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CHARACTERIZATION OF HIGH PENETRATION OF PHOTOVOLTAIC SYSTEM

DIKE, DAMIAN OBIOMA

Senior Lecturer, Department of Electrical and Electronic Engineering, Federal University of Technology, Owerri, Nigeria
E-mail: damian.dike@futo.edu.ng

ABSTRACT

The world is facing an increase in environmental pollution basically as a result of combustion of conventional energy sources. Nigeria currently depends on conventional energy to supply power to her teaming population. Due to this, the energy generated does not meet demand. Consequently, power supply is erratic and areas isolated from the main cities lack power supply. Therefore, the need to develop a non-conventional source of energy generation such as solar cannot be over emphasized. A photovoltaic system that can increase energy output and/or supply power to isolated areas of the country is a good choice, considering the abundance of solar radiated energy in Nigeria. The performance of such system requires a precise knowledge of P-V, I-V and P-I characteristics curves. This work focuses on the simulation of the performance of 60W photovoltaic panel using Matlab/Simulink toolbox so as to characterize these parameters. This model is designed to work either as a standalone PV system or as grid integrated. The developed model may be useful in the prediction of PV cell behavior under different physical and environmental parameters. The result obtained showed the maximum power output and the corresponding maximum voltage of solar module.

Keywords: ***High Penetration, Parameter Characterization, Solar Radiation, Photovoltaic Panel, Maximum Power Output.***

1. INTRODUCTION

Currently in Nigeria, the use of renewable energy is sparingly used to support conventional source of energy, this has led to over reliance on energy generated diesel power plants, dam's powered plants and coal powered plants in Nigeria. Because of this most isolated areas do not have sufficient power or no power at all in cases where the transmission lines are not assessable. A high penetration of solar energy known as photovoltaic (PV) energy in Nigeria will result in Power being evenly distributed to all parts of the country, Reliable power supply, Reduce the rate pollution of the environment, Increase in the amount of power generated in the country, Power supply to isolated areas of the country where it will cost more to build transmission line to such areas.

The intensity of solar radiation reaching earth surface which is 1369 watts per square meter is known as Solar Constant. It is important to realize that it is not the intensity per square meter of the earth's surface but per square meter on a sphere with the radius of 149,596,000 km and with the sun at its center. The efficiency of a PV device is dependent on the spectral distribution of solar radiation. The evaluation of PV devices is generally done with reference to a standard spectral distribution. There are two standard terrestrial distribution defined by the American Society for Testing and Materials (ASTM), direct normal and global AM1.5. The direct normal standard corresponds to the solar radiation that is perpendicular to a plane directly facing the sun. The global corresponds to the spectrum of the diffuse radiations. Radiations which are reflected on earth's surface or influenced by atmospheric conditions are called diffuse radiations. To measure the global radiations an instrument named pyranometer is used.

Solar radiation assessment is a critical activity for setting up solar projects. The quality of the resource also impacts the type of technology which may be used at a specific place for solar power generation. The measurement of this data should ideally be undertaken at the micro level through site specific ground based weather monitoring stations over a period of time (preferred time is between 12 to 18 months). A micro level of assessment is required to assess solar resource attractiveness of the proposed site. This shall include assessment of parameters like

a) Global Horizontal Solar Radiation
b) Diffused Horizontal Solar Radiation

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c) Direct Normal Solar Radiation
d) Wind Speed/Direction
e) Rain Accumulation
f) Air Temperature
g) Atmospheric Pressure (SLP)
h) Relative Humidity

Solar panels produce electricity from sunlight. The first solar panel-powered satellite was launched in 1958 by Hoffman Electronics. A solar panel consists of number of photovoltaic (PV) solar cells connected in series and parallel. These cells are made up of at least two layers of semiconductor material (usually pure silicon infused with boron and phosphorous). One layer has a positive charge; the other has a negative charge. When sunlight strikes the solar panel, photons from the light are absorbed by the semiconductor atoms, which then release electrons. The electrons, flowing from the negative layer (n-type) of semiconductor, flow to the positive layer (p type), producing an electrical current. Since the electric current flows in one direction (Like a battery), the electricity generated is DC.

A photovoltaic array (PV system) is an interconnection of modules which in turn is made up of many PV cells in series or parallel. The power produced by a single module is not enough for commercial use, so modules are connected to form arrays to supply the load. Most PV arrays use an inverter to convert the DC power into alternating current that can power the motors, loads lights etc. the modules in a PV array are usually first connected in series to obtain the desired voltages; the individual modules are then connected in parallel to allow the system to produce more current.

There are huge works, research, thesis, implementation, design consideration and Improvement on solar technologies is going on around the world as well as in our country. That is why we have more than 35 [1] company doing business, implementation and research on solar technologies, University students around the globe working with solar system. Like A group of students of Ahsanullah University of science and technology designed a solar system for their university. A group of students of the Pennsylvania State University has designed and simulated a Distributed photovoltaic system for their university as their thesis. Again Rajamangala University of Technology Thanyaburi of Thailand installed PV system for their university to promote solar energy project. Scientist working on developing the solar panels, like scientist of Korea and California has develop a new way of boosting the efficiency of plastic solar panels [2]. By this they make it more competitive to traditional solar panels. Commercial building's, houses, offices, companies are installing solar system for green energy. Such as the largest solar powered building in Dezhou, Shangdon, Province in northwest China[3].

Various types of mounting of solar panel can be done depending on the location and system. These include pole mounting, ground mounting, building integrated photovoltaic (BIPV) and roof mounting [4, 5]. Pole mounting may be at the top of the pole, pole side or special mounted to continuously change direction in order track maximum sunlight path. Roof mounting is the preferred, but where there is insufficient space at the roof to accommodate the number of panels required, ground mounting may be adopted in residential estates and for few commercial applications in isolated and/or secured places.

BIPV though more expensive, is a unique kind of mounting where the PV modules are placed on the building surface, vertical walls or at the atriums to blend with the building architecture. This makes the house more beautiful; provide shedding for improved cooling system in very hot places as well as protection [5].

Roof mounting is two types - pitched roof mount and flat roof mount. Pitched-roof mounting is difficult because depending in the orientation and angle; proper mounting has to be done. Need to fix the tilt angle for the optimum output. We cannot hope all these categories a roof can match. That is why there are 3 types of roof mounting. They are- Flush mount, Angle mount and Fin mount.

2. PHOTOVOLTAIC SYSTEM DESIGN:

There are three possible configurations of solar PV system. Each of these configurations has its own advantages and disadvantages. System requirements determine which type of system configurations has to be used. In this work, two possible configurations, the first one is grid connected solar PV system without battery and the second one is stand-alone solar PV system with battery. When the demand is high then the system will deliver energy same as a grid connected solar PV system without battery as described. But when the demand is low or in an off day the battery can store energy by solar panel through charge controller. This stored energy can be used as backup for gloomy day or at night.

A typical solar PV system consists of solar panel, charge controller, batteries, inverter and the load.

2.1 Charge Controller

The charge controller is an electronic device whose function protects the battery to avoid overcharging or excessive discharge. When battery is included in a system, the necessity of charge controller comes forward. In a bright sunny day the solar cells produce more voltage that can lead to battery damage.

2.2. Batteries

To store charges batteries are used. Mostly used batteries are nickel/cadmium batteries. There are some other types of high energy density batteries such as- sodium/sulphur, zinc/bromine flow batteries. But for the medium term batteries nickel/metal hydride battery has the best cycling performance. For the long term option iron/chromium redox and zinc/manganese batteries are best, our battery is 32MWh.

2.3 Inverter

The inverters are responsible for transforming the DC electricity from the photovoltaic panels into AC electricity to be sent to each transformer. The same inverters have a microprocessor, responsible for ensuring a sinusoidal wave with minimal distortion. It also incorporates batteries to regulate the power factor according to the needs. Solar panel generates dc electricity but most of the household and industrial appliances need ac current. Inverter converts the dc current of panel or battery to the ac current. We can divide the inverter into two categories. Stand alone and Line-tied or utility-interactive [6-8].

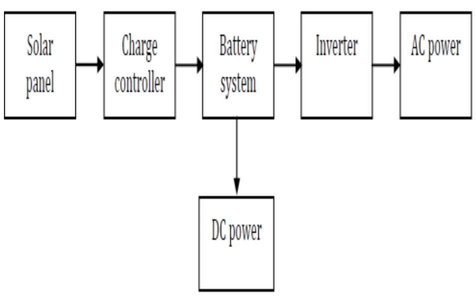

Fig. 1: Block diagram of a typical solar PV system

2.4. System Sizing

We will select the number of PV module can be installed in the selected area. The no. of inverter, combiner box and other equipment's is needed to complete the whole designing. We will also find that.

2.5. Number of Module Selection

The no of module can be accommodate on both roof top and facade can be calculated by the following formula,
No. of module accommodation = Total usable area/area of a selected PV module

2.6. PV Array Design

To design the array there are some parameter to check. The most important thing is to choose proper inverter and combiner box so that, they can withstand the PV modules' voltage and current.

ZONZEN ZZ-ZB 10kW inverter's MPPT voltage range= 100-500 V
SAMSUNG LPC250S module's open circuit voltage =37.6 V
12 module in series = 37.6* 12 = 451.2 V
This is within the inverter's MPPT voltage range. We didn't put more modules due to safety.
Module's maximum power voltage = 30.9 V
Inverter MPPT voltage range: 100-500V.
(100-500V)/12 = 8.33-41.66 (module maximum power voltage = 30.9).
So, power maximum power voltage is in the inverter's voltage range.

ZONZEN ZZ-ZB 10kW inverter's current rating:
Inverter's rated voltage = 360 V
Maximum current: (10000/360) = 27.77 A
At 694.04 W/m2 maximum short circuit current = 6.01 A
If we put 3 parallel string (1 string consist of 12 series module) = 3*6.01 = 18.03 A

We cannot put more string, because if there is rise in a weather condition with low temperature and high isolation excessive current can flow. For safety considering 35% excessive current = 24.34 A

This is also in inverter's capacity SMA SCCB-10 combiner box maximum input fuse rating = 600 V, 20A
This is also can withstand 3 parallel string each consist of 12 series modules. Therefore, our chosen PV array design is 3 parallel strings of each consist of 12 series modules for 1 combiner box and 1 inverter. As we need to arrange 492 modules we need 14 configurations.

2.6.1. Number of inverter calculation

No of inverter = Total no of module / (no. of module in series in a string*no. of parallel string) = 492 / (12*3) = 13.66 approximately 14.
We will need combiner box is equal to the number of inverter. So, we will need 14 combiner boxes.

2.6.2. Wiring arrangement

Rated short circuit current is 8.66 A from the PV module. If there is an effect of higher insolation and lower temperature access current can flow. To prevent these to happen the safety factor is considered. Average isolation at Owerri city is 694.04 W/m2. Therefore, maximum short circuit current will be = 6.01 A
For 3 parallel string = 3*6.01 = 18.03 A
Considering 35% safety factor Maximum current rating is 25 A. So, we have chosen 25A rating wiring.

2.6.3. Photovoltaic system and energy storage

The main benefit of integrating storage with renewable energy is the capability of shifting the peak demands using charging/discharging (charging when the excess electricity

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is stored, discharging when there is a peak demand). The storage can be charged from the renewable sources or from the grid. The demand on the grid can be met with the renewable sources (wind, solar) or energy storage or both.

The other benefits are [9]:
a. Mitigation of short-term solar power intermittency and wind gust effects and minimizing its impacts on voltage, frequency, and power fluctuations in power system.
b. Lowering the transmission and distribution costs by increasing the confidence in renewable distributed generation.
c. Improving power system stability and reduction of harmonics.

2.6.4. Characteristics of Energy Storage System

Energy storage plays a crucial role not only in maintaining system reliability but also in insuring energy efficiency and power quality. The functions of an energy storage system vary from its applications. The role of storage in power system determines the size and type of storage used. The problem is to analyze the domain of application of the storage system. With an appropriate choice of storage parameters, the storage unit may be used as multifunctional device, able to solve a wide number of problems. The combination of storage with storage connected PV system is beneficial.

There are different applications that an energy storage system can fulfill:
• Generation capacity deferral
• Frequency control
• Integration with renewable generation
• Load leveling
• Transmission line stability
• Distribution facility deferral
• Transit system peak
• Reliability, power Quality, uninterruptible power supply

3. SOLAR PHOTOVOLTAIC DESIGN METHODOLOGY

Since analytical technique was used, the design methodology involved (a) mathematical modeling, (b) algorithm and flowchart development and (c) implementation in MATLAB/Simulink environment.

3.1. Mathematical Modeling

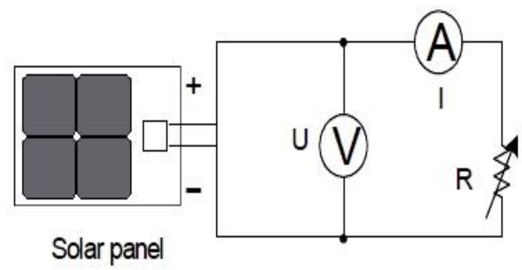

Fig. 2 Generalized panel equivalent circuit

With reference to the circuit in Figure 2 for a generalized panel equivalent circuit, the I-V characteristics of solar cell can be expressed in terms of physical and electrical parameters by the following mathematical expressions.

The most general formulation of the energy equation for an open system under steady state assumption, using the first law of thermodynamics can be written as in equation (1):

$$E_{in} - E_{out} = E_{loss} \quad (1)$$

The equation is a general equation for the energy balance: Enout is the maximum amount of energy that can be obtained from a system whose supplying energy is Enin: the smaller the energy consumed, the smaller the energy loss. A solar cell's energy conversion efficiency is the percentage of power converted (from absorbed light to electrical energy) and collected, when a solar cell is connected to an electrical circuit. Energy efficiency of the solar PV can be defined as the ratio of power output to energy input of the solar PV.

The output power and energy efficiency of the PV system, however, fluctuates depending on solar isolation and surface temperature. The energy conversion efficiency of the solar PV (ηenergy) is calculated from equation (2):

$$\eta_{energy} = (V_{oc} * I_{sc} * FF)/(A * G) \quad (2)$$

The current-voltage characteristics of the electric circuit of solar cell can be described by the following simplified equation.

$$I = I_1 - I_0 * \exp[(q*(V-IRs))/(A*K*T)] \quad (3)$$

The electric power output of PV is: $P_{el} = I \times V$ (4)

Maximum output power is given by:

$$P_{max} = V_{OC} \times I_{SC} \times FF = V_{mp} \times I_{mp} \quad (5)$$

The solar energy absorbed by the PV modules is converted to electric energy and thermal energy, which is

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dissipated, by convection, conductive, and radiation. The rate of the heat transfer process depends on the design of the PV system. To achieve the efficiency of a PV module its operating temperature TC must be determined which is for simplicity could be assumed homogenous on the plate and it is depends on the ambient conditions. The higher surface temperature could cause reduction in PV efficiency. Therefore, the cells may be cooled artificially by passing air or water on the backside of the module especially in the hot region. A dynamic thermal model proposed by Duffie and Beekman, included a lump overall loss coefficient UL for a unit area.

3.2. Analysis of energy efficiency of solar panel

Energy analysis includes a consideration of energy quality or capability, which permits evaluation of the most effective, not just most efficient, use of energy potential. For the steady-state flow process during a finite time interval, the overall energy balance of the solar PV can be written as follows.

Energy Input = Energy Output + Energy Loss + Irreversibility (6)

This degradation in the quality of energy is called energy loss (availability loss). The energy loss is also called irreversibility the solar radiation emitted by the solar cells translated by two ways; Electrical and Thermal.

The electrical energy is utilized and it is considered as "Electrical Energy"

The thermal energy is dissipated to the ambient as a heat loss, it becomes energy destruction.

Energy efficiency of the photovoltaic module is also defined as the ratio of total output energy to total input energy

$\eta_E = (E_{output})/(E_{input})$ (7)

Inlet energy of a PV system includes only solar radiation intensity energy.

$E_{in} = AG\,[1 - 3/4\,(Ta/Ts) + 1/3\,(Ta/Ts)\,4]$ (8)

The energy output of the photovoltaic system can be calculated as outlet energy for a PV system includes thermal Energy and Electrical Energy.

$E_{out} = E_{thermal} + E_{electrical}$ (9)

The Thermal energy is given as:

$E_{thermal} = Q\,[1 - T_a/T_m]$ (10)

Where Q = UA(Tm - Ta)

Overall heat loss coefficient of a PV module includes convection and radiation losses

$U = h_{conv.} + h_{rad}$ (11)

Convective heat transfer coefficient is given as:

hconv. = 2.8 + 3Vw (12)

Radiactive heat transfer coefficient between PV array & surroundings are computed as:

hrad = Ɛσ (Tsky +Tm)(Tsky2 + Tm2) (13)

Effective temperature of the sky

Tsky = Ta – 6 (14)

Temperature of the module can be calculated on the base of NOCT value.

Tm = Ta + (NOCT - 20)G/800 (15)

Electrical Energy in the output electrical power of PV module

En Electrical = Voc * Isc * FF (16)

Band Gap Energy is given as:

Eg = Ego – (alpha*T*T)/(T+beta)*q (17)

Photocurrent is computed using:

Iph = [(Iscr+Ki(TTrefK))](s/100) (18)

Saturation Current

The saturation current of the solar photovoltaic cell can be expressed as Irs:

Irs = Irr(T/TrefK)3exp(q.Eg(1/TrefK – 1/T)/(K.A)) (19)

Output Current

The output current of the solar photovoltaic cell can be expressed as Io

Io = Np*Iph±Np*Irs*(exp(q/(K*T*A)*Vo/Ns) – 1) (20)

Power

The output power of the solar photovoltaic cell can be expressed as in equation (21):

Po = Vo*Io (21)

Solar Radiation S(t) is computed using equation (22):

S(t) = Smax [exp – (t – tc)/ 2σ2] (22)

Maximum Power is given by equation (23) as:

Pmax = Vmax * Imax = Voc.Isc.FF (23)

Ideality constant of different PV technology is presented in Table 1

Table 1: Factor A dependence on PV technology [10]

Technology	A
Si-mono	1.2
Si-poly	1.3
a-Si;H	1.8
a-Sr;H tandem	3.3
a-Sr;H triple	5
Cd;Te	1.5
CIS	1.5
AsGa	1.3

4. IMPLEMENTATION

4.1. Algorithm

i. Input T(k) – Varied temperature
ii. Initialize variables
iii. Input data's **-**
iv. Counter for B = 5 and I = 1 for I = 1:5
v. Compute Band gab energy
vi. Compute photocurrent
vii. Compute saturation current
viii. Compute output power

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ix. Calculate I = i +1 and B = i – 1, if B ≠ 0 return to step 5. If B = 0 move to step 10
x. Output result and end

4.2. Requirement for Implementation

To implement the proposed solar PV system for the University estate/small village, we need to have a clear concept of the implementation cost.

Table II: Approximate component cost calculation [10]

After doing calculation the total cost stands around 608670.476 USD.

4.3. Implementation in Matlab/Sumulink Environment**.**

A block diagram of the functional PV model based upon the equations is represented in Simulink

Component	Description	Quantity	Cost
PV module	Samsung LPC250S	492	350,116,056$
Inverter	ZONZEN ZZ-ZB10kw	14	42,000$
Combiner box	SMA SCCB – 10	14	6790$
Surge arrester	-	14	1,200$
Lightning Rod	-	2	200$
Mounting	-		31428.57$
Meters	-		30$
Wiring	-		3000$
Transportation, installation, LC, maintenance	40% of all costs		173,905.85$
Total Cost			608670.476$

In this regard, we computed approximate cost in USD for each component is presented in Table II. These components are: PV modules, inverters, combiner boxes, surge arrestors, lightning rod, mounting, meters and wiring. also we have to consider the transportation, installation, and LC and maintenance costs.

environment. Figure 3 in the appendix shows the implementation flowchart, while Figure 4 is the simulation Matlab/Simulink module for obtaining the module characteristics with different irradiances and temperature.

This circuit is built to illustrate and verify the non - linear I-V output characteristics of PV module. The PV system is modeled to supply power to the load. Energy production in twenty five years in kWh is 735.3*25*365 which gives $6709612.50. The cost per unit of energy produced in twenty five years is 608670.476/6709612.5= 0.0907.
So we may be able to generate per unit of energy at $0.0907 or (0.0907*70)TK=6.350TK.

We consider our proposed PV system life is 25 years. So, the cost per unit of energy by the designed system will be the total cost of the system as $608670.476

4.4. Simulation

Two different types of simulation are performed
i. Varying irradiance (1000W/m2, 800W/m2, 600W/m2, 400W/m2, and 200W/m2) and constant temperature.
ii. Varying temperature (25° C, 30° C, 35° C, 40° C, 45° C)

5. RESULT AND DISCUSSION

Figure 5, 6, 7, 8, 9, 10(a) and 10(b) shows the simulation results of I-V, P-V, P-I characteristics for the above two conditions. It is very clear that current generated increases with increasing solar irradiance and maximum output power also increases. On the other hand voltage is staying almost constant and it is not varying much. Similarly with increase in cell temperature the short circuit current of the P-V module increases whereas the maximum power output decreases. The results thus confirm the non-linear nature of P-V module. The simulation results obtained are identical with the curves given by the manufacturer.

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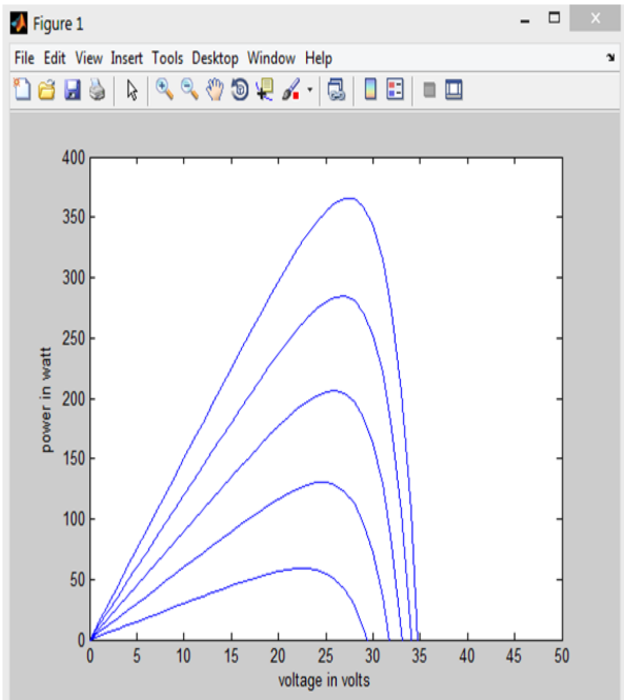

Fig. 5 P-V Characteristics of a solar PV Module at different insulation level.

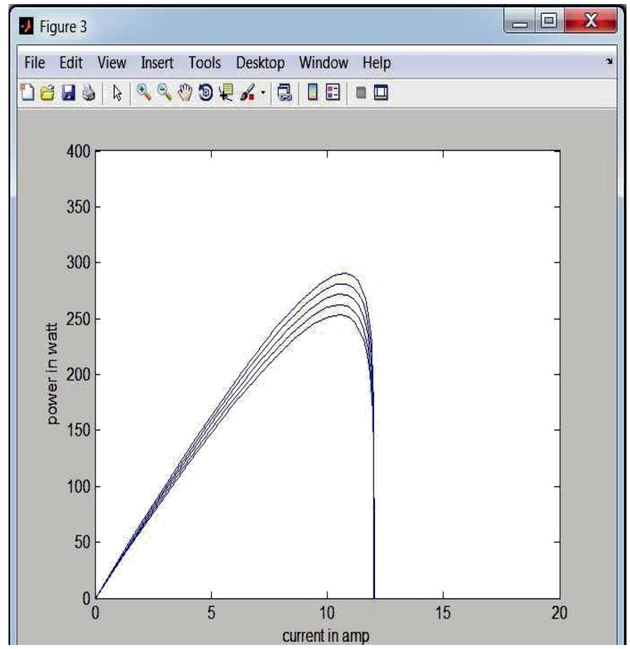

Fig. 7 P-I Characteristics of solar PV module at different cell temperature

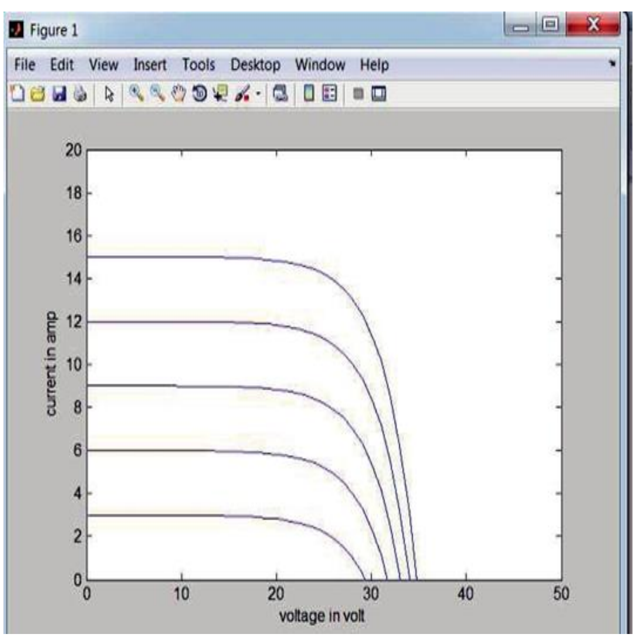

Fig. 6 V-I Characteristics of a PV Module at different insulation level.

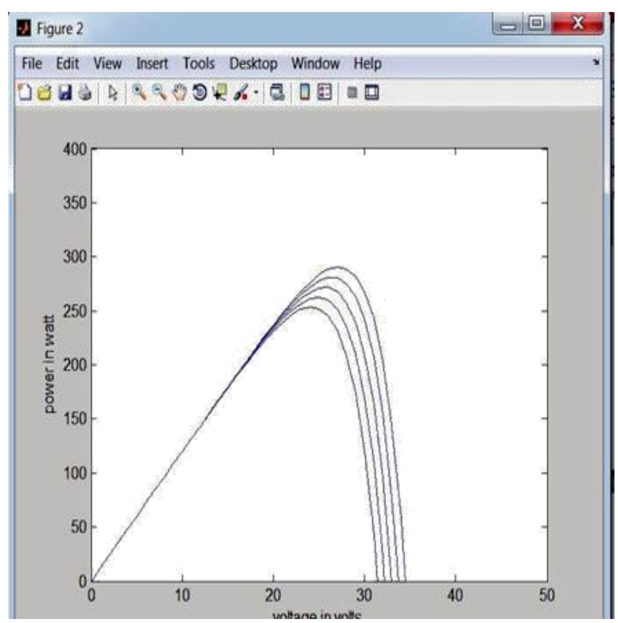

Fig 8 P-V Characteristics of a PV Module at different cell temperature

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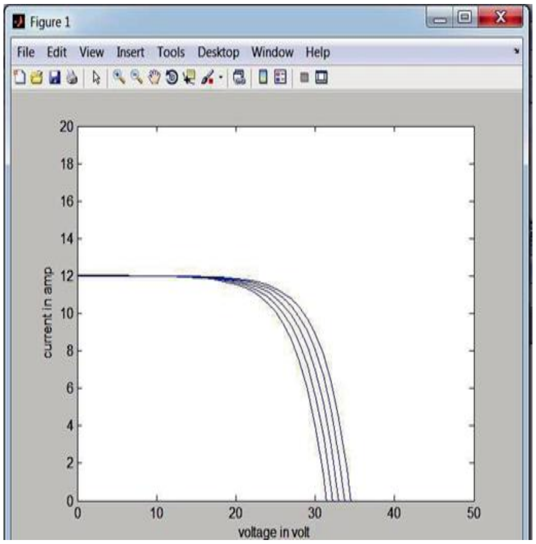
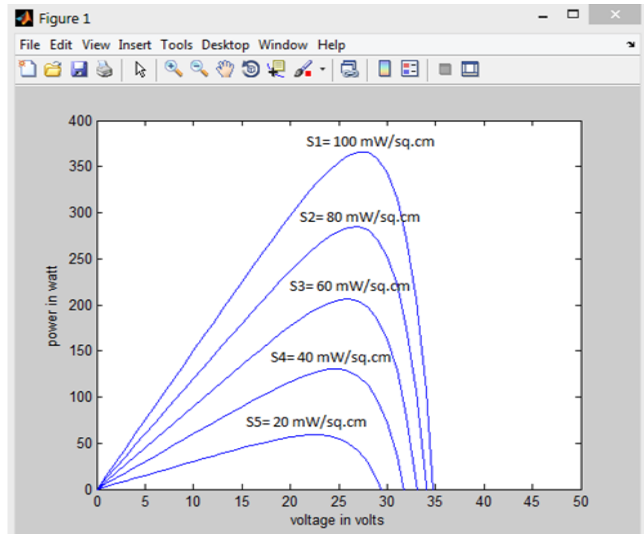


Fig 9 V-I Characteristics of solar PV module at different cell temperature.



10 (b) P-V Characteristics for different insolation values.

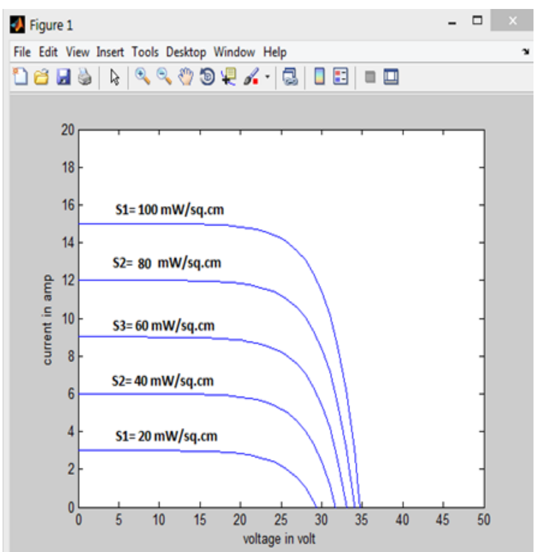


Fig 10 (a) I-V characteristics for different isolation values.

6. CONCLUSION

The full mathematical models for PV array modules have been fully developed including the inherently nonlinear I-V characteristics and variations under ambient temperature and solar irradiation conditions.

The stand-alone renewable photovoltaic simulated and validated using the MATLAB/Simulink software environment.

The proposed low cost stand-alone renewable photovoltaic energy utilization schemes is suitable for resort/village/estate electricity application in the range of (1500 watts to 50000 watts), mostly for water pumping, ventilation, lighting, irrigation and village electricity use in arid remote or isolated communities.

We are facing fuel shortage for electricity generation and in the near future the whole world going to face the same scarcity because of world's limited fuel stock. So worldwide renewable energy demand and research are rising and our government also taking steps for green energy. So, we choose solar energy for a University estate as secondary energy source.

The developed model has been used for energy yield determination based on the experimental data of solar insolation. The energy yield of solar module in one day from 8:05 a.m. to 5:00 p.m. is simulated under Nigeria climatic condition. This is to find out the maximum power and energy yield that can be obtained from the PV module for the given surface area. This calculation helps to determine the size of the PV system in the outdoor condition more precisely. The energy yield can be estimated as

$Ey = 1/60\ \Sigma\ Pmax$

Where Ey represents energy yield and Pmax is maximum power evaluated from the proposed model. The energy yield of the solar module based on the proposed model was determined to be 2564 Whr/day. The annual energy yield from the PV system based on 250 days of sunshine hours was estimated to be 641 KWhr.

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APPENDIX 1: IMPLEMENTATION FLOWCHART

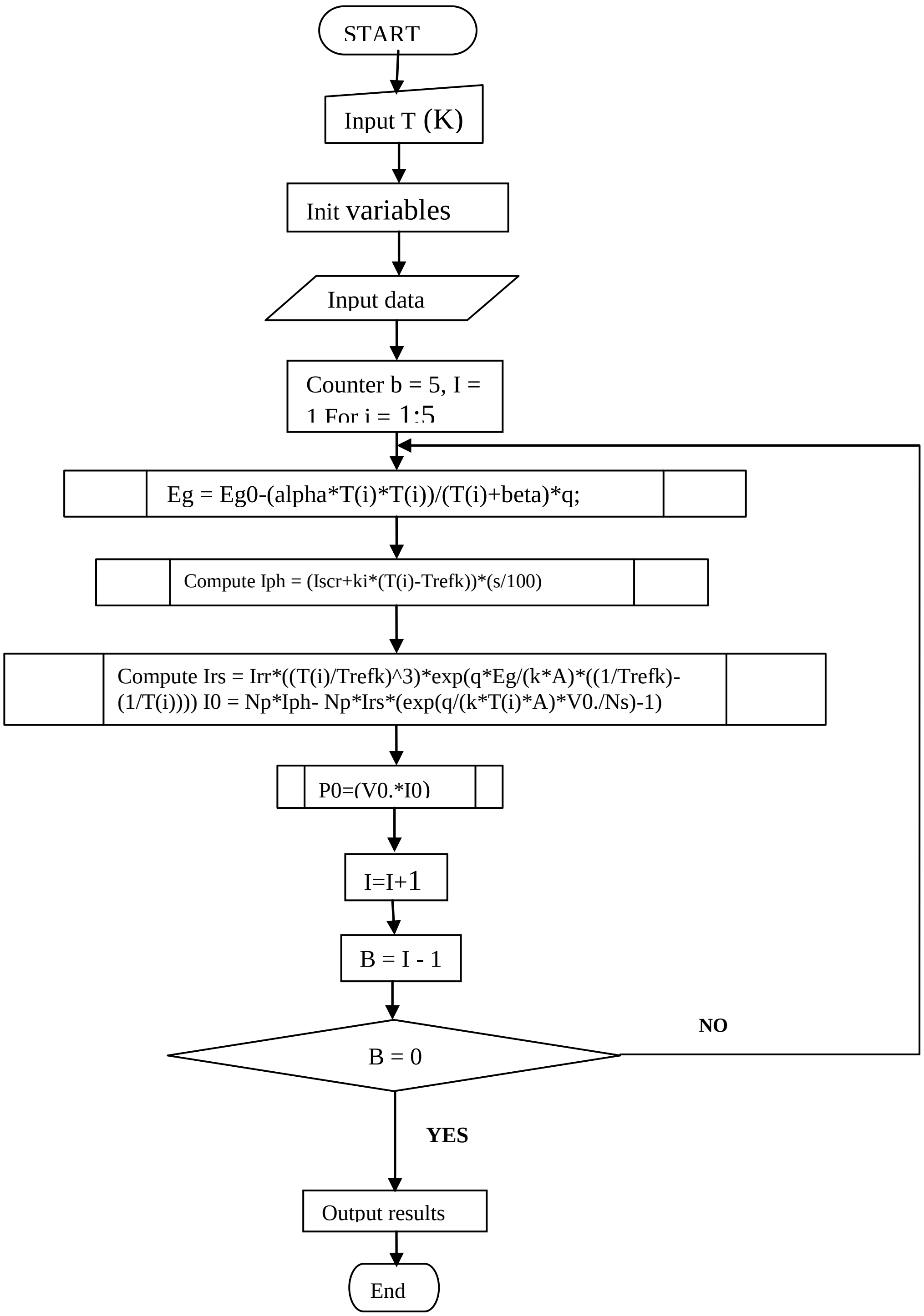

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FIG 3: IMPLEMENTATION FLOWCHART

APPENDIX II :

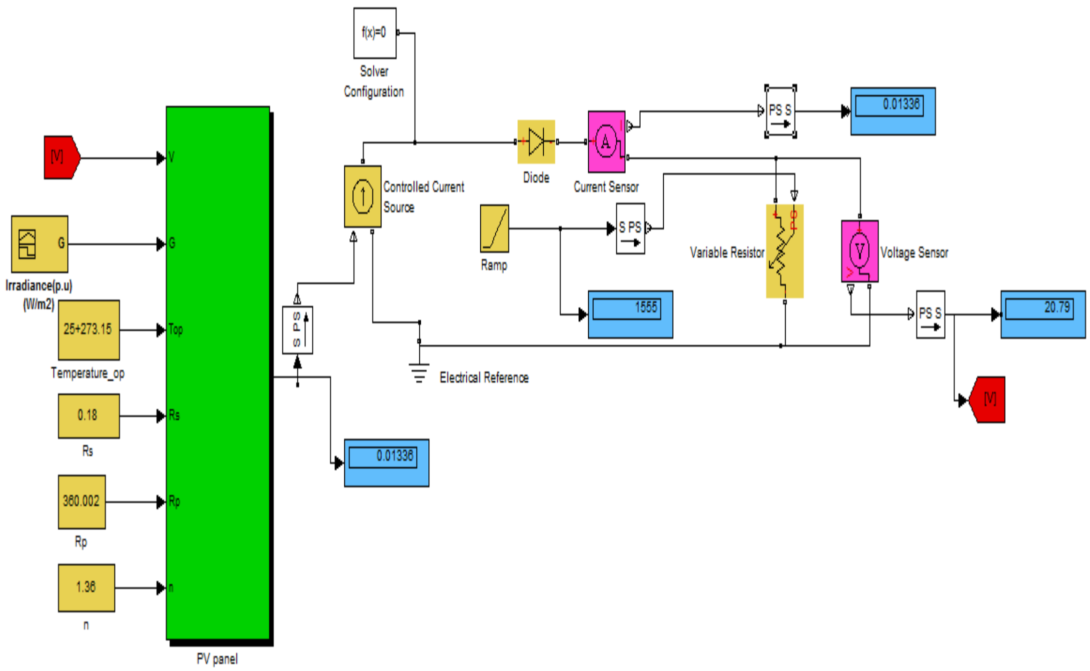

Fig 4: SIMULINK model of photovoltaic array