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A Review Paper on Solar Photovoltaic Systems

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ABSTRACT

Renewable energy has experienced a phenomenal growth in recent years due to its technological improvement and its aim to reduce the production of carbon dioxide, which is one of the gases responsible for the greenhouse effect. For future generation, the willingness to prevent the planet against pollution and in addition to produce electricity with an unlimited source, renewable energy sources especially solar photovoltaic systems are opted. This paper describes some of the major factors affecting the efficiency of solar photovoltaic cells and the solution techniques used in the literature to improve the efficiency of solar cells are also discussed.

Keywords: Renewable Energy; Solar Photovoltaic systems; Solar collectors; Fill factor.

1. INTRODUCTION

Electricity can be produced in many ways but due to some constraints like; the increasing prices of fossil fuels and concerns about the environmental consequences of greenhouse gas emissions, priority is to be provided to renewable energy sources. In particular, the Fukushima nuclear power plant accident was a turning point to give more interest to other reliable and secure energy sources. [5]

Many renewable energy resources are known, like hydro power plant, wind, solar etc. This paper will discuss about the solar system of producing electricity, materials used for the production, problems affecting the efficiency, propose solution to increase the efficiency of solar cells and finally the economic point of view of solar cells.

2. SOLAR ENERGY

Electrical energy can be produced in many ways from sun light using different techniques like photo-chemical, thermal, solar cells etc. Figure 1 shows the flow chart of electrical energy generation from sun light.

By observing figure1 it can be stated that all starts with the nuclear fusion of the sun then solar energy is realised in radiation form and with the help of solar collectors, electrical power can be produced in different ways. Collectors can be of different type depending on the methods used to produce the energy needed [7], few of them are:

2.1. Tank-type collector

In an Integral collector storage unit the solar radiations are absorbed by water collected in the storage tank. These tanks are usually mounted in an insulation box and have glazing on one side and are painted black, dark blue or coated with a selective surface. The sun shines through the glazing and hits the painted tank, warming the water inside the tank. Steel is typically used to manufacture these tanks, while copper is used for water tubes [6].

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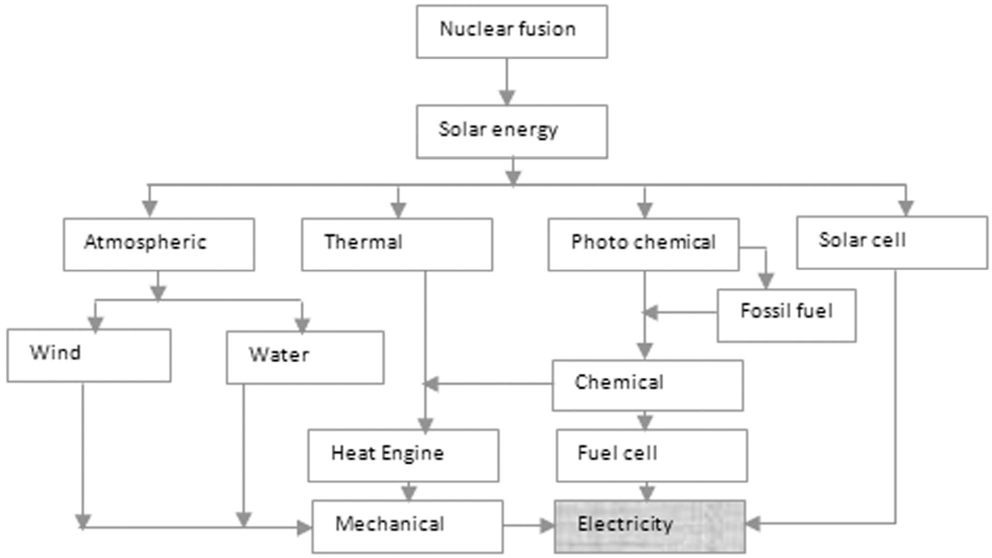

Figure 1: Solar Power Generation

2.2. Pool collector

Heating swimming pool water is among one of the important applications of active solar heating systems.To heat water in the seasonal swimming pool, special types of collectors have been developed.These type of collectors are usually unglazed and special copolymer plastic is used for their construction. These collectors are not able to withstandsolidifying conditions and are operated at an approximate temperature range of 10 – 20 ºC [4].

2.3. Flat-plate collector

In solar space heating and domestic solar water heating applications, Flat-plate collectors are among the most widely used collectors in the world[6]. These type of collectors are typically used up to a temperature range of 75 ºC [10]. However it is possible to have higher temperature operating range from high efficiency collectors. As the evaporation temperature of water is 100 ºC, it has to be replaced bysome other heat transfer liquid in such type of high efficiency collectors.These collectors are of two basic types' i.e. liquid type and air type [9]. They do not require any tracking system and cost of maintenance is also less [14].

2.4. Evacuated tube collector

Evacuated tube collectors vary widely in their operation and construction. They are made up of a number of annealed glass tubes, having an absorber plate within each of them. As tubes are the natural configuration of an evacuated collector, they becomes different from plat-plate collectors which are made up in the same way and perform from one band to another [4].

2.5. Concentrating collector

They are used for higher temperatures using optical systems (reflectors and refractors) to concentrate energy on an absorbing surface. The reflectors are usually mirrors, parabolic dishes, etc. These collectors can achieve very high temperatures 150-500 ºC because the diffused solar resource is concentrated in a small area. In order to have an efficient operation, the reflectors must be able to track the sun continuously.The geometrical concentration area ratio is given by [14]:

$$C = \frac{A_a}{A_r} = \frac{R^2}{r^2} = \frac{1}{\sin^2 \theta_s} \quad (1)$$

Where

C – Concentration ratio, non-dimensional value;
Aa – area of the collecting aperture, m^2;
Ar – area of the absorber, m^2;
R – Distance from the sun to the concentrator, m;
r – Radius of the sun, m;
θs – half of an angle subtended by the sun, º.

This ratio depends on whether the concentrator is a three-dimensional (circular) concentrator such as a paraboloid or a two-dimensional (linear) concentrator such as a cylindrical parabolic concentrator [14].

3. PHOTOVOLTAIC TECHNOLOGY

It is possible to convert solar energy directly into electrical energy by the means of a photovoltaic cell. The solar cell operates on the principle of photovoltaic effect, which is the process of generating an EMF (electromagnetic field) as the result of the absorption of ionizing radiation [8]. Therefor it can be said that a solar cell is a transducer which converts the sun's radiant energy directly into electrical energy and basically a semiconductor diode.

3.1. Circulation of current and voltage

With the N-type and P-type semiconductors, current is created in this manner: when proton of energy 'hv" (h = plank's constant 6.62×10^{-27} and v = velocity of light 2.99×10^{8} m/s) is on P region will tend to migrate to N region, when 'hv' exceeds and when 'hv' is less it is the N region neutron will tend to P region proton

The diffusion of free electron from N to P region and holes from P to N region, the current will start flowing in the circuit. [8].

As the semi-conductor material used in a solar panel acts like a diode that means there is a voltage across it. Depending on the material used as semi-conductor the voltage varies from 0.5-1 volts [8].

Other than the voltage capacity, the wattage of the panel depends on the current generating capacity of the panel and the current depends on the size of the panel. The generated current of Si-cell is about 30mA/ cm^2 at 100W/m^2 of solar radiation therefore a standard Si-cell of 15cm x15cm will generate about 6.75A. Thus, module of 36 solar cells will produce power of about $15 \times 6.75 = 101.25W_p$ (W_p = peak power output) [21]. Figure 2 show the V-I (voltage-current) characteristic of solar cell.

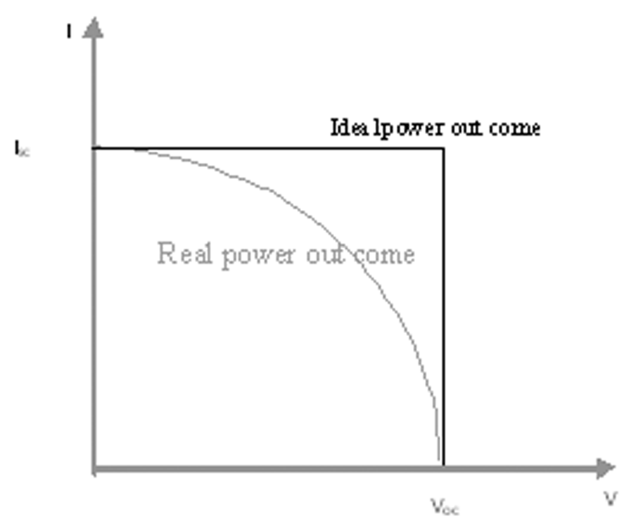

Figure 2: V-I characteristics of a solar cell.

I_{sc} = short circuit current of the cell

V_{oc} = open circuit voltage

The V-I equation of a single solar cell is given as:

$$I = I_L - \left[I_0 e \frac{q\left(V + IR_S\right)}{nkT} - 1 \right] \tag{2}$$

Where I_L is the light generation current, I_0 is the reversed saturation current, R_S is the series resistance, n is the diode (semiconductor) ideality factor, k is the Boltzmann's constant and T the temperature.

The performance ratio or fill factor is a relationship between the actual yield power and the targeted power. No power is generated under short or open circuit conditions. The maximum power P produced by the conversion cell is calculated with the help of fill factor. This is shown graphically in Figure 2, where the position of the maximum power point represents the area of the rectangle [14, 20].

$$FF = \frac{P_{pratical}}{P_{theoritical}} = \frac{V_m \times I_m}{V_{oc} \times I_{sc}} \tag{3}$$

ff = fill factor

V_m = maximum voltage output in practical conditions

I_m = maximum current output in practical conditions

V_{oc} = voltage at opened circuit

I_{sc} = current at Short Circuited conditions

3.2. Type of Photovoltaic solar cells

The solar cells can be categorised by the materials used as semiconductors. The structure and efficiency of few materials is discussed as:

3.2.1. Silicon photovoltaic cell

Three types of Silicon photovoltaic cell are known depending on the structure used on the configuration of the semiconductor.

a) Monocrystalline silicon solar cell: Here the P-type semiconductor is doped by 'baron' and the N-type by 'phosphor'. For a 10 × 10 cm cell, with a radiation of 1000w/cm^2, covered by synthetic glass; we have 0.5V output opened circuit voltage and 1 watt as power output. It has an efficiency in the range of 15-18 % and is used in power plants.

b) Polycrystalline silicon solar cell: Here liquid silicon is used, poured in small blocks and cut into plates. When solidification is done, different types of crystal structure is formed and its size depend on the weather conditions such as temperature, humidity and solar radiation. In same conditions the efficiency observed is about 17-18%.

c) Amorphous silicon solar cell (Thin film): When silicon is deposited on a subtract material such as glass, this method is called amorphous (formless or shapeless). The layer is about 1μm thick (in some conditions even less than this) and having an efficiency of about 13%. It is used for low power applications such as calculators or watches.

3.2.2. Cadmium sulphide photovoltaic cell

The Cadmium sulphide (CdS) is usually selected for the stability under ambient conditions and CdS is used when the surface of the cell is doped with Copper (Cu) atoms. Copper is used as donor material P-Type, CdS as accepter material N-Type and PEDOT: PSS (Poly 3, 4-ethylenedioxythiophene) polystyrene-sulfonate is used as buffer layer.

In open circuit conditions the output voltage is 0.59V and an efficiency of nearly 14%.

3.2.3. Cadmium telluride photovoltaic cell

The cadmium Telluride (CdTe) is used with the epitaxial method which consists of overlaying crystals in the same direction. The problem with the Epitaxial CdTe is to find an appropriate substrate. Some of the substrates are discussed [24] as:

a) Highly doped CdTe buffer layer: It is very difficult to obtain a heavily doped CdTe buffer that is why the doping of CdTe buffer is limited.

b) Expended bandgap buffer layer: Adding a higher bandgap buffer layer to act as an electron reflector can have positive affect on the efficacy of the cell up to 20% of efficiency, this is due to the velocity of exchange of the material.

c) Incorporation of an InSb (Indium antimonide) tunnel diode: The incorporation of an InSb (Indium antimonide) tunnel acting as a diode improves the efficiency up to 27.4 %, which is one of the highest efficiency found [24].

3.2.4. Copper Indium Selenium photovoltaic cell

When proton of In are replaced by Ga, the Copper Indium Selenium (CIS) photovoltaic cell is also known as Copper indium gallium selenide (CIGS). This technique is of free polarity (can conduct current in all the directions) and nearly no degradation of the material with an efficiency of 17.2% [1].

The most interesting thing with this material is that the payback time is very less, nearly 0.75 years when other material like Silicone is about 1.5 years. In addition its fill factor is very high [1].

3.2.5. Organic and other photovoltaic cells

Organic and other materials used in photovoltaic cells are not commercialized because they are too costly and their manufacturing time is also long.

The figure 3 shows the landscape of materials used in the manufacture of photovoltaic solar cells.

4. FACTORS INFLUENCING THE PERFORMANCE OF A SOLAR CELL

The performance of a solar cell is influenced by many factors, like temperature, solar irradiation, Energy Conversion Efficiency, Maximum Power Point Tracking, etc. The most influencing factors which affects the solar cells are discussed [11] as:

4.1. Temperature

In normal functional conditions the temperature of the cell is usually 20 to 30 degree Celsius more than the ambient temperature. It is also known that the power output of a solar cell depends on the temperature at which the module is operating. At its turn the temperature is also subjected to condition such as the wind speed, radiation intensity etc. At an average ambient temperature of 35°C the solar cell has an approximate temperature of 55°C to 60°C. This is due to the glass used to cover the cell [11].

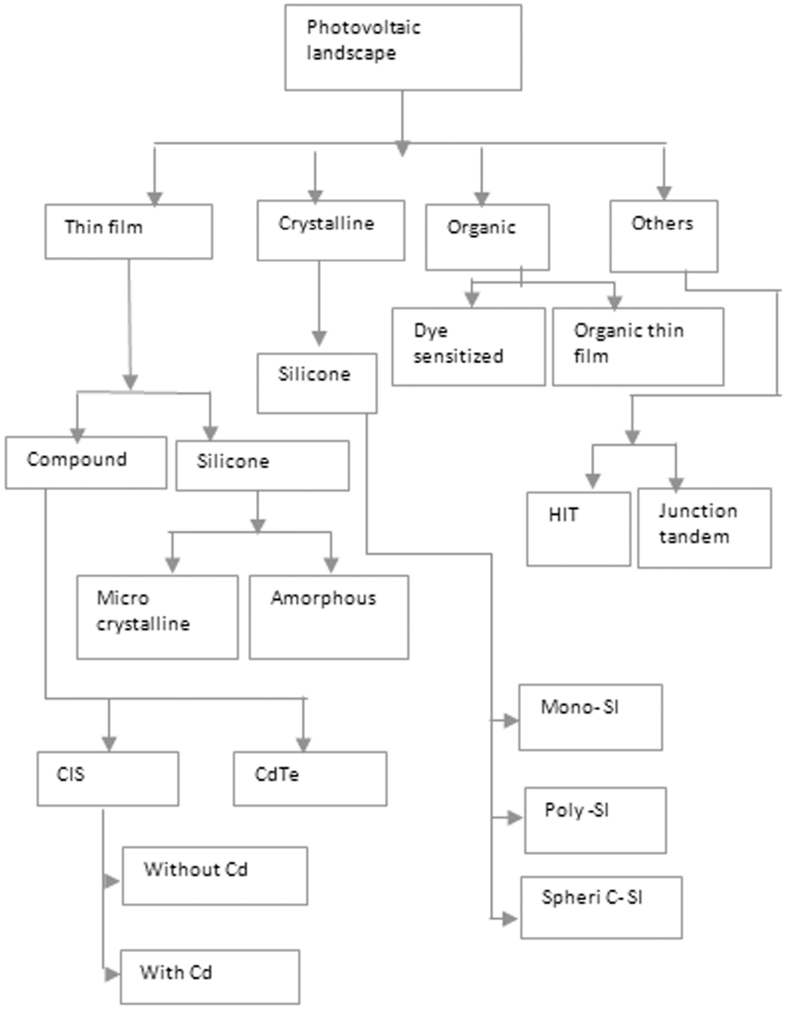

Figure 3: Photovoltaic landscape

The rise in temperature of a solar cell will result into increase in I_{SC} and decrease in V_{OC}. The decrease in voltage is eminent than the increase of current. Therefore, the power and efficiency of the solar cell decreases with the rise in operating temperature.

The following empirical formula gives the relationship between ambient temperature and the module temperature.

$$T_{mod} = T_{amb} + KP_{in} \tag{4}$$

Where,

T_{mod} is temperature of the module

T_{amb} is the ambient temperature

P_{in} is the radiation intensity in W/m^2

K is a constant $0.02 \leq K \leq 0.03$ depending on wind speed, humidity etc.

4.2. Solar irradiation

The power output of a solar panel depends at higher percentage on the solar irradiation hitting it, the relationship between power output of a solar cell and the solar irradiation is almost linear and proportional, this means that if solar irradiation increases, thepower output will also increase and the same if the solar irradiation decreases the power output will too decrease. This relation between solar irradiation power output of the solar cell result into the change of the power output throughout the day [11].

5. SOLUTION TECHNIQUES

Many techniques have been implemented in the literature for getting high efficiency from solar cells; some of them are discussed as:

5.1. Tracking system

The tracking system is a method which consist of making the panel to follow the direction of sun light (making a possible angle of 90°) to have maximum efficiency of the panel. This is due to the average availability of the sun shine in most part of the world during 8:30am to 3pm [17]. In order to achieve this track many techniques have been introduced in the literature as:

1. For tracking the sun a commercial webcam (camera) as the sensor element is used. It can track the sun more effectively and efficiently under all the different weather conditions in comparison to other trackers being used presently and are having elements such as light dependent resistors and photodiodes to detect the approximate position of the sun [3].
2. In order to ensure that the parabolic dish concentrator always tracks the sun, a light dependent resistor (LDR) sensor can be used in the system.The function of the sensor is to detect the sunlight and then to transmit the signal to Atmega 32 microcontroller for further control action [16].
3. A combination of two types of automatic tracking systems viz. using solar sensors and following a predetermined trajectory can also be done to achieve low power consumption. It also allows monitoring and control of the tracking system both locally and remotely using standard interfaces. Solutions and algorithms proposed were verified experimentally on a prototype developed by the authors [2].
4. Two dual operator-amplifiers are used as comparators for comparing the light intensity in two different axes. To develop this dual axis tracking system light dependent resistors (LDR) are used as sensors. The resistance of LDR decreases with increase in light intensity. Diodes are used for neglecting the negative voltages coming from the comparators. The microcontroller generates the suitable control signals to move the motors in the proper direction. A gain of 52.78% is found compared to a normal solar panel using this method [18, 28].
5. Image recognition method can also be used, here the difference of the sun brightness is compared and each pixel plays the role of sensor indicating the brightness with 256 levels for more accuracy [22, 25]. The image is collected using a CCD (charged couple device) camera.

This method is based on a light source tracking multi-control embedded systems which is composed of TCU (tracker control unit) and GCU (group control unit) [26].

5.2. Water cooling method

The cooling method is used to reduce the temperature of the cell. As stated earlier higher is the temperature of the cell, lower will be its efficiency. The cooling is done in a similar manner to a car radiator, where water runs through a tube placed adjacent to the panel and makes a close loop system in order to reduce temperature of the cell.

5.3. Implementation of artificial intelligence

1. A fuzzy algorithm can also be developed to achieve optimal solar tracking. The function of the fuzzy controller is to generate pulses for motor drivers, so that their step angle can be controlled as per the desired angles [23, 27].

2. PI (Proportional Integral) control can also be applied to the system to control a permanent magnet DC motor (PMDC), which rotates the panel so that the tracking can be achieved at desired angles [15].
3. Two fuzzy logic controllers can be implemented on modern FPGA (Field Programmable Gate Array) card to increase the energy generation efficiency of solar cells. The tracking mechanism is composed of photovoltaic module, stepper motor, sensors, input/output interface and expert FLC controller implemented on FPGA so that it can track the sun and keep the solar cells always face the sun throughout the day [13].

6. ECONOMIC VIEW OF SOLAR CELLS

The economical point of view of solar cells is very important in order to find the ideal point between the technical parts and the commercial parts of the cell. The commercial point of view of some of the solar cells is discussed here to have an optimal feasible choice of the material to be used.

As per the overview of the solar cell market in 2015, the more commercialised materials used for the production of solar cells [1, 12] are:

- Standard Crystalline Si 83%
- Cadmium Telluride (CdTe) 6%
- Amorphous Si (thin Film) 5%
- Supper Mono Crystalline 4%
- Copper indium gallium selenide (CIGS) 2%

With the growth in percentage of each type of PV cell [1, 12]:

- Standard Crystalline Si 246%
- Cadmium Telluride (CdTe) 141%
- Amorphous Si(thin Film) 169%
- Supper Mono Crystalline 141%
- Copper indium gallium selenide (CIGS) 257%

From the data above, it can be concluded that the Standard Crystalline PV cell is the most used solar cell. However the crystalline PV cell can be expensive on a small term investment but will make a comparison in short and long term investment of this type of PV cell [19].

Table 1
Long and Short Term Investment For SI - PV Cell [19]

	Short term	*Long term*
In put (g/Wp)	11.4	4.0
Fraction used	46%	37%
Wafer(g/Wp)	5.2	1.5
Wafer thickness (μm)	300	100
Cell efficiency	14.7%	16.5%
Specific cost($/Wp)	0.23	0.08

Therefore long term investments for silicon photovoltaic solar cells are cheaper than short term investments.

7. CONCLUSIONS

A comprehensive review of solar photovoltaic systems has been carried out to explore their application in future generation systems. The power and efficiency of solar photovoltaic system gets affected by variations in operating temperature as well as by solar irradiation striking on the panel. By designing a continuous tracking system to have maximum irradiation throughout the day and by reducing the temperature of solar panel with a suitable cooling method, the efficiency of solar cells can be improved. The new developments in solar photovoltaic module materials will result in improved efficiency of solar cells in the near future.

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