine solar cell was built around 1883 by Charles Fritts, who used junctions formed by coating selenium (a semiconductor) with an extremely thin layer of gold. So the photovoltaic is a high-technology approach to converting sunlight directly into electrical energy.

The electricity is direct current and can be used that way, converted to alternating current or stored for later use. Conceptually, in its simplest form, a photovoltaic device is a solar-powered battery that's only consumable is the light that fuels it. There are no moving parts, operation is environmentally benign, and if the device is correctly encapsulated against the environment, there is nothing to wear out, because sunlight is universally available, photovoltaic devices have many additional benefits that make them usable and acceptable to all inhabitants of our planet. Photovoltaic systems are modular, and so their electrical power output can be engineered for virtually any application, from low-powered consumer uses-wristwatches, calculators and small battery chargers-to energy-significant requirements such as generating power at electric utility central station. Moreover, incremental power additions are easily accommodated in photovoltaic systems, unlike more conventional approaches such as fossil or nuclear fuel, which require multi-megawatt plants to be economically feasible. [1] The open-circuit voltage, V_{OC}, is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current. The open-circuit voltage is shown on the IV curve Figure 4.

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II. ADVANTAGES OF PHOTOVOLTAIC CELL

A. Review of Solar cells

Solar cells are long-lasting sources of energy which can be used almost anywhere. They are particularly useful where there is no national grid and also where there are no people such as remote site water pumping or in space.

Solar cells provide cost-effective solutions to energy problems in places where there is no mains electricity. Solar cells are also totally silent and non-polluting. As they have no moving parts they require little maintenance and have a long lifetime. Compared to other renewable sources, they also possess many advantages; wind and water power rely on turbines which are noisy, expensive and liable to break down [2]. Most installed solar modules in sunny countries easily reach higher temperatures than 25°C. In fact, temperatures of 40°C and above are easily reached. Solar cell performance decreases with increasing temperature, fundamentally owing to increased internal carrier recombination rates, caused by increased carrier concentrations. The operating temperature plays a key role in the photovoltaic conversion process. The climate of Kingdom of Saudi Arabia is generally hot and dry, characterized by extremely hot and dry summers with very large diurnal temperature ranges and moderately cold winters this case has been studied in this paper.

III. DISADVANTAGES OF PHOTOVOLTAIC CELL

The main disadvantage of solar energy is the initial cost. Most types of solar cell require large areas of land to achieve average efficiency. Air pollution and weather can also have a large effect on the efficiency of the cells. The silicon used is too costly and the problem of nocturnal down times means solar cells can only ever generate during the daytime. Solar energy is currently thought to cost about twice as much as traditional sources (coal, oil etc.). Obviously, as fossil fuel reserves become depleted, their cost will rise until a point is reached where solar cells become an economically viable source of energy. When this occurs, massive investment will be able to further increase their efficiency and lower their cost [2].

IV. SOLAR RADIATION

Solar radiation is the electromagnetic radiation emitted by the Sun. Solar radiation interacts with the Earth's atmosphere to create three types of irradiance at ground-level:

- **Direct Radiation**: solar radiation available directly from the sun.
- **Diffuse Radiation**: scattered solar radiation available from the entire sky, but not including the direct radiation.
- **Global Radiation**: it is the total radiation consisting of direct radiation and diffuse radiation.

Solar radiation can be represented as a total for the year (kWh/m2) or commonly on an average daily basis for a given month annually (kWh/m2-day). Regional-scale satellite-based maps and initial ground-based solar resource monitoring data indicate that Saudi Arabia possesses a huge potential for solar energy. Table (1) shows the radiation incident on a horizontal surface (W/m^2-day) in Riyadh [3].

TABLE I
The average daily radiation in Riyadh

Months	The average daily radiation (Wh/m^2)
Jan	4200
Feb	5800
Mar	6200
Apr	6428
May	7280
Jun	8000
Jul	7570
Aug	7200
Sep	6500
Oct	6000
Nov	4500
Dec	4100

A. *Why Solar Energy Now in Saudi Arabia*

Solar energy has become a clean source of electricity. The cost of installing these systems is already within reach of the middle class. In marginal areas, the cost of producing electricity from renewable sources is lower than conventional electricity because of the savings in the construction of infrastructure and laying of cables. Now the power of any house, irrigation system or network of streets can be provided through the sun and completely dispensed with government electricity. The climate of KSA

The climate of KSA is generally hot and dry, characterized by extremely hot and dry summers with very large diurnal temperature ranges and moderately cold winters [3].

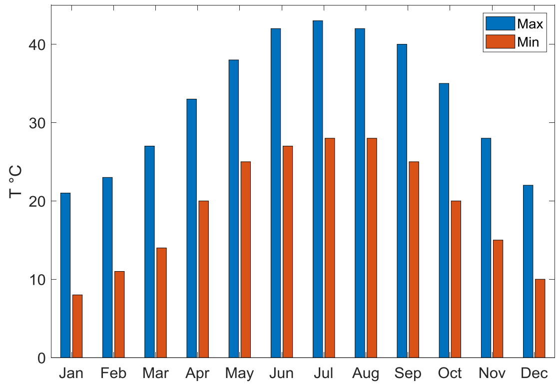

Fig. 1 Mean monthly temperatures of the KSA

Figure.1 shows the mean monthly temperature for the KSA. The consumption of electricity depends mainly on the temperature in KSA.

V. CHARACTERIZATION OF PV SYSTEM

A. *PV Cell Module*

In this Section the behavior of the calculated equivalents circuits is analyzed. The aim is to check if the calculated circuit models reproduce the experimental data of the solar panels included in the manufacturer's datasheet. Obviously, the mentioned circuits are characterized by the parameters already calculated. As shown in Figures 6 and 7. Several simulations have been performed at different irradiation levels, calculating the I-V curve in each case. The results there are included in Figures 6–8. PV cells can be modeled as a current source in parallel with a diode as shown in figure 2 is the simple model of solar cell. When there is no light the PV cell behaves like a diode. As the intensity of incident light increases, current generated by the PV cell increases [4-7]:

The total current I is equal to the difference between the current I_{ph} generated by PV effect and the diode current according to the equation:

$$I = I_S\left(\exp\left(\frac{qV}{KT}\right) - 1\right) - I_L \qquad (1)$$

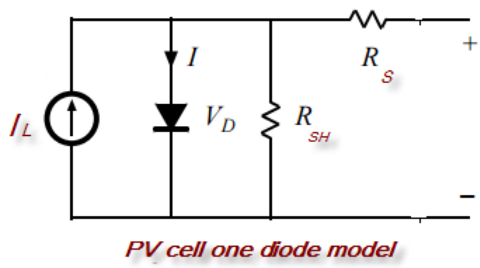

Fig .2 models of the most commonly used PV cell

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The open-circuit voltage decreases with temperature because of the temperature dependence of I_0. The equation for I_0 from one side of a *p-n* junction is given by;

$$I_0 = qA\frac{Dn_i^2}{LN_D} \tag{2}$$

B. *Short circuit current in solar cell*

The Short circuit current in solar cell is given by equation 3 As:

$$I_{SC} = \langle I_S\left[\exp\left(\frac{qV}{KT}\right) - 1\right] - I_L\rangle \qquad \text{at V=0} \tag{3}$$

And the open circuit voltage is given by equation 3

$$V_{OC} = \frac{kT}{q} ln\left(\frac{I_L}{I_S} + 1\right) \tag{4}$$

From equations 2 and 3 the open circuit voltage and Short circuit current in solar cells are highly dependent on the temperature.

$$I = \langle I_L - I_S\left[\exp\left(\frac{qV+IR_S}{nkT}\right) - \frac{V+IR_S}{R_{SH}}\right]\rangle \tag{5}$$

In the above equation, many of the parameters have some temperature dependence, but the most significant effect is due to the intrinsic carrier concentration, $\boldsymbol{n_i}$. The intrinsic carrier concentration depends on the band gap energy (with lower band gaps giving a higher intrinsic carrier concentration), and on the energy which the carriers have (with higher temperatures giving higher intrinsic carrier concentrations). The equation for the intrinsic carrier concentration is [4];

$$n_i^2 = 4\left(\frac{2\pi kT}{h^2}\right)^3 (m_e^* m_h^*)^{3/2} \exp\left(-\frac{E_{G0}}{kT}\right) = BT^3 \exp\left(-\frac{E_{G0}}{kT}\right) \tag{6}$$

From equation for the intrinsic carrier concentration the carrier is highly depended of temperatures.

While equation 4 is the effect of series $\boldsymbol{R_s}$ and parallel shunt $\boldsymbol{R_{SH}}$ resistance to the total current of the cell, all these values attached in the panel data sheet [5].

C. *PV inverter*

To connect PV modules to the grid, two stages are needed to achieve efficient power conversion and accurate synchronism with a utility. Fig. 3 shows the block diagram of a PV system with two stages. The first stage includes a DC-DC converter to regulate the voltage across the DC-link and apply maximum power point tracking (MPPT), while the second stage includes a DC-AC inverter interface of a PV module to the grid through an LC filter. Both stages require a controller and pulse width modulation (PWM). several PV grid-tied inverter topologies have been proposed to mitigate connection issues and to improve power conversion efficiency [6]. Nonetheless, two-level voltage source inverters (VSIs) are still widely used in connecting PV systems to medium- and low-voltage distribution networks. This is due to the simplicity of the inverter structure, where fewer components are needed for this topology, leading to higher reliability [6]. In addition, the ease of controllability is the main reason for implementing two-level VSIs

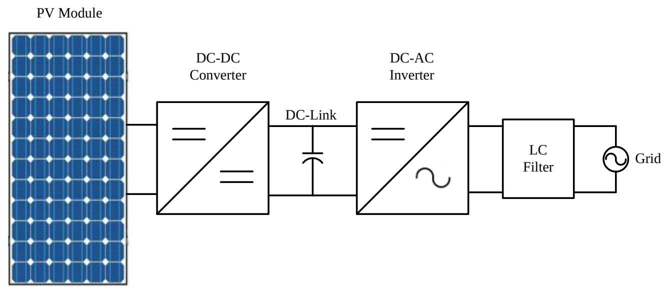

Fig. 3 Block diagram of a PV system with two stages

VI. Mathematical Model of PV System

All semiconductor devices are sensitive to temperature. Increases in temperature reduce the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature increasing the energy of the electrons in the material. Lower energy needed to break the bond. In the bond model of a semiconductor band gap, reduction in the bond energy also reduces the band gap. Therefore, increasing the temperature reduces the band gap. In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage. The impact of increasing temperature shown in figure.4.

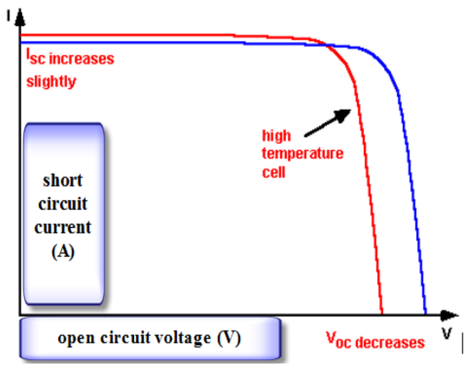

Fig .4 effect of temperature on *I-V* characteristics of a solar cell

There are several models that can be used to model PV cell. The most common one uses current source parallel with one diode. A single-diode model [7-9] has four components: photo-current source, diode parallel to source, series of resistor $\boldsymbol{R_s}$, and shunt resistor $\boldsymbol{R_{sh}}$. There are another model using two-diode model: [10-11] can be used for accurate calculation.

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The power produced by the cell in Watts can be easily calculated along the I-V sweep by the equation P=IV [12]. At the I_{SC} and V_{OC} points, the power will be zero and the maximum value for power will occur between the two. The voltage and current at this maximum power point are denoted as V_{MPP} and I_{MPP} respectively experimental measurements . The detailed model of PV cell circuit is mentioned in [14].

The ambient temperature impacts the output power of PV inverter, and it contributes to the thermal losses in the power electronics switches. Therefore, high ambient temperatures can degrade the efficiency of the PV inverter. For this reason, the thermal model, as shown in Fig.5, of power electronics devices can be used to estimate the total losses in PV inverter [6]. Each layer in the IGBT switch module (for PV Inverter) can be represented by its equivalent thermal impedance. The temperature at each node between the layers can be found by solving for the equivalent circuit of the thermal model. The ambient temperature is modeled as a voltage source. The thermal path from the ambient air to the device chip. Therefore, we can estimate the power losses in each switch easily. The thermal model of PV inverter is modeled in Matlab/Simulink and shown in Fig. 5.

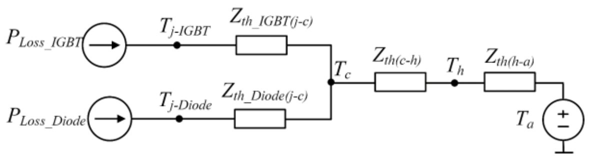

Fig .5 effect of temperature on *I-V* characteristics of a solar cell

VII. Results

In this Section the behavior of the calculated equivalents circuits is analyzed. The aim is to check if the calculated circuit models reproduce the experimental data of the solar panels included in the manufacturer's datasheet. In order to produce results, the equivalent circuits of the solar panels have been modeled using Simulink Matlab. Obviously, the mentioned circuits are characterized by the parameters already calculated in experimental results. Several simulations have been performed at different temperature and irradiation levels, calculating the output voltage curve in each case. The results thereof are included in Figures 6-8. As shown in figure .6 Measured I_V curve of the of photovoltaic panel for maximum power P_{MPP} it's the actual power can be delivered from the panel and the effect of temperature.

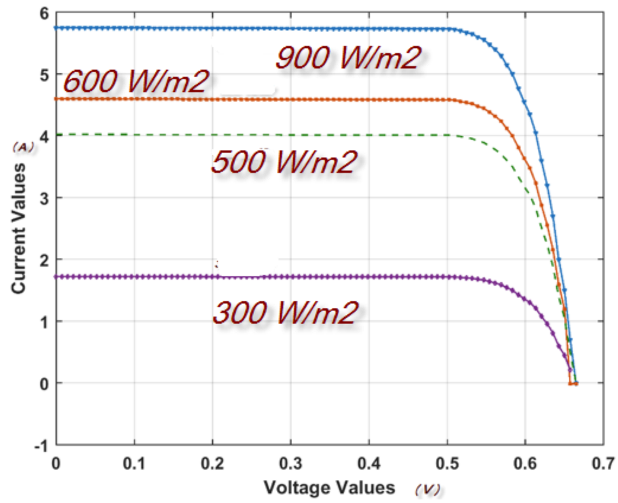

Fig. 6 Simulated I-V curve of different illumination of Solar cell at 25° C

As shown introduction high temperature reduce the open circuit voltage and output current should be the same. And in figure .7 simulated output voltage of solar module during the day and the effect of high temperature appears for the output voltage. The seeped voltage measured using the automatic load in sunlight on a day. In figure. 8 the simulation of the cell in Matlab and the I-V characteristic curve of the cell calculated at different illumination of Solar cells at 25° C.

For the PV inverter, simulations were carried out using MATLAB/Simulink and PLECS® to investigate the thermal performance of the inverter switches. A three-phase inverter module from a leading manufacturer was selected for this purpose. The PV inverter was connected to a secondary distribution feeder of 240 V. The electrical and thermal parameters of the PV inverter are given in [6]. The thermal model was used to calculate the losses and the junction temperature in the inverter for a wide range of loading conditions and ambient temperatures (Ta). For solar radiation of 1000 W/m2, the efficiency of the inverter at 25° C and 50° C is found to be 98% and 96.5%, respectively. Therefore, the ambient temperature can impact the performance of PV inverter and reduce its efficiency.

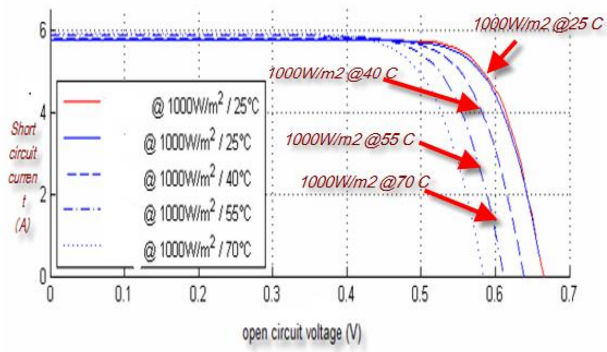

Fig .7 Simulated PV-cell open circuit voltage and short circuit current at different temperature

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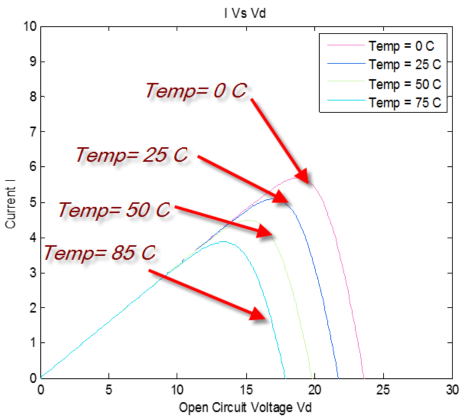

Fig. 8. Simulated effect of temperature to output voltage P-V curves for various temperatures

VIII. Conclusion

Photovoltaic solar energy is clean (does not make environmental pollution), safe and is almost free maintenances. The maximum conversion efficiency of solar cells observed in laboratory has exceeded 24%. In this paper detailed simulation of the photovoltaic cell connected with boost converter is carried out by using SIMULINK software that comes with MATLAB program. The results from simulation show that the effect of the irradiance on the output power of photovoltaic solar cell. When the irradiance increases; the output power from the cell increases and vice versa. The effect of high temperature is studied in Saudi Arabia and the efficacy of the cell effect by increasing the temperature as shown in simulation the measured values at all sun rise on day light and the effect of the high temperature of the output voltage of the cell as shown in the simulated figures. In addition the impact of ambient temperature on PV inverter thermal performance has been investigated. The results show that the efficiency of PV inverter decreases when exposes to higher temperatures.

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