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Study of the Specific Factors Effecting the PV Solar Cell's Efficiency in Saudi Arabia

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Abstract This paper presents the study of some specific factors that affect the performance of the photovoltaic (PV) solar cells including characteristics, types, advantages and disadvantages and the most important factors effecting the efficiency of the solar cells. The outdoor performance of PV module is influenced by many factors. Some of these issues are related to the module itself and others are related to the location and the environment. Few of these factors are material degradation, solar irradiance, module temperature, parasitic resistances, fill-factor, shading, soiling and Potential Induced Degradation (PID). The solar energy productivity of two major cities of Jeddah, and Riyadh in Saudi Arabia were presented and discussed.

Keywords: *PV, solar, cells, renewable, efficiency, Jeddah, Riyadh*

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1. Introduction

Nowadays, renewable energy is becoming more important in the generation of electricity. Fossil resources do not present a sustainable option for the future since they are non-renewable sources of energy that contribute to environmental pollution. Within the sources of renewable generation, photovoltaic energy is the most used, and this is due to many solar resources existing throughout the planet. At present, the greatest advances in PV systems are focused on improved designs of photovoltaic systems, as well as optimal operation and maintenance [1]. The PVs is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current result that can be used as electricity as show in Figure 1 [2].

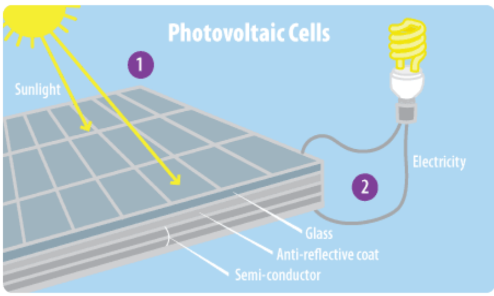

Figure 1. Photovoltaic cell [2]

2. PV's Characteristics

The solar cell I-V characteristic curves show the current and voltage behaviour of a PV cell, module or array giving a detailed description of its solar energy conversion ability and efficiency [4]. Knowing the electrical I-V characteristics of a solar cell, or panel is critical in determining the device's output performance and solar efficiency [4]. The main electrical characteristics of a PV cell or module are summarized in the relationship between the current and voltage produced on a typical solar cell I-V characteristics curve [4]. The intensity of the solar radiation (insolation) that hits the cell controls the current (I), while the increases in the temperature of the solar cell reduces its voltage (V). Solar cells produce direct current (DC) electricity and current times voltage equals power, so we can create solar cell I-V curves representing the current versus the voltage for a photovoltaic device [4].

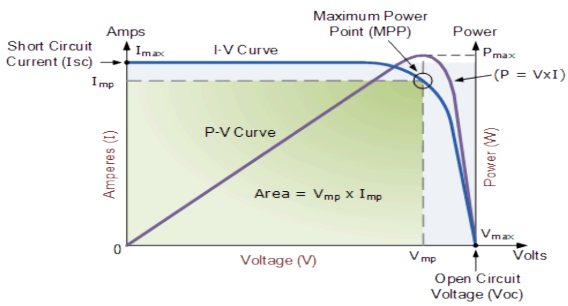

Figure 2. Solar cell I-V characteristics [5]

[Figure 2](#) shows the I-V characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a solar cell is the product of current and voltage (I xV) [4].

3. Types of PV Cells

There are several types of the PV cells.

3.1. Monocrystalline Solar Cell Silicon

It is also called "single-crystal silicon", "mono c-Si", or just mono-Si) is the base material for silicon chips used in virtually all electronic equipment today.

3.2. Polycrystalline Solar Cell Silicon

It is also called polysilicon or poly-Si, is a high purity, polycrystalline form of silicon, used as a raw material by the solar PV and electronics industry.

3.3. Thin Film Solar Cell (TFSC)

It is also called a thin-film photovoltaic cell (TFPV), is a second-generation solar cell that is made by depositing one or more thin layers, or thin film (TF) of PV material on a substrate, such as glass, plastic or metal.

3.4. Amorphous Silicon (a-Si)

This type is the non-crystalline form of silicon.

3.5. Copper Indium Gallium Selenide Solar Cells (CIGS)

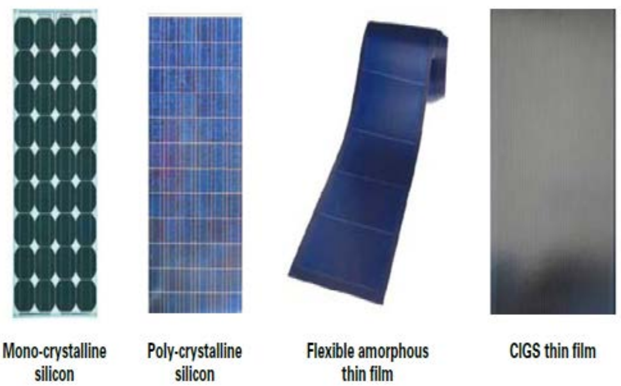

Figure 3. Types of PV cells [7]

Table 1. Conversion efficiency of PV types [8]

Technology Module	Efficiency
Mono-crystalline Silicon	12.5-15%
Poly-crystalline Silicon	11-14%
Copper Indium Gallium Selenide (CIGS)	10-13%
Amorphous Silicon (a-Si)	5-7%

Copper Indium Gallium Selenide Solar Cells (CI (G) S) Copper Indium Gallium Selenide Solar Cells (CI (G) S) One of the most interesting and controversial materials in solar is Copper-Indium-Gallium-Selenide, or CIGS for short [6]. Figure 3 shows the types of PV cells. Table 1 shows the efficiencies of different types of the silicon solar cells. Table 2 shows the advantages and disadvantages of PV cells.

Table 2. Advantages and disadvantages of silicon solar cells [8]

Advantages	Disadvantages
Renewable Energy Source	Cost
Reduces Electricity Bills	Weather Dependent
Diverse Applications	Solar Energy Storage is Expensive
Low Maintenance Costs	Uses a Lot of Space
Technology Development	Associated with Pollution

4. Factors Effecting Performance of PV Systems

The PV cells are semiconductor devices which convert energy of light into electricity. A semiconductor is a substance, usually a simple element or a compound, that can conduct electricity under some conditions but not always, making it a good medium for the control of electric current. There are several factors affecting performance of PV systems.

4.1. Degradation of PV Module

The manufacturers of the PV solar systems usually guarantee the performance life of 25 years for the modules. The PV solar panels usually degrade at a faster rate in the first few years of their life. In general, rated power output of solar panels typically degrades at about 0.5% year. These degradation processes may be chemical, electrical, thermal or mechanical in nature. Early degradation of the PV modules may be due to design flaws, poor quality materials or manufacturing issues. In most cases, module failures and performance losses are due to gradual accumulated damages resulting from long-term outdoor exposure in harsh environments. [9]

4.2. Module Temperature

A PV cell, like any other semiconductor device, is very sensitive to temperature. The efficiency and power output of a PV cell reduces with increase in its temperature. From the normalized values of current, voltage and power at 25°C, with increase in temperature, cell current increases slightly, but voltage drops at larger rate, leading to the larger drop in the power output. If cell temperature falls below 25°C, the current falls slightly but voltage and power increases as shown in Figure 4.

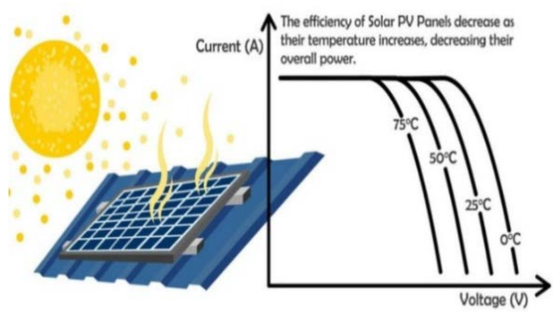

Figure 4. The effect of temperature in PV module [10]

In general, up to about 0.5% loss of efficiency per degree Celsius increase in temperature is typical in silicon cells [11].

4.3. Shading

The shading results in mismatches in the generated currents of individual cells of a module. Even partial shading on a single cell can significantly reduce the power output of the entire module as if all the cells were shaded. A shaded cell produces much less current than the unshaded ones. Since cells in a module are connected in series, same current has to flow through all the cells. If more current than the shaded capability is forced through a shaded cell, it will be over-heated and might be damaged [11]. Figure 5 shows the effect on the performance of your whole photovoltaic system can have a considerable impact.

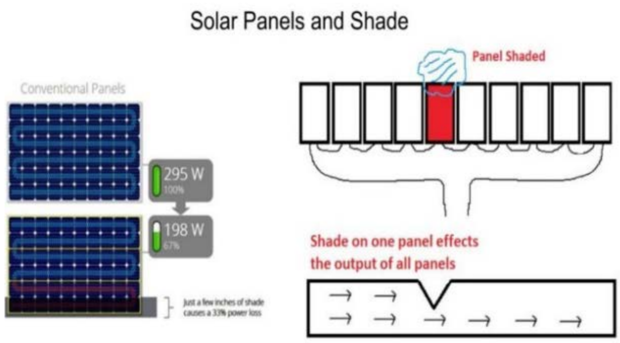

Figure 5. Effect of shading on the performance of the PV system [12]

4.4. Soiling

The soiling is the accumulation of dust, dirt, and other contaminants on a PV module. It leads to the formation of a thin screen over a module and thus reduces the light falling on one or many cells. Dust represents minute solid particles of diameter less than 500 µm. Dust settlement depends on factors such as dust properties (shape, size, weight) as in Figure 6 shows the different between soiled module and clean module.

Figure 6. Soiled and clean module [11]

Weather conditions (rain, humidity, snow), location (coastal or dusty area), module tilt angle, surface finish and wind speed. Permanent soiling can occur if humidity condensate sticks dust to the surface, particularly at the bottom of a tilted module. Collection of dust and the growth of lichens along the module frame produce partial shadings on the bottom row cells and may damage the coating and seals [12,13].

4.5. Variation in Solar Radiation

The performance of PV modules under varying light conditions will differ significantly, which in turn has a severe impact on the yield of PV systems as in Figure 7.

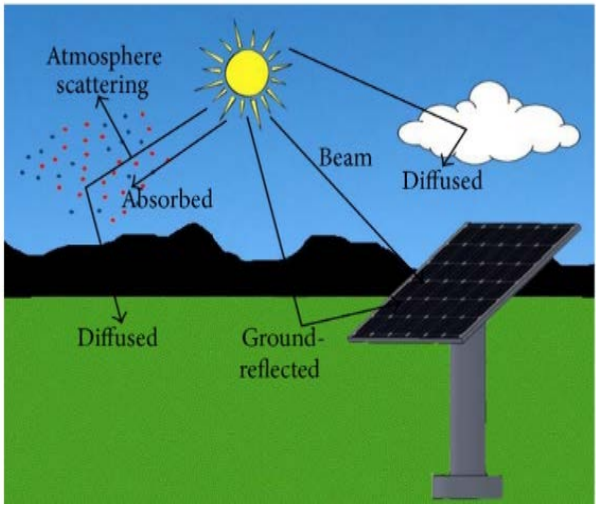

Figure 7. Types of solar irradiance [13]

Variations in the intensity of solar radiation falling on a PV module affect many of its parameters, including I_{sc}, V_{oc}, power, FF and efficiency [14].

4.6. Filling Factor

The filling factor of the PV cell is defined as the ratio of the maximum power to the product of V_{oc} and I_{sc}. A good quality PV module is expected to have fill-factor above 70%. A lesser filling factor indicates larger value of R, increased recombination current in the space charge region and increased reverse saturation current of the junction I_o, all these conditions representing increased losses.

4.7. Parasitic Resistances

The series and shunt resistances of a PV cell, called Parasitic Resistances, results in increased $I2R$ losses, which eventually results in reduced module efficiency. The series resistor (R_s) represents the internal resistance of the PV cell. It comprises of the resistance of metal contacts, fingers, impurities, and resistance of the semiconductor itself. The shunt resistor (R_{sh}) represents the leakage resistance and is responsible for the leakage current. The resulting reductions in area of the I-V curve leads to a reduction in fill-factor, and thereby drop in cell efficiency.

4.8. Potential Induced Degradation

The Potential Induced Degradation (PID) is a performance degradation mechanism in the PV systems due to stray currents, leading to gradual loss of power up to 30% or more. The PID generally occurs in PV systems with ungrounded inverters. There are two issues with PID including the loss of useful generated power and the degradation of the front surface passivation, leading to increased recombination and cell damages. The PID occurs only a few years after installation of the PV system. Figure 8 shows the images of a standard module and the modules with the TiO_2 coated cover glass before and after the PID test: (a) standard module, (b) module with a 50 nm-TiO_2 film deposited on the cell side of the cover glass, and (c) module with a 100 nm-TiO_2 deposited on the cell side of the cover glass. The standard module was seriously shunted after the PID test, while the module with 50 nm-TiO_2 was less affected and the module with 100 nm-TiO_2 appeared to be unaffected [16].

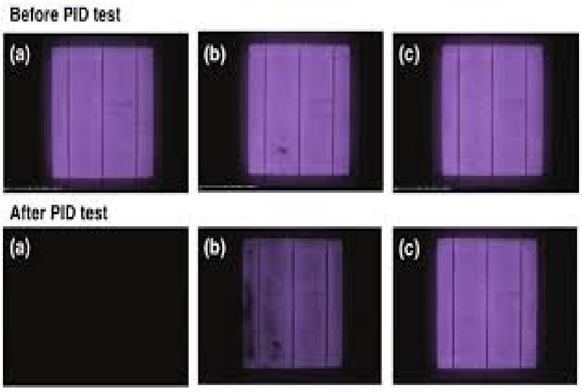

Figure 8. Images of a standard module and the modules with the TiO_2 coated cover glass [16]

5. Solar Energy Productivity Comparison between two Different Cities in Saudi Arabia

The comparison shows the difference between Jeddah and Riyadh in solar energy productivity as shown in Figure 10 and Figure 12. The system implemented is On-Grid PV system with output power of 14.4 kW and energy 72 kw/h per day. The number of the PV cells is 40 cells each cell generates 360 W as shown in Figure 9 the PV module is made with Mono-crystalline silicon cells that give high performance together with high efficiency.

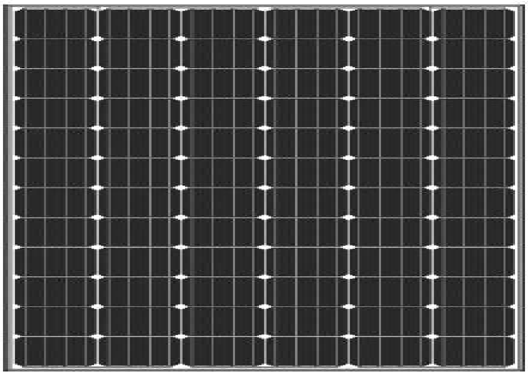

Figure 9. PV modules

The main technical characteristics of the PV modules AS-360 W are expressed below in Table 3.

Table 3. Characteristics of PV modules

Power (Wp):	**360**
Short circuit current (A)	9.89
Open circuit voltage (V)	46.7
Operating current (A)	9.45
Operating voltage (V)	38.1
Efficiency (%)	18.55

Figure 10 and Figure 11 and Table 4 shows the totale grid feed in for the PV system in Jeddah is 23,900 kwh/year, while in Figure 12, Figure 13 the totale grid feed in for the PV system in riyadh is 24,405 kwh/year. The energy produced from the PV system located in Riyadh is better than the PV system in Jeddah because of different factors such as the performance of PV modules under varying light conditions will differ significantly, which in turn has a severe impact on the yield of PV systems, module temperature, soiling and all the other factors can effect the performance of the PV system in different places.

Figure 10. Production forecast Jeddah

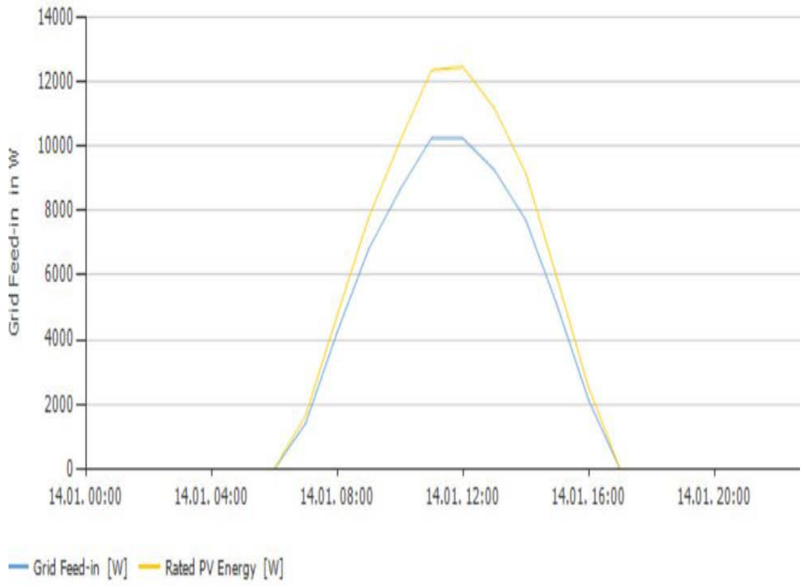

Figure 11. Rated PV Energy

Table 4. Energy generated per month

Month	**Energy**
Jan	2145
Feb	1974
Mar	2019
Apr	2122
May	2133
Jun	1963
Jul	1969
Aug	1909
Sep	1951
Oct	2081
Nov	1868
Dec	1762

Figure 12. Production forecast

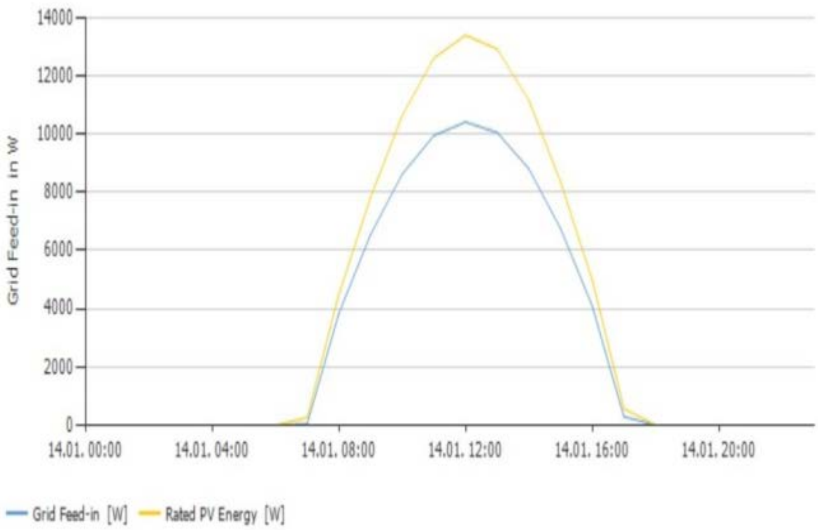

Figure 13. Rated PV Energy Riyadh

6. Conclusion

In this paper, we presented several issues of the PV solar cells including the characteristics, types, advantages and disadvantages and a study of some specific factors effecting the solar cell's efficiency. the weather and location are the most important factors that affect solar cell's efficiency and output energy. A case study of two major cities in Saudi Arabia was presented to show the effect of the factors mentioned in this paper. Finally, it is recommended that a detailed study is important during the design of the solar cells project. This will lead to perfect installation and very efficient solar system. Also, we have found in this study that the the energy produced from the PV system located in Riyadh is better than the PV system in Jeddah because of different factors such as the performance of PV modules under varying light conditions will differ significantly, which in turn has a severe impact on the yield of PV systems, module temperature ,soiling and all the other factors can effect the performance of the PV system in different places.

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