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CALCULATION AND COMPARISON OF TEMPERATURE EFFECT ON PHOTOVOLTAIC EFFICIENCY FOR DIFFERENT SOLAR CELLS

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ABSTRACT
Nowadays, renewable energy has attracted the attention of many researchers. One type of renewable energy is the solar one that can be used by different solar cells. One of the most important required energy is the electrical one, because of that generating this kind of energy by means of solar cells is very significant. Therefore, in this paper, at first, we express all kinds of solar cells and their advantage and disadvantage. Secondly, historical records of photovoltaic effect and the importance of the temperature effect on this phenomenon are considered briefly. Then to approach finding the best kind of solar cells in generating electrical energy, photovoltaic efficiency and the effect of temperature on photovoltaic are calculated for all kinds of solar cells. Finally, we compare all kinds of solar cells in terms of above quantities and declare which solar cell is the best one to use in photovoltaic phenomenon.

KEYWORDS: photovoltaic efficiency, photovoltaic solar cells, renewable energy, temperature effect.

INTRODUCTION
Todays, one of the most issues that is considered by scientists and concerned them is consuming too much available energy by human. Most energy resources are expired rapidly. In addition, consuming too much energy made too much pollution in our environment. Therefore, finding a kind of energy that made less pollution and have an ability to use several times that means it has the less dissipation, have attracted a lot of attention from researchers. So, scientists think that they have to find a way to use the natural energy that exists around us. These kinds of energy are called renewable energy such as wind energy, solar energy and etc. Solar energy is radiant ultraviolet light and heat from the sun and it is converted into wind, wave power, hydroelectricity and biomass. A portion of this vast renewable energy source available on earth is directly used by humans. Earth receives 174×10^{15} Watts at extraterritorial level: 30% is reflected back to space, and 70% is absorbed by clouds, water and land masses (Smil, 1991). One of the most important energy that mostly use is electrical energy. For this reason, generating electrical energy is matter to scientists. Among all kinds of renewable energy, using solar energy is more important, because it's very available and by different kind of solar cells we can produce electricity. According to the importance of what we mentioned above, in this paper, in the first step, we express the kinds of solar cells and their performance, advantage and disadvantage of them. In the second step, the photovoltaic effect is introduced and its historical records are mentioned. In the third step, the thermal limitations that affect the photovoltaic efficiency are presented and we study it for all kinds of solar cell. At last, all kinds of solar cells are compared with each other in term of temperature effect on photovoltaic efficiency and the best solar cell will be introduced.

Introducing All kinds of solar cells and their pros and cons

1. kinds of solar cell
Solar cells are usually divided into three main categories called generations. The first generation contains solar cells that are relatively expensive to produce, and have a low efficiency. The second generation contains types of solar cells that have an even lower efficiency, but are much cheaper to produce, such that the cost per watt is lower than in first generation cells. The term third generation is used about cells that are very efficient. Most technologies in this generation is not yet commercial, but there is a lot of research going on in this area. The goal is to make third generation solar cells cheap to produce (Lund et.al, 2008)

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1.1 First generation of solar cells
The first generation includes cells consisting of Silicon or Germanium that are doped with Phosphorus and Boron in a p-n-junction. This generation is dominating the commercial market. Silicon cells have a quite high efficiency, but very pure silicon is needed, and due to the energy-requiring process, the price is high compared to the power output (Lund et.al, 2008).

1.2 Second generations of solar cells
1.2.1 Amorphous silicon cells
In Amorphous Silicon Cells, hydrogen is introduced to the silicon to make it possible to dope the silicon with boron and phosphorus. The cells are built up in this sequence from bottom to top: metal base contact, n-layer, intrinsic layer, p-layer, transparent contact, glass substrate. These cells experience a drop in efficiency when they are exposed to sunlight, and this effect is created in the intrinsic layer. The effect can be reduced by, instead of one layer, using several thinner layers (Lund et.al, 2008).

1.2.2 Polycrystalline silicon on low cost substrate
These cells use antireflection layers to capture light waves with wavelengths several times greater than the thickness of the cell itself. This can be done by using a material with a textured surface both in front and back of the cell, rather than a flat surface. This causes the light to change directions and be reflected, and thus travels a greater distance within the cell then the cell thickness (See Fig.1) (Lund et.al, 2008).

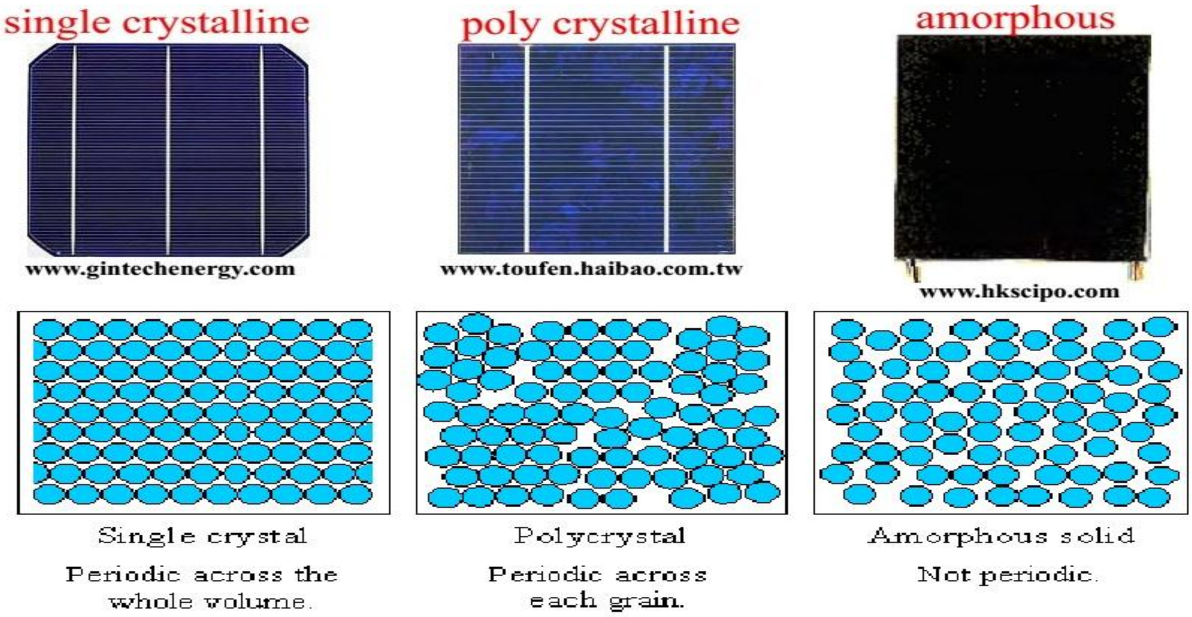

Figure 1: internal structure and general shape of three kinds of silicon solar cell are shown.

1.2.3 Copper Indium diSelenide (CIS) Cells

Copper Indium Diselenide consists of $CuInSe_2$. This material is one of the best light absorber known, and about 99% of the light is absorbed before reaching 1 µm into the material. There have been made homojunctions of CIS, but a heterojunction with cadmium sulfide (CdS) has been found to be more stable and efficient (See Fig. 2.) (Lund *et.al,* 2008).

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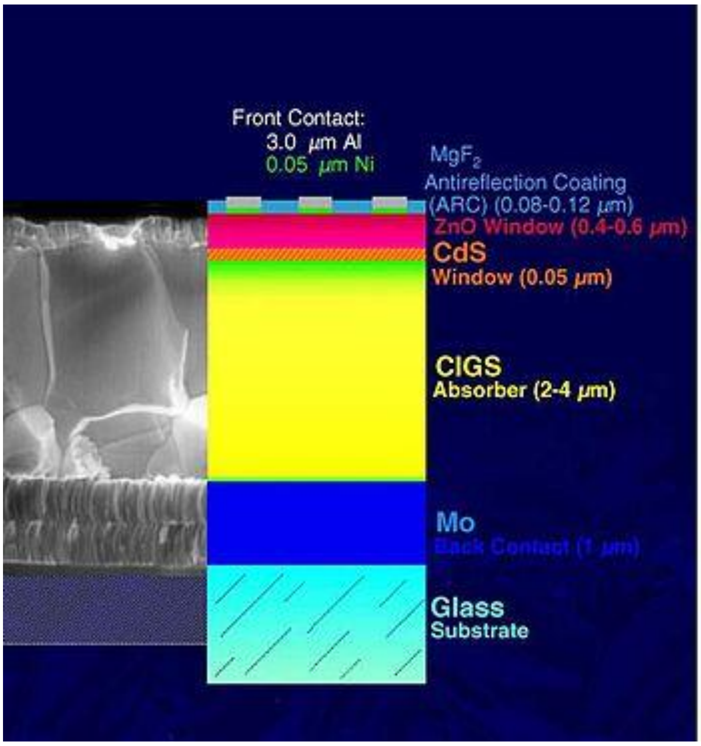

Figure 2: internal structure of Copper Indium diSelenide (CIS) Cells is shown

1.2.4 Cadmium Telluride Cells

These cells are made from a heterojunction with cadmium sulfide, just like the copper indium diselenide. Cadmium telluride cells also have an ideal band gap (1.44eV) (See Fig.3.)(Lund et.al, 2008)

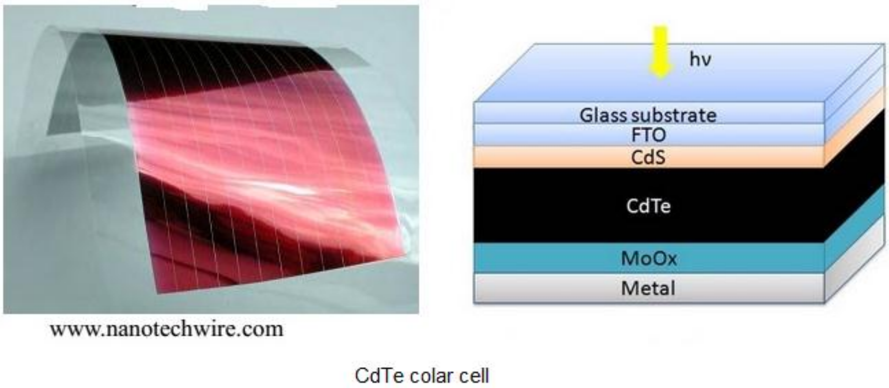

Figure 3: internal structure and general shape CdTe solar cell is shown.

1.3 Third generations of Solar cells

1.3.1 Quantum Dot (QD) Solar Cells

There are several technologies in this generation. One of them is Quantum Dot (QD) Solar Cells. These are built up of a semiconductor (silicon) coated with a very thin layer of quantum dots. Quantum dots is just a fancy name of crystals in the size range typically a few nanometers in diameter. These crystals are mixed into a solution and placed on a piece of silicon which is rotated really fast. The crystals are then spread out due to the centrifugal force. The reason these quantum dots are given so much attention is that normally one photon will excite one electron creating one electron-hole pair. The energy loss is the original energy of the photon minus the energy needed to excite the electron(also

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called the band gap) However, when a photon hits a quantum dot made of the same material, there may be several electron-hole pairs created, typically 2-3, but 7 has been observed (See Fig. 4.) (Lund *et.al,* 2008).

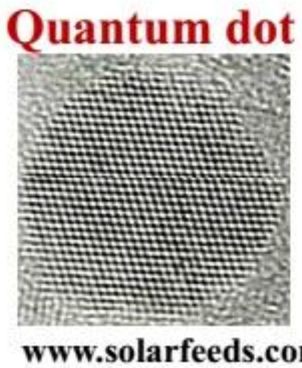
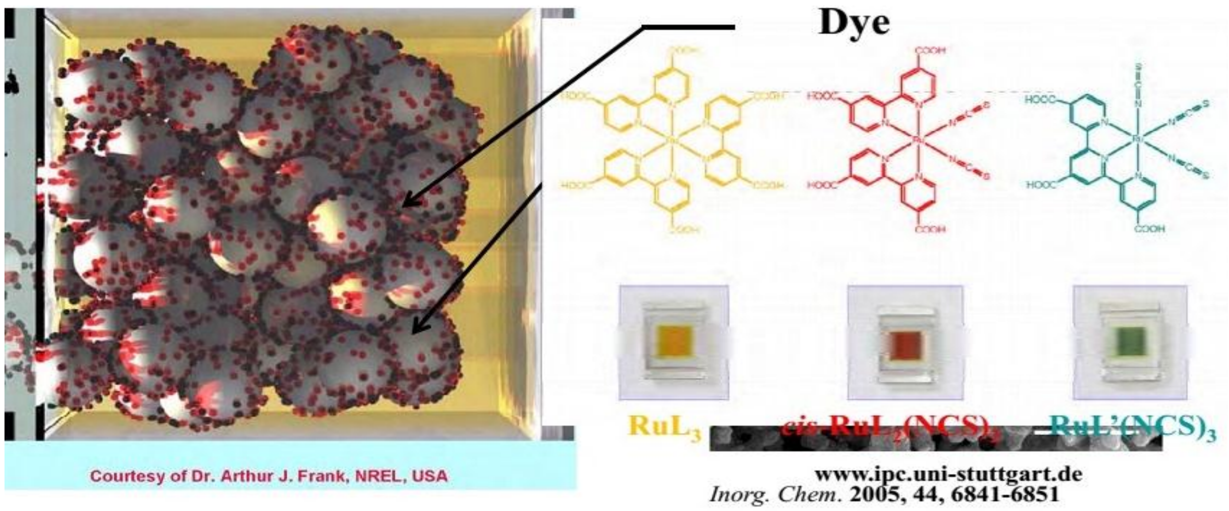


Figure 4: the structure of Quantum Dot solar cell is shown.

1.3.2 Solar cells based on organic materials

Organic solar cells in comparison with their counterparts have less efficiency. But because their producing costs are low and they have some abilities such as flexibility, these kinds of solar cells are very suitable in nonindustrial uses. All kinds of organic solar cells are included Dye Sensitized solar cell (See Fig.5.), Polymer solar cell and liquid crystals solar cells.



Dye Sensitized Solar Cell

Figure 5: internal structure of Dye Sensitized Solar cells is shown.

2. Pros and Cons of solar cells

Pros and Cons of solar cells in term of their generation are given briefly in Table 1. (King *et.al*, 2012 and Jansen *et.al*, 2006) .

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Table 1: Pros and Cons of different solar cells by considering their generation are shown.

		Solar cells generation	Advantage	disadvantage
First generation		Single crystal silicon wafers	- Single crystal silicon is capable in converting solar cell into electricity, So they are the best choice to make high efficiency panels. - Are not dangerous for environments - they have a wide range of absorption spectrum	- high costs: high cost producing technology like: a) silicon extraction of sand and purification before growing the crystals b) consuming high energy during growing and cutting bars - dissipation of the most high energy photons at the end of blue and violent wave length as heat - consuming energy as fossil fuels
Second generation		Amorphous silicon cell Poly crystalline silicon Copper Indium Gallium diselenide alloy Cadmium Telluride Cell	- Low costs to produce, it requires less materials to produce because low cost per power unit and they are light - flexibility and its effect on matching on panels, curve surface or flexible materials and light material like cotton, the capacity of rolling	- lower efficiency than first generation cells - natural defect because of lower quality in controlling way - instability of amorphous silicon - high toxicity
Third generation		Quantum dot solar cell	- low energy technology to mass production - controllability of polymeric solar cell in chemical sensitize and also low cost sensitizing - in the low light condition they work, improvability and chargeability for dye sensitized solar cell	- lower efficiency than first generation cells - polymeric solar cells: destructibility and lowering the efficiency during time because of environmental effect, high energy gap - destroying electrodes by electrolyte in photochemical cells
	Organic solar cell	Dye sensitized		
		polymeric		
		Liquid crystals		

Photovoltaic effect

The definition of photovoltaic effect

The photovoltaic (PV) effect is the process by which solar cells convert light energy into electrical energy. Not all wavelengths can contribute to this process. Absorption occurs when each incident photon comes sufficient energy to excite an electron from a lower energy state. For each incident absorbed photon, an electron-hole pair will be generated and can potentially contribute to a current. Some excess energy will dissipate as heat. There are efficiencies associated with each step in the conversion process (Wu *et. al*, 2004). Solar cells use p-n junction structure to produce electrical energy from incident photons when solar cells are exposed to appropriate wavelengths, electrons in the p-type region will be excited from valence band to conduction band. The excited carriers flow across and out of the junction. Hence, power is supplied to an attached load (Wu *et. al*, 2004).

The history of photovoltaic effect

The discovery of photovoltaic effect referred to 1839, but its developing and applying happened slowly. By improvement in quantum mechanics in the beginning of 20th century, explaining the phenomenon that related to converting light into electricity became possible. And the importance of single semiconductor crystal and the behavior of p-n junction are explained. In 1954, Chopin and their colleagues in Bell laboratory invented a silicon solar cell with 6% efficiency. In the late 1950s, solar cells were used to provide electrical power for satellite systems because these elements did not need any protection for a long time and without any loss in the converting efficiency, were useful. In 1970s, scientist discovered that using the photovoltaic effect and be a suitable suggestion in order to produce energy from other natural energy instead of fossil resource)Fujikake *et al*., 1996) (Yano *et al*., 1987) (Okinawa *et al*., 1982) (Kishi *et al*., 1992).

Photovoltaic Solar panels

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaic include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium

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gallium selenide/sulfide. Photovoltaic solar panel is the most commonly used solar technology to generate electricity energy (Kurtz, 2009).

Role of photovoltaic in renewable energy

Energy from the sun naturally powers the weather, affecting the temperature that causes the water and wind cycles. The sun provides energy to living organisms: plants generate energy from the sun’s rays through photosynthesis and a smaller amount of energy is transmitted from the plant to other living organisms through consumption. The innovation in technology provides society with the ability to capture and utilize solar energy to fulfill increasing energy demands (Shikder, 2011).

Definition of photovoltaic efficiency

Solar cell efficiency is measured by the ratio of output solar energy per incident solar energy. Efficiency depends on spectrum, intensity of solar light and the temperature of cell. For comparison we consider a solar cell with 1.5 air mass and 25 degrees. The equation of solar cell efficiency is given by Eq. 1(Honsberg, 2010II)

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}} \tag{1}$$

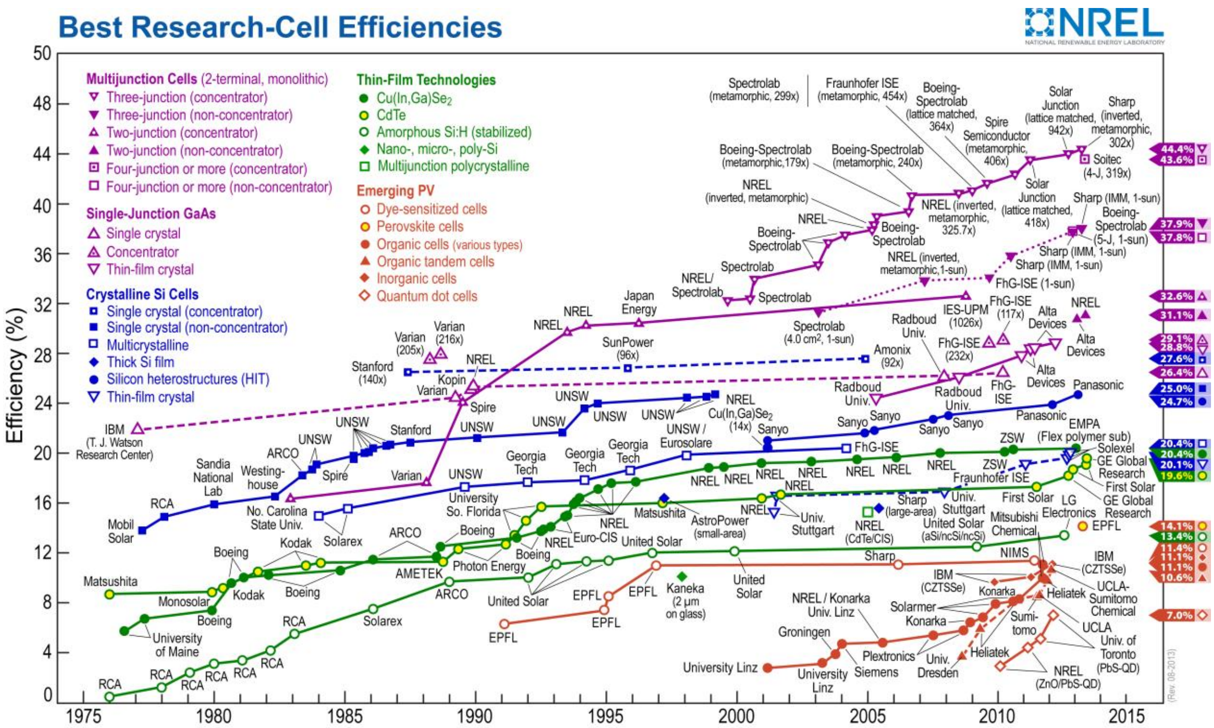

Figure 6: lab efficiency for different solar cell is shown (Kazmerski, 2012).

In equation (1), P_{in} is the power of incident solar light, FF is the fill factor, I_{SC} is the current of short equivalent circuit and V_{OC} is the open circuit voltage. Fill factor (See Fig. 7) is defined as a ratio of maximum power per limitation of theoretical power that is related to solar cell and is given in Eq.2

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Fill Facto (2)

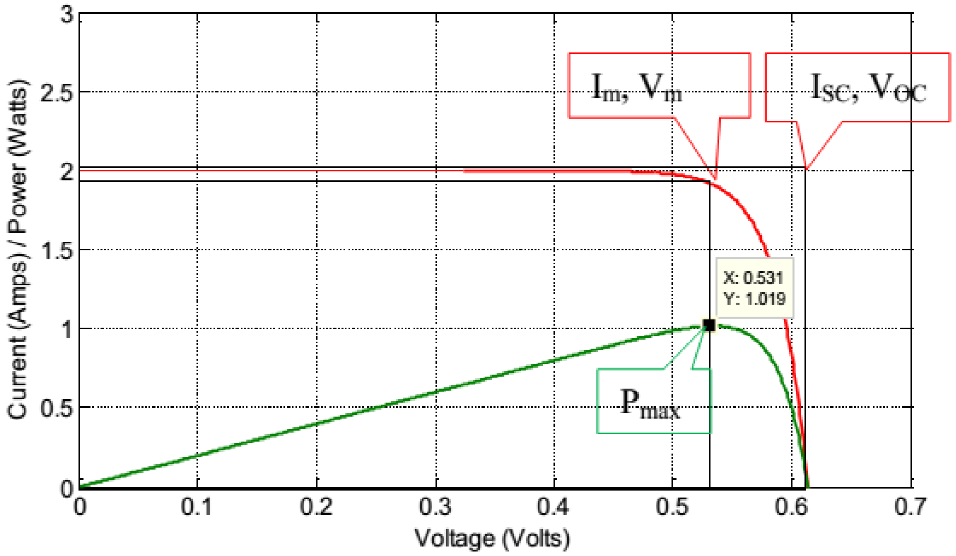

Figure 7: The plot of fill factor and the maximum of power for one solar cells are shown

The short circuit current is the maximum current through the solar cell and occurs when the voltage across the cell is zero. Normally the short circuit current depends on incident solar radiation, cell area, optical properties, collection probability etc. Under 1.5 airmass (AM) spectrum the theoretical current density for a silicon solar cell is 46 mA/cm^2. In the laboratory 42 mA/cm^2 current has been measured whereas commercial silicon cell short circuit currents are between 28 mA/cm^2 and 35 mA/cm^2 (Honsberg, 2010I). The open circuit voltage is the maximum voltage available across the solar cell with zero output current.

The importance of temperature effect on the photovoltaic cells

Temperature has a significant role in photovoltaic systems. The efficiency of photovoltaic cells depends on temperature so much. At lower temperatures, PV systems produce more power. For higher temperatures, optimum operation requires modification of electrical load and removal of excess heat. Several technologies and approaches are available to improve PV system efficiency. An experimental study of temperature dependence in solar cells and an associated mathematical model provides insight into the management of solar power systems.

Much work has been done on Photovoltaic (PV) cells. Many studies included information on temperature dependence. The loss mechanisms differ for high and low temperatures. At high temperatures, two predominating effects can cause efficiency to drop. As thermal energy increases, (1) lattice vibrations interfere with the free passing of charge carriers and (2) the junction begins to lose its power to separate charges. Low-temperature losses are, if any, more complex and less understood. They are important, however, only for deep-space PV applications. For an ideal solar cell, no resistance loss is associated with the photovoltaic process. In physical devices, series resistance loss and shunt resistance loss are present within the solar cell. The series resistance is caused by metal- semiconductor contact, ohmic resistance in the metal and ohmic resistance in the semiconductor substrate; the shunt resistance is cause by leakage currents at the edge (Wu *et. al*, 2004)

Studying the temperature effect on photovoltaic efficiency for different kinds of solar cells

Because of the affection that temperature has on photovoltaic efficiency, it is better to plot the photovoltaic efficiency for different solar cells all together and see which one is the best. As the temperature of PV cells increase, the output drops. This is taken into account in the overall system. Temperature relating is given in Eq.3 (See Fig. 8)

$$\eta_t = 1 - [\gamma \times (T_c - T_{STC})] \quad (3)$$

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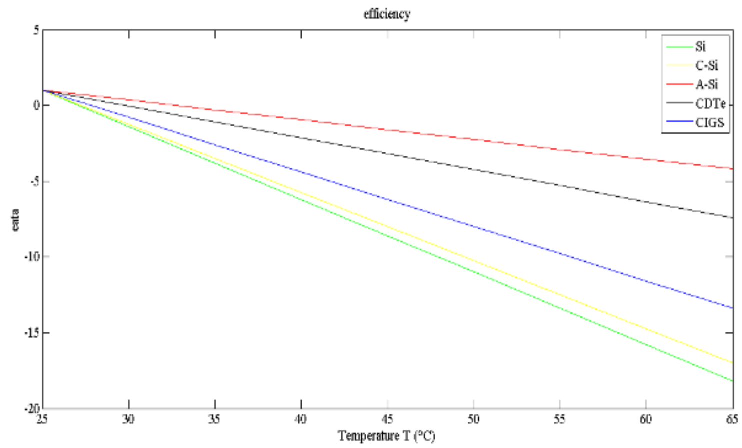

Figure 8: In this shape changes efficiency in term of thermal changes is shown

If we study the changing of temperature during a year, it is convenient to find the right time to use solar cells (See Fig. 9)

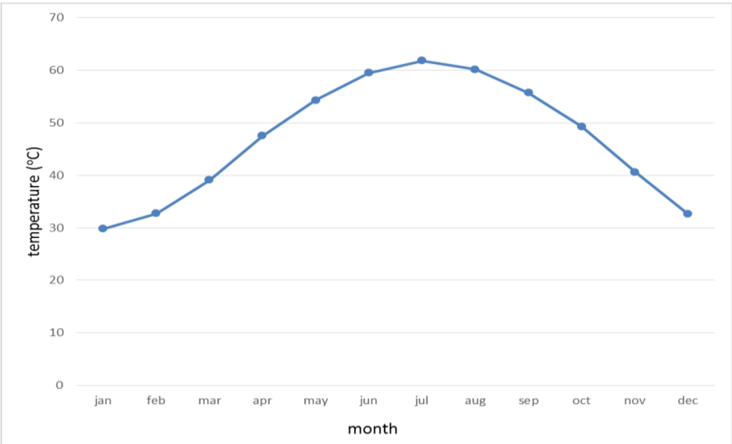

Figure 9: Thermal changes during months of the year are shown.

CONCLUSION

In this paper, we tried to gather suitable information about one of the renewable energy (solar energy). So, important quantities about this kind of energy are introduced. The plot in figure 8 is shown that other experimental research about decreasing efficiency with increasing the temperature is seen again in this work. According to Fig 8 we can put different solar cells in order in terms of the worstefficiency to the best efficincy are included: silicon thin film, single crystal silicon, CIGS, CdTe and amorphous silicon. In conclusion, it seems that using amorphous silicon might be a better choice. According to the importance of studying on decreasing efficiecny in solar cells by increasing the temperature, it is better to find the cheap cooling ways systems in order to produce these cells widely and by this way consuming solar cells can be suitable. In addition, we can study on internal solar cells structure to find the best lattice structure for cooling.

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