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# Photovoltaic System Optimization Review and Approach

**Onyedikachi Vincent Okereke[1*], Biliyok Akawu Shekari[2], Jonathan Dangwaran[3], Hussein U. Suleiman[4], Gokhan Koyunlu[5], Sadiq Thomas[6]**

[1,2,3,4]Dept. of Elect/Elect Engineering, Nile University of Nigeria, Abuja, Nigeria
[5,6]Dept. of Computer Engineering, Nile University of Nigeria, Abuja, Nigeria

**Corresponding Authore: 191234012@nileuniversity.edu.ng*

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***Abstract***— optimization is a major contribution of modern research to decision processes. In this project, we take a good look at the photovoltaic system while shedding light on the possible ways in which we can optimize its output. The various ways that are being considered includes the reduction of heating from solar PV module, bypassing diodes to help in reducing damages and increase functionality under shading, tilt position of the module, and the usage cellulose nanocrystals (CNC's) and other intriguing suggestions. Thereafter, practical and mathematical method employed to be able to get efficiency as desired off a solar PV system. So as more power is being wasted to heat and other factors, it is logical to mention, low efficiency creates room for more improvements.

***Keywords:*** Solar PV, Optimization, Efficiency.

## I. INTRODUCTION

There's not a single doubt that the world will gravitate towards significantly utilizing renewable forms of producing energy and also producing it in a greener way. This is because the most conventional forms of which electricity being produced today are harmful that causes greenhouse gases which depletes the ozone layer and in turn risks humanity existence as we know it.

Due to the impending need and general use of the solar PV systems, it is imperative to find a way in which we can get more out of the PV systems. The necessity of these systems cannot be altered as its source, the sun, is an everlasting continuous source of energy. The method used in trapping the sun follows a black painted glass of a silicon interior based material, doped at junctions where light (photons) passes to knocks electron loose. These loose electrons will flow creating a current which is transferred through wires. These are the critical steps in which PV systems produce its electricity. Generally, solar photovoltaic (PV) systems converts sun light to power at a very low efficiency; utilizing about 30% of sun light and reflecting the about 70% to the atmosphere. This is the case of a regular solar PV systems used. The best PV modules generally accounting for 22.8% of module efficiency which may seem as a very good form but, why can't it have more.

In regards to the power sector, especially Nigeria's, it is important to know with yet another round of increase in electricity tariff, consumers in Nigeria will have no choice but to brace themselves for harder times. This means paying more for the occurring irregular electricity supply and random disconnection [1]. Nigeria is encouraged to urgently look into diversifying her energy sources in order to avoid being stuck in perennial lack of gas supply.

As we look into solutions to fix power problems in Nigeria, we can vividly state renewable energy as the way. Putting into consideration a form of renewable energy, solar photovoltaic systems, which is one of the most reliable, easy to install, easy to maintain, and has a life span period of 20-25 years of steady efficiency until a gradual degeneration. [2]. Solar PV efficiency is determined by how much sunlight can be converted (with the use of a photovoltaic system) into electricity by solar cells. Despite the photovoltaic modules are made to produce more electricity in hotter climates, reasons like high temperature build-up can gradually reduce the PV modules electricity production, also wrong tilt angle or MPPT (maximum point of tracking), cloud cover, sun intensity and relative humidity amongst more [3].

The term photovoltaic effect generalizes how current and voltage are being generated utilizing the sun energy as method of electricity production, this as a result aids in reducing heat to the surface of earth, thereby validating the system to be a significant means in reducing global warming when introduced in a large scale in relation to other forms of producing energy [4].

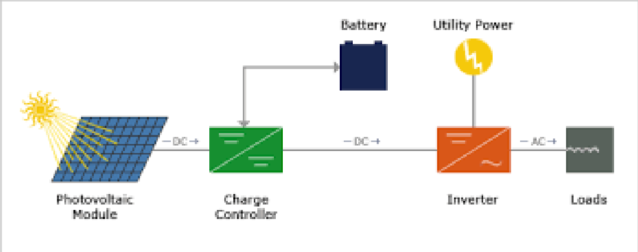


Fig. 1 Power generation using PV module

 

Figure (1) shows the process of generating electricity using a PV module, its ideal connection to loads and utility. The PV system consists of thin layers (wafer like) semi-conducting materials made of silicon. There are various types of PV modules which includes; Monocrystalline silicon, Polycrystalline silicon, Gallium Arsenide, Thick-film silicon PV, Organic-based PV (molecular or polymeric absorbers having electron acceptors (fullerene)), Thin film PV, Amorphous silicon.

The most commonly used PV cells are; monocrystalline and the polycrystalline cells, which is discussed below briefly.

### 1.1 MONOCRYSTALLINE

Monocrystalline cells as the prefix "mono" implies "single or one", are single silicon coated crystalline structural element. Here silicon is formed into bars and then cut into wafers, because of this, it allows more room for the flow of electrons. This are more costly than the polycrystalline cells, and it's output power production is significantly better. Owing to its aesthetics, this monocrystalline cell has a complete dark sky blue look which visually differentiates it from the Poly[5].

### 1.2 POLYCRYSTALLINE

Polycrystalline is also a very good silicon coated material. From its prefix "poly" which means "many", the polycrystalline cell is made up of silicon fragmented crystals of which are dissolved and joined together to make a wafer. This form allows the flow of electron but not as fast as that of the Monocrystalline. Its aesthetic gives you a multi-colored sky-blue form of silicon fragments. It is less expensive and has lesser output power. However, in both cases the efficiency is relatively low [5,6].

## II. RELATED WORKS AND PROPOSED ADDITIONS

Taking into consideration, a monocrystalline cell, below are reviewed methods from related projects;

- Bypass
- Temperature Regulation
- Tilt angle &
- Cell materials using cellulose nanocrystals (CNCs).

### 2.1 BYPASS

Shading of a solar PV module occurs when there is an obstruction of light by structures, objects, trees, by clouds during cloudy days. Shading is one of the many factors that can reduce or hinder power production of a solar PV system, causing heating of the cells, and also cause damages to the system due to fluctuations. It is therefore interesting to figure out ways by which one can gain a reasonable power output during such situations.

The diagram below, figure (2) considers a way we can avoid shading which can reduce the capacity of the modules or sometimes damage the modules entirely by introducing a bypass diode and a blocking diode. Using a *bypass diodes;* the diode has to be connected in a parallel manner to a photovoltaic cell or module representing a shunt to make the current flow by and not through the particular cell or module depending on the case, while the *blocking diodes* should be connected in "series" to the PV modules in order to prevent current flowing backwards. This happens when any cell in the module gets shaded out the current follows the next best conducting route thereby bypassing the shaded cell in order to produce power regardless. Shading effects is determined by the amount of cells which is shaded [7].

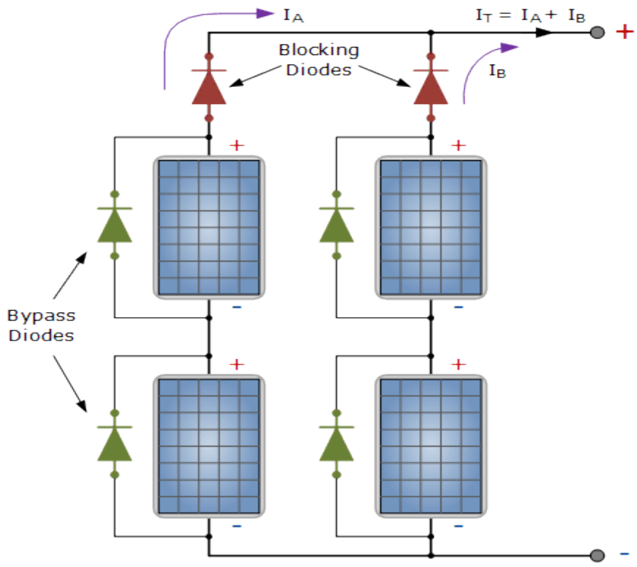


Figure 2. Bypass Diode

Another method suggested in [8] "Active hotspot and arc fault protection". In regards to this, since when we bypass instead of using a bypass diode, we can consider using switching devices that turns of the connection to the cell or module in any case, when shaded, reroute the current another switch that turns on by a desired current received.

### 2.2 TEMPERATURE REGULATOR

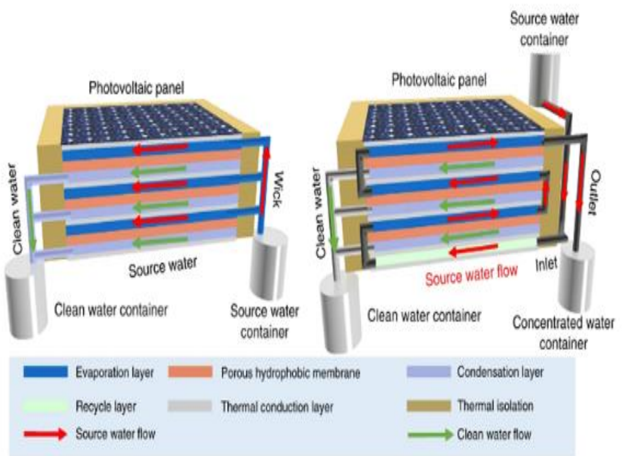


Figure 3. Temperature Regulator of a PV system

 

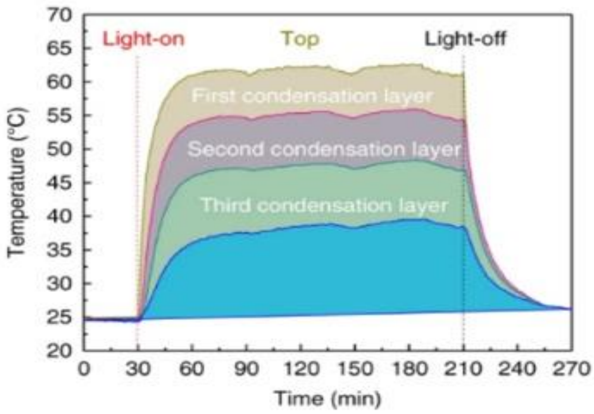

Figure 4. Temperature vs Time of a solar PV module

Figures (3) and (4) above show the impact of a temperature regulator which uses the working principle of coolants in order to reduce the temperature. Having liquid storage tanks at the four corners and layers of tubes flowing behind the PV module, where the coolants absorbs the heat at a layer closer to the module and dissipates the heat while the coolant runs through a complete cycle dumping hot and collecting cooler water from the tanks. At higher heat levels creates lower voltage. So in this case if we can lower the heat we will find and increase in voltage thereby increasing power production. Modules should be installed a few inches above the roof so as to create a convective air flow to cool the modules. Having air as a coolant has been found to decrease the solar cells temperature by 4.7 °C also increases the efficiency of solar module by 2.6%, on the other hand using water as a coolant decreases cells temperature by 8 °C and efficiency by 3%. Furthermore, ensuring modules are made with materials that are light helps to reduce heat absorption [9].

Recent studies considering temperature effects and the cost of energy (COE) with the total net present cost (NPC) was observed. The optimum solar system design will be possible, as both NPC and COE had been found to be inversely proportional to the temperature coefficient of power, and direct proportion with operating temperature of the cell [10].

## 2.3 TILT ANGLE

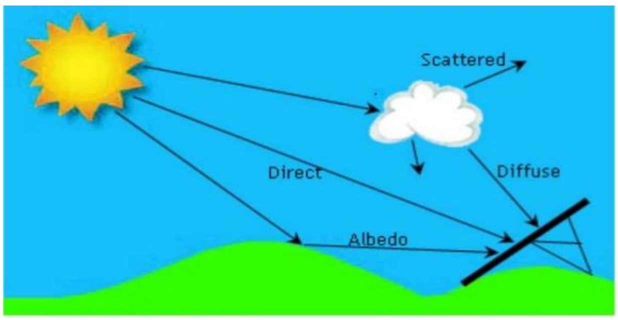

Figure 5: How Solar Radiation Reaches the PV System

Solar radiation has a major impact on tilt angle of PV system. The standard radiation test for a PV system is 1000w/m^2. Solar radiation (in figure 5) refers to the amount of solar energy that passed through the atmosphere either directly, scattered or diffused. However, the factors that affect the radiation are the orientation of the earth relative to the sun, day of the year, hour of the day and atmospheric conditions [11].

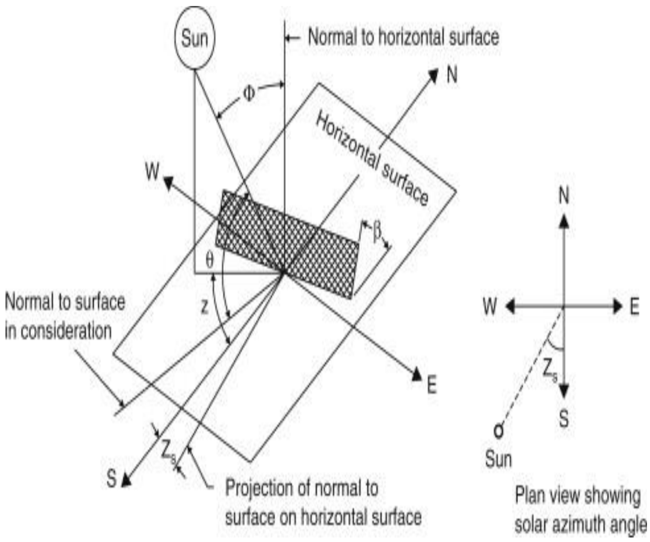

Figure 6: obtaining ideal tilt angle

Figure (6) shows that the further a house is from the equator, the higher your tilt angle would be. For example, some states located at lower latitudes witnesses the sun higher up in the sky. These states, a solar PV module requires a lower tilt in order to capture direct sunlight. While recent model uses the ability to track the sun, it is important to track it at an optimal angle which yields desired results. For fixed systems, getting optimal tilt angle is best to have a seasonal tilt. Seasons occurring four or three or two times during a year desires to be occasionally tilted during these periods. Therefore, the optimization of PV system using an optimal tilt angle will only have environmental parameters changes, such as solar irradiance and temperature [12].

## 2.4 CELLULOSE NANOCRYSTALS (CNC'S).

Cellulose nanocrystals (CNC's) are Organic electronic components that use very thin carbon-based semiconductor as layers, and it is about 1,000 times thinner than the average human hair. Using cellulose nanocrystals (CNC's); it can be used to develop new semiconductor devices, and still offering environmental benefits. Applications include CNC's based solar cells of which power conversion efficiencies claims 4% increase. Efficiencies can reach 10% but would require more expensive materials. Noting the glass substrate poses manufacturing and transportation problems because of its ability to be rigid and breakable, the CNC's are with low cost and are flexible paper-based OLEDs, it also can make displays and this can be the size of a wall as desired [13].

## 2.5 PROPOSED ADDITIONS

**2.51 MATERIALS USED IN ABSORBING LIGHT**; a semiconducting material silicon is used, doped with elements like boron having 3 valence electrons are used for p-type **doping** and phosphorus with 5-valence electrons for n-type **doping** making a PN junction, allowing current flow in only one direction (forward bias).

Proposing a gate phototransistor, connected in series with a capacitor in an even manner across sections of the PV module/module in order to bypass a section of cells or group of cells, to achieve a functional PV module while shadowed, and has a gate which regulates its turning on and off. Increasing the voltages, the transistors will be connected in series, and for current, in parallel. This will be stated on the manufacturer sheet; under shadow conditions module will be a *shunted capacitance* thereby giving more voltage, and vice versa for current increase in a module (each module having voltage or current incremental characteristics). While generally the module connection without shade will be the usual circuit. Also a phototransistor can also be modified by modifying its levels of irradiation detection which can capture light as long as it is during the day to a level of shade. A phototransistor is an electronic switching and current amplification device that is able to rely on exposure to light to operate, as light falls on the junction, reverse current flows which are proportional to the luminance [14].

### 2.52 GLAZING

Materials used in glazing of a PV module is glass, and in its structure, glass has a melting point of 1600 degree Celsius which is good in this application but it is not a conductor of electricity on its own.

There is a method of converting heat to electricity termed *thermoelectric effect;* This process creates voltage from temperature difference using a material called (Bismuth telluride $Bi_2Te_3$). Here glass is mixed with $Bi_2Te_3$ to create a conductive transparent layer of glazing. Due to the heat capacities of these substances it will be possible to use heat as a boost rather than heat affecting the voltage increase of the system as usual. Hence, it will be possible to receive additional current from the glazed section of the module when wired accordingly. This in-turn increases the efficiency of a PV system [15].

In addition, with Solid-state devices that directly convert heat to electricity without the use of moving parts, TEG's (thermoelectric generators) are typically made from inorganic semiconductors (polymers). These qualities will enable a design for high-efficiency and can operate without active cooling, which would dramatically reduce its production costs. Assuming TGE's are produced in small quantities; figure (7) having (a) connected to each module, at a position that it can absorb the excess heat to the system, vice versa for (b). It can drastically reduce the heating of the module and in-turn increase efficiency by also producing electricity [16].

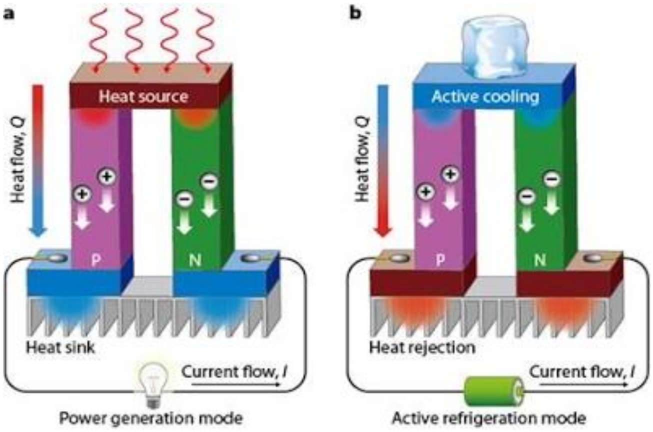


Figure 7. Thermal generators TGE's

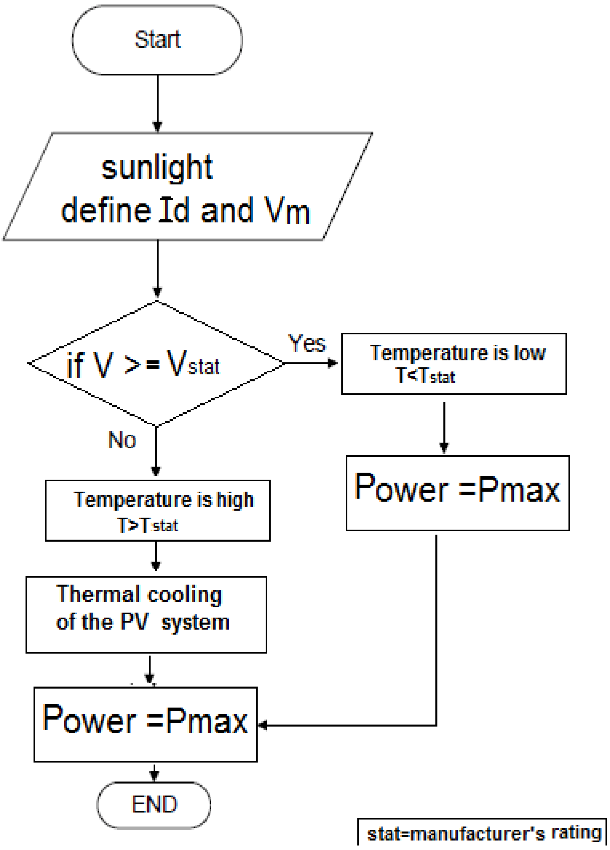


Figure 8. Using thermal cooling

## III. ANALYSIS

### 3.1. ENVIRONMENTAL IMPACTS

With minimal environmental impacts, solar PV systems yield shocking results relative to alternative energy options also in mitigating greenhouse gasses.

Although the production of a solar PV system has a mild impact as the materials and chemicals used in making a semiconductor photovoltaic (PV) are toxic. This include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane, gallium arsenide, copper-indium-gallium-dieseline, cadmium-telluride and acetone.

 

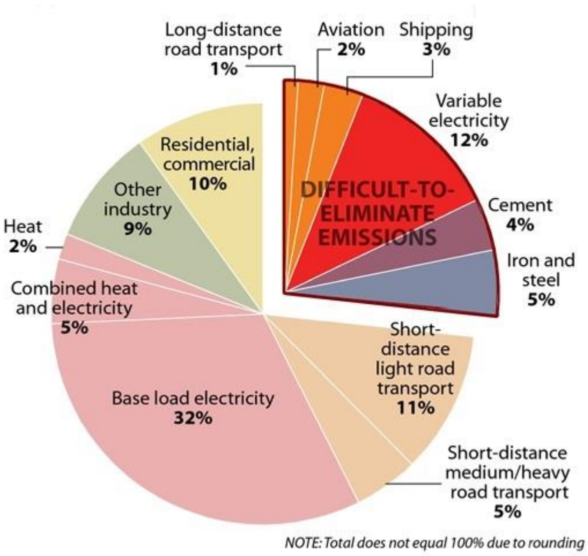

Figure 9. Emissions that are hard to get rid off

The benefit of solar PV system further promotes its relevance referring to Figure (9) which specifies emissive factors that are hard to eliminate. One of which is significant is the based load electricity which further emphasizes the need for an emission-less source of generating electricity. [17].

## IV. METHODOLOGY

With the following we are able to calculate efficiency, temperature, power, energy and area of a PV system and also design a system as desired.

When the temperature of the solar module rises, its current tends to increases exponentially, accordingly the voltage is decreases linearly. Notably the voltage reduction can be used to accurately measure temperature [18].

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

$\eta_t$ : Temperature efficiency in a cell,

$\gamma$ : Power temperature coefficient typically 0.005 for crystalline silicon.

$T_c - T_{stc}$: Temperature of a PV module at standard temp & saturated temperature.

As a result, heat can severely reduce the solar module's production of power.

For the modeling of a solar module we can use the following;

To calculate the series connection:

$$\#\text{ modules in a string} = \frac{V_{array}}{V_{module}} \quad (2)$$

Varray: total voltage needed for the project.
Vmodule: voltage of a single module

Parallel connection:

$$\#\text{ modules in a group} = \frac{I_{array}}{I_{module}} \quad (3)$$

Iarray: total voltage needed for the project.
Imodule: voltage of a single module

$$A.M = \frac{1}{\cos\theta} \quad (4)$$

A.M(air mass) is the direct optical path length through the earth's atmosphere. (4)

$$Energy\ (Wh) = I_{\boldsymbol{irradiance}} \times area \times efficiency \times peakhour \quad (5)$$

In calculating Energy of a solar module or that of an entire array (Eq.5) can be used.

$$power(W) = eff \times I_{irr} \times area \quad (6)$$

$$I_{rradiance(tot)}\left(\frac{W}{m^2}\right) = 1.1 \times 1.353 \times 0.7^{A.M^{0.678}} \quad (7)$$

$$v_{oc} = v_t \times ln\left(\frac{I_{photon}}{I_o}\right) \qquad (V) \quad (8)$$

Voc = open circuit voltage

$$I_{photon} = -I_{oc} = -I_o e^{\frac{v_{oc}}{v_t}} \qquad (A) \quad (9)$$

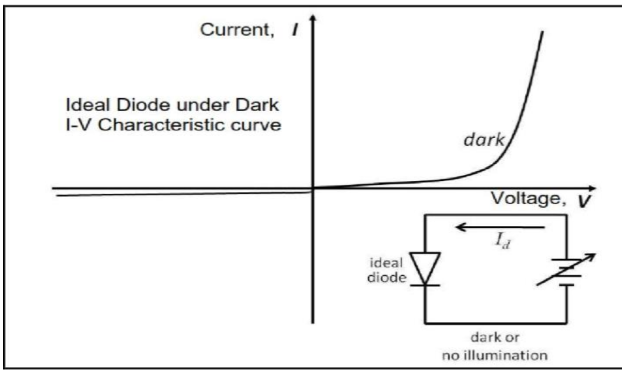

Figure 10. Graph of an Ideal Diode with no illumination and the equivalent circuit (1)

The above on the plotted graph (in figure 10) shows an ideal diode behavior in a PV cell. On the left side labeled the dark region, where we have a negative voltage with a close to zero current in the diode. This behavior occurs when a diode is shaded partially or completely. And on the bottom right of the graph shows an electrical circuit that noted a cut in the source of power to the ideal diode mimicking its behavior on the graph.

The output voltage during shading is given by the equation:

$$V_{SH} = \left(\frac{n-1}{n}\right) * V - \left(I - I_{phshaded}\right) * Rp \quad (V) \quad (10)$$

 

The drop in output voltage while shaded is given by the equation:

$$\Delta V = \left(\frac{V}{n}\right) + \left(I - I_{phshaded}\right) * Rp \quad (V) \qquad (11)$$

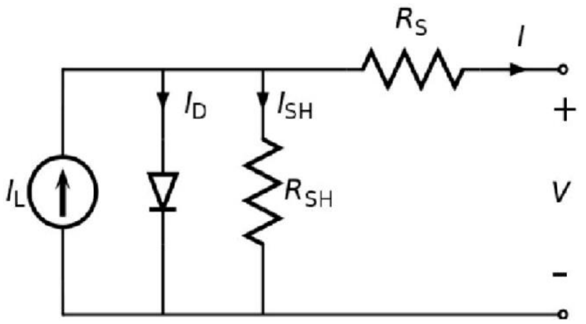


Figure 11. The Equivalent circuit diagram of a PV cell.

Figure (11) above we consider an equivalent circuit of a PV cell, by using the ideal diode formula, we can by increasing the voltage (Vm) decreased the temperature while using appropriate structural materials as discussed earlier.

$$I = I_d = I_{photon} - I_o e^{\frac{vm}{vt}} \quad (A) \qquad (12)$$

Id= I = maximum current (amp) to the diode

Io = reverse saturation current for the diode

Vt = thermal voltage. Where VT = kT/q,
k :boltzmann constant,
T: the temperature expressed in kelvin, and
q : electron charge.

Vm = maximum voltage

Iphoton = the photocurrent delivered

Equation (9) shows the ideal diode or Shockley equation.

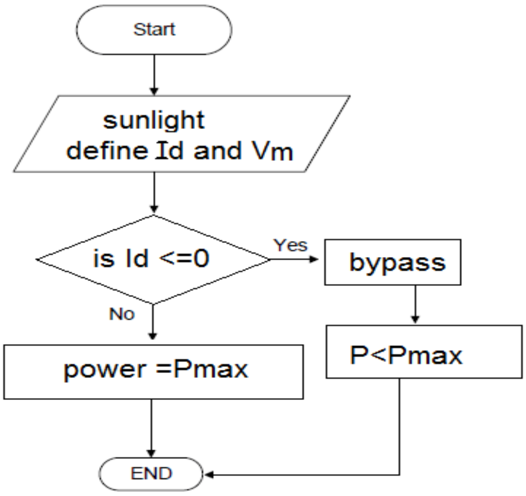


Figure 12. By pass diode flowchart

## V. RESULT AND DISCUSSION

A group of solar PV cells is termed as module. And a collection of modules is termed an array. These modules in an array are arranged in strings and groups depending on the requirements and esthetics considered. A cell is quite small in size, below describes more;

$1cell = 10cm \times 10cm = 100cm^2$
$(200-300)\ watt\ module\ are\ from (1.2\ to\ 2)m^2$

A single cell of 100cm^2 produces voltage in the range of 0.5-0.65 V

Below we calculate the efficiency rating using the manufacturer's data sheet.

Take the maximum peak Power rating (Pmpp) of a module specification is 260Watts = 0.260 kWp (1,000 watts to a kilowatt)

The surface area of the module, in this case we use a module of 1.7m by 1.25m having a surface area of = 2 m^2.

We can get the number of cells in the module to be
(2 m^2/0.01m^2)=200cells

And the power output of each cell will be;

Pcell = 260Wp/200cells= 1.3Wp/Cell

The efficiency rating = kWp / (surface area of the module*Irradiance).

Taking the irradiance for the location to be 1000W/m^2

$$Efficiency\ rating = \frac{0.260KW}{2m^2 \times 1KW/m^2} = 0.13\%\ or\ 13\%$$

Using the above calculations, after considering the voltage and temperature we can determine the efficiency rating of a solar PV system.

**Discussion**
Efficiency of a solar PV system is as a result of how much solar energy is being converted to electricity. This efficiency tends to be affected by some other important measures as listed below [19].

- ***Wavelength***: PV cells respond differently to changes in light wave lengths, thereby producing varying qualities of electricity.
- ***Materials***: with different PV materials, behaviours are different.
- ***Reflection***: as much light that is reflected, the efficiency of the cell decreases.
- ***Resistance***: electrical resistance creates losses due to heat thereby affecting the efficiency.

 

## VI. CONCLUSION

A solar PV system's lack of optimal efficiency has been discussed following factors like; high temperature, angle of irradiation, shading and materials used in production, and so optimal reviews and suggestions have been made following the advent of ideas and methodologies.

"Where there is low efficiency there is room for improvement". After all being reviewed and proposed, it is indeed interesting to know due to the event of solar PV system take over, opportunities presents itself in order to optimize the system. It is therefore an on-going field of research to figure out best and cost effective ways in which it can be optimized. Coming across all plausible methods, it is clear to say that optimization is within reach without compromising the solar PV general integral process of producing electricity [20].

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## AUTHOR'S PROFILE

Okereke Vincent O. Obtained his Bsc in Energy Systems Engineering at Girne American university, TRNC. Currently undergoing postgraduate studies in Electrical Electronics Engineering at Nile University of Nigeria.

Sadiq Thomas is an associate professor and the head of department of Computer engineering department in Nile University of Nigeria. He obtained his bachelor's degree from the University of Brunel, UK, in 2002, and in 2005, he obtained a doctoral degree in Finite Modelling of EMAT from the University of Leeds, UK.

Biliyok Akawu Shekari Dept. of Elect/Elect Engineering Nile University of Nigeria Abuja, Nigeria

Gokhan Koyunlu is a professor in the Dept. of Comp. Engineering Nile University of Nigeria

Jonathan Dangwaran Dept. of Elect/Elect Engineering Nile University of Nigeria Abuja, Nigeria

Hussein U. Suleiman is an associate professor in the Dept. of Elect/Elect Engineering Nile University of Nigeria Abuja, Nigeria

 