IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

“Solar Cell Parameter Extraction”

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Abstract: To develop precise solar cell simulators or design a high-performance photovoltaic generation system, it is important to accurately understand the physical properties of solar cells. However, solar cell models have a non-linear form with numerous parameters.

To obtain accurate parameter values, assumptions that differ from real operating conditions must be made to avoid computational complexity. In this paper, a new method for extracting parameter values is proposed. The proposed method deduces the characteristic curve of an ideal solar cell without resistance using the I–V characteristic curve measured and reported by solar cell manufacturers and calculates the difference between the deduced and actual measured curves. In addition, the precision of the proposed method is demonstrated by calculating the correlation between the I–V characteristic curve based on modeling parameters and the I–V curve actually measured employing the least-squares method.

1. Introduction

Today the demand of electricity is a crucial problem all over the world due to increasing population, industrial demands and digital technology developments. Renewable energy (RE) resources play a prominent role in the satisfaction of the electricity demand. Solar, hydel, wind, geothermal and tidal energies are some renewable energy sources. Out of these, solar energy is the most significant system due to its reliability, clean and harmless emissions to the environment. The low conversion efficiency of solar PV module has triggered a constantfocus for the improvement of its conversion efficiency in the name of maximum power point tracking (MPPT) with the help of the parameter extraction process

Among existing methods to extract solar cell parameters, a relatively simple method is to estimate series and shunt resistances of solar cells using the slope of the current–voltage (I–V) curve at the point of open circuit voltage and short circuit current, respectively.

Solar cell parameter extraction is a crucial aspect of analyzing the performance of photovoltaic devices. By accurately determining the parameters of a solar cell, researchers and engineers can understand how the cell operates and identify areas for improvement. In this report, we will explore the various methods used to extract solar cell parameters, including the current-voltage (IV) curve, the external quantum efficiency (EQE), and the capacitance-voltage (CV) measurement. We will also discuss the significance of each parameter and how they can be used to optimize solar cell performance. By the end of this report, you will have a comprehensive understanding of the various techniques used to extract solar cell parameters and how they can be applied to improve the efficiency and reliability of photovoltaic devices.

The ideality factor was found using characteristics of the diode obtained from the I–V curve of a solar cell, and the reverse saturation current was calculated from a solar cell equation that neglected resistance. The values were substituted into the solar cell equation to give ideal I–Vcurve data with no resistance. Values of series and shunt resistances were determined by calculating the difference between the ideal curve and measured curve. The correlation between the I–V curve drawn using final parameter values and the measured I–V curve.

2.1 Solar cell model

2. Theory

The model of the solar cells for which the superposition principle is applicable can be represented by the equivalent circuit in Fig. 1 and expressed as Eq. (1) which includes light- generating current source (Iph), series resistance (Rs) and shunt resistance (Rsh) of diode with the diode equation shown by Eq. (2).

I=Iph-Isat(exp(q(V+IRs)/Nsnkt-1)-V+IRs/Rsh …(1)

Id=Isat(Exp.qVd/nKt-1) ...(2)

Isat is the reverse saturation current, n the quality factor, k the Boltzmann's constant, T the absolute temperature, q the electron charge, Ns is the number of cells in series. Measurement data provided by the manufacturer include the I–V curve, open circuit voltage (Voc), short circuit current (Isc), and voltage (Vmpp), current (Impp), and power (Pmax) at the maximum power point (MPP), measured at 25C under a standard AM 1.5 solar spectrum and irradiation of 100 mW/cm2. To establish the singular diode solar cell model in Eq. (2), four parameters of the solar cell equation—Rs, Rsh, n, and Isat—must be extracted using data provided by the manufacturer.

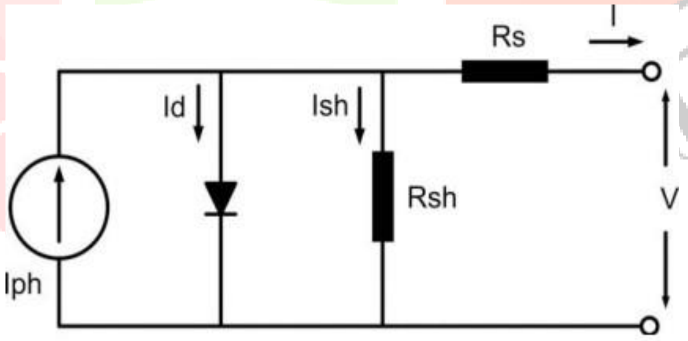


Fig. 1. Equivalent circuit model of the solar cell.

2.2 Solar cell operation

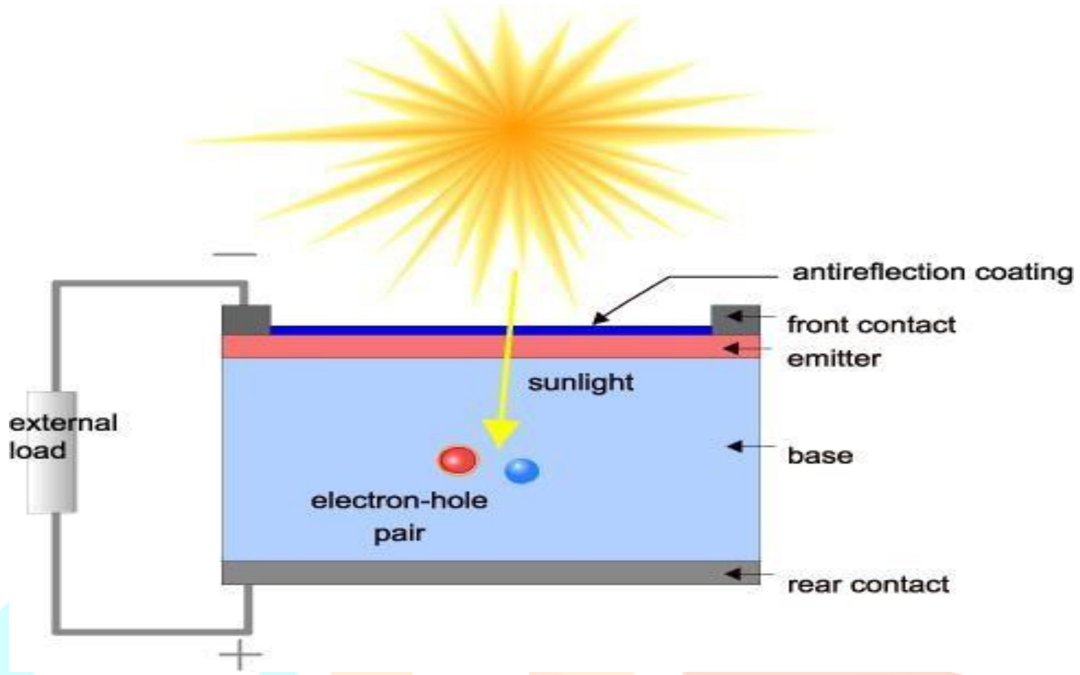
A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higherenergy state, and secondly, the movement of this higher energy electron from the solar cell intoan external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a *p-n* junction.

The basic steps in the operation of a solar cell are:1)the generation of light-generated carriers;

2)the collection of the light-generated carries to generate a current;3)the

generation of a large voltage across the solar cell; and

4)the dissipation of power in the load and in parasitic resistances.



2.3 Solar cell parameter

2.3.1 Ideality factor

The ideality factor is an important parameter used in solar cell characterization to determine the efficiency and performance of the device. It represents the deviation of the solar cell's behavior from the ideal Shockley-Queisser model, which assumes perfect recombination and absorption of charge carriers within the device.

The ideality factor is typically extracted from the dark current-voltage (I-V) characteristics of the solar cell, which is measured when the device is not exposed to light. The ideality factor can be calculated using the diode equation:

$I = I0(\exp(qV/kT) - 1)$

where I is the current through the device, I0 is the reverse saturation current, q is the elementary charge, V is the voltage across the device, k is the Boltzmann constant, and T is the temperature.

The ideality factor, n, is then extracted from the slope of the semi-logarithmic plot of I versus V, using the equation:

$n = \ln(I1/I2) / \ln(V1/V2)$

where I1 and I2 are the currents at two different voltages, V1 and V2, respectively.The idealityfactor provides insight into the recombination mechanisms and quality of the solar cell material. A lower ideality factor indicates less recombination and a more efficient device. Typically, a value of 1 is assumed for an ideal solar cell, while real-world solar cells have ideality factors ranging from 1 to 2.5

2.3.2 Series resistance

Series resistance is an important parameter in solar cell characterization, which affects the performance and efficiency of the device. It is the resistance that exists between the metal contact and the p-n junction in a solar cell. Series resistance causes a voltage drop across the device, which reduces the output voltage and power of the solar cell.

The effect of series resistance can be seen in the I-V characteristics of the device. At high currents, the voltage drop across the series resistance becomes significant, leading to areduction in the output voltage. This effect is more pronounced in high-efficiency solar cells with low saturation currents.

Series resistance can be extracted from the I-V characteristics of the solar cell using the following equation:

V = Voc - IR_s - I_diodeRswhere V is the voltage across the solar cell, Voc is the open-circuit voltage, I is the current through the device, R_s is the series resistance, and Idiode is the diode current. The series resistance can be obtained by fitting this equation to the I-V data.

The presence of series resistance affects the fill factor (FF) and the maximum power output ofthe solar cell. The FF is reduced due to the voltage drop across the series resistance, while the maximum power output is reduced due to the decrease in the output voltage. Therefore, it is important to account for the series resistance when evaluating the performance of a solar cell.

In summary, series resistance is an important parameter in solar cell characterization that affects the performance and efficiency of the device. It can be extracted from the I-V characteristics of the solar cell and should be considered when evaluating the device's performance.

2.3.3 Shunt resistance

Shunt resistance is another important parameter in solar cell characterization that can affect the performance and efficiency of the device. It is the resistance that exists in parallel with the p-n junction in a solar cell. Shunt resistance allows a small amount of current to flow around the p-n junction, which can reduce the efficiency of the device.

The effect of shunt resistance can be seen in the I-V characteristics of the solar cell. At low currents, the voltage drop across the shunt resistance becomes significant, leading to areduction in the output voltage. This effect is more pronounced in high-efficiency solar cells with high open-circuit voltages.

Shunt resistance can be extracted from the I-V characteristics of the solar cell using the following equation:

I = Iph - I0(exp(qV/kT) - 1) - (V/Rsh)

where I is the current through the device, Iph is the photocurrent, I0 is the reverse saturation current, q is the elementary charge, V is the voltage across the device, k is the Boltzmann constant, T is the temperature, and Rsh is the shunt resistance. The shunt resistance can be obtained by fitting this equation to the I-V data.

The presence of shunt resistance can reduce the efficiency of the solar cell by allowing a small amount of current to bypass the p-n junction. This can lead to a reduction in the fill factor (FF)and the maximum power output of the device. Therefore, it is important to account for the shuntresistance when evaluating the performance of a solar cell.

In summary, shunt resistance is an important parameter in solar cell characterization that can affect the performance and efficiency of the device. It can be extracted from the I-V characteristics of the solar cell and should be considered when evaluating the device's performance.

2.3.4 Photon current

In solar cell parameter extraction, photo current is an important parameter that characterizes the performance of a solar cell. Photo current refers to the current that is generated by the absorption of photons in the semiconductor material of the solar cell.

To extract the photo current, the solar cell is illuminated with a known light source at different intensities, and the resulting current is measured. The data is then plotted on a graph of current versus voltage, called the IV curve. By analyzing the IV curve, the photo current can be determined.

The photo current is an important parameter because it provides information about theefficiency of the solar cell in converting light into electrical power. A higher photo current indicates a more efficient solar cell, as more of the absorbed photons are being converted intoelectrical power.

In addition to the photo current, other important parameters that can be extracted from the IV curve include the open circuit voltage, short circuit current, fill factor, and series resistance. These parameters are used to optimize the design and performance of the solar cell for specific applications.

The photo current in a solar cell can be determined from the following equation: Iph =

Isc - Id

2.3.5 Saturation current

In solar cell parameter extraction, saturation current is an important parameter that characterizes the behavior of a solar cell in the absence of light. Saturation current, also knownas the reverse leakage current or dark current, refers to the current that flows through the solar cell in the absence of light when a voltage is applied to the cell.

To extract the saturation current, the solar cell is placed in a dark environment and a voltage is applied to the cell. The resulting current is measured and plotted on a graph of current versus voltage, called the dark IV curve. The saturation current can be determined by analyzing the dark IV curve at low voltages, where the current is dominated by the reverse leakage current.

The saturation current is an important parameter because it provides information about the quality of the semiconductor material in the solar cell. A lower saturation current indicates a higher quality material, as less current is flowing through the cell in the absence of light.

In addition to the saturation current, other important parameters that can be extracted from the dark IV curve include the diode ideality factor, which describes the behavior of the solar cell at high voltages, and the series resistance, which describes the resistance in the electrical path of the solar cell. These parameters are used to optimize the design and performance of the solar cell for specific applications

The saturation current in a solar cell can be determined from the following equation: I0 =

Is*(exp(qV/kT) - 1)

3.1 Introduction

A PV module consists of individual solar cells electrically connected together to increase their power output. They are packaged so that they are protected from the environment and so that the user is protected from electrical shock. However, several aspects of PV module design which may reduce either the power output of the module or its lifetime need to be identified. The following chapter will examine how solar cells are encapsulated into PV modules and examines some of the issues which arise as a result of interconnection and encapsulation.

The most important effects in PV modules or arrays are:

1)losses due to the interconnection of mismatched solar cells;2)the

temperature of the module; and

3)failure modes of PV modules.

3.2 Module structure

A PV module consists of a number of interconnected solar cells encapsulated into a single, long-lasting, stable unit. The key purpose of encapsulating a set of electrically connected solar cells is to protect them and their interconnecting wires from the typically harsh environment in which they are used. For example, solar cells, since they are relatively thin, are prone to mechanical damage unless protected. In addition, the metal grid on the top surface of the solar cell and the wires interconnecting the individual solar cells may be corroded by water or water vapor. The two key functions of encapsulation are to prevent mechanical damage to the solar cells and to prevent water or water vapor from corroding the electrical contacts.

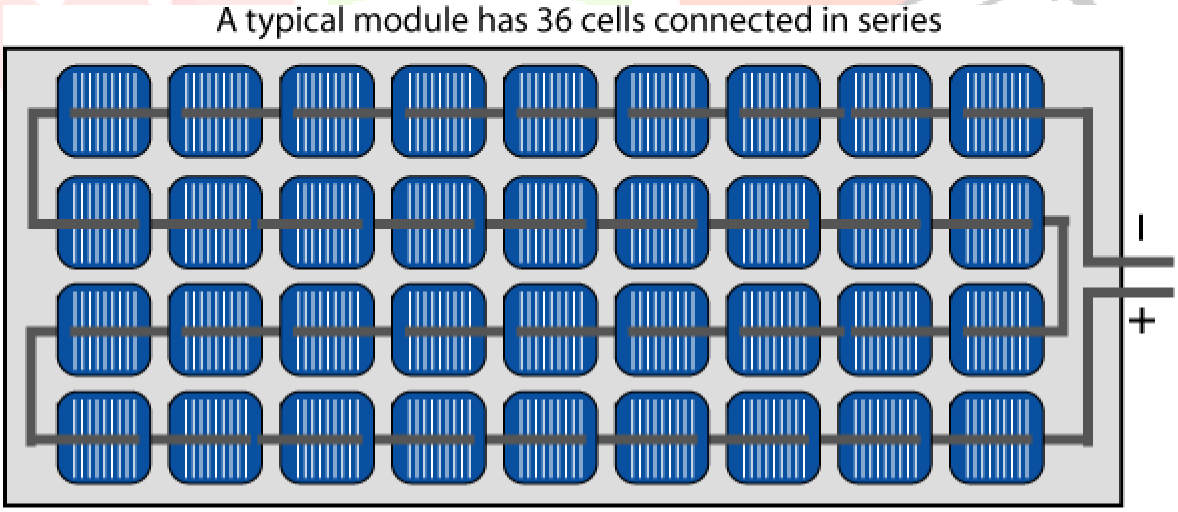
Many different types of PV modules exist and the module structure is often different for different types of solar cells or for different applications. For example, amorphous silicon solarcells are often encapsulated into a flexible array, while bulk silicon solar cells for remote power applications are usually rigid with glass front surfaces.

The most common modules have either 60 cells or 72 cells with three bypass diodes. 60 cell modules were originally designed for ease of handling in residential applications and heavier 72 cell modules for large utility installations where cranes and hydraulic lift are available. However, it is quite possible to use 72 cell modules in residential installations so long as the rest of the system is designed to handle the large size.

Module lifetimes and warranties on bulk silicon PV modules are over 20 years, indicating the robustness of an encapsulated PV module. A typical warranty will guarantee that the module produces 90% of its rated output for the first 10 years and 80% of its rated output up to 25 years. A third party reinsurance company ensures these warranties are valid in the event the manufacturer goes bankrupt.

3.3 Module circuit design solar cell has a voltage at the maximum power point around 0.5V under 25 °C and AM1.5 illumination. Taking into account an expected reduction in PV modulevoltage due to temperature and the fact that a battery may require voltages of 15V or more to charge, most modules contain 36 solar cells in series. This gives an open-circuit voltage of about 21V under standard test conditions, and an operating voltage at maximum power and operating temperature of about 17 or 18V. The remaining excess voltage is included to account for voltage drops caused by other elements of the PV system, including operation away from maximum power point and reductions in light intensity.

A bulk silicon PV module consists of multiple individual solar cells connected, nearly always in series, to increase the power and voltage above that from a single solar cell. The voltage of a PV module is usually chosen to be compatible with a 12V battery. An individual silicon

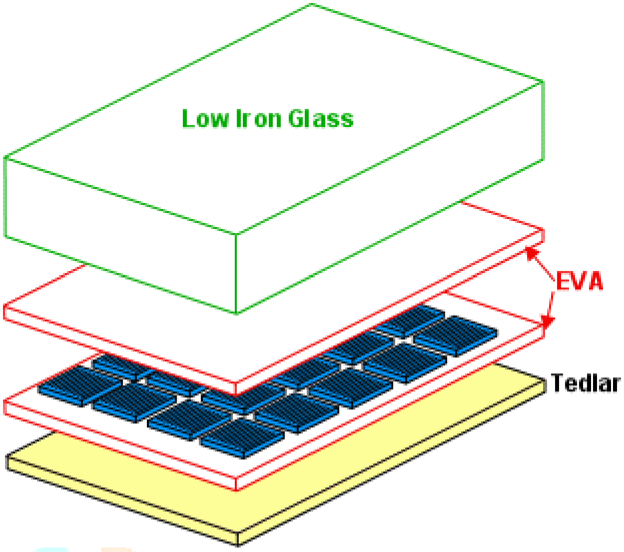


In a typical module, 36 cells are connected in series to produce a voltage sufficient to charge a12V battery.

The voltage from the PV module is determined by the number of solar cells and the current from the module depends primarily on the size of the solar cells. At AM1.5 and under optimum tilt conditions, the current density from a commercial solar cell is approximately between 30 mA/cm2 to 36 mA/cm2. Single crystal solar cells are often 15.6 × 15.6 cm2, giving a total current of almost 9 – 10A from a module.

3.4 Module materials

Most PV bulk silicon PV modules consist of a transparent top surface, an encapsulant, a rear layer and a frame around the outer edge. In most modules, the top surface is glass, the encapsulant is EVA (ethyl vinyl acetate) and the rear layer is Tedlar, as shown below.



3.4.1 Front Surface Materials

The front surface of a PV module must have a high transmission in the wavelengths which can be used by the solar cells in the PV module. For silicon solar cells, the top surface must have high transmission of light in the wavelength range of 350 nm to 1200 nm. In addition, the reflection from the front surface should be low. While theoretically this reflection could be reduced by applying an anti-reflection coating to the top surface, in practice these coatings are not robust enough to withstand the conditions in which most PV systems are used. An alternative technique to reduce reflection is to "roughen" or texture the surface. However, in this case the dust and dirt is more likely to attach itself to the top surface, and less likely to be dislodged by wind or rain. These modules are not therefore "self-cleaning", and the advantages of reduced reflection are quickly outweighed by losses incurred due to increased top surface soiling.

In addition to its reflection and transmission properties, the top surface material should be impervious to water, should have good impact resistance, should be stable under prolonged UV exposure and should have a low thermal resistivity. Water or water vapor ingress into a PV module will corrode the metal contacts and interconnects, and consequently will dramatically reduce the lifetime of the PV module. In most modules the front surface is used to provide the mechanical strength and rigidity, therefore either the top surface or the rear surface must be mechanically rigid in order to support the solar cells and the wiring.

There are several choices for a top surface material including acrylic, polymers and glass. Tempered, low iron-content glass is most commonly used as it is low cost, strong, stable, highly transparent, impervious to water and gases and has good self-cleaning properties.

3.4.2 Encapsulant

An encapsulant is used to provide adhesion between the solar cells, the top surface and the rear surface of the PV module. The encapsulant should be stable at elevated temperatures and high UV exposure. It should also be optically transparent and should have a low thermal resistance. EVA (ethyl vinyl acetate) is the most commonly used encapsulant material. EVA comes in thin sheets which are inserted between the solar cells and the top surface and the rear surface. This sandwich is then heated to 150 °C to polymerize the EVA and bond the module together.

3.4.3 Rear Surface

The key characteristics of the rear surface of the PV module are that it must have low thermal resistance and that it must prevent the ingress of water or water vapour. In most modules, a thin polymer sheet, typically tedlar, is used as the rear surface. Some PV modules, known as bifacial modules are designed to accept light from either the front or the rear of the solar cell. In bifacial modules both the front and the rear must be optically transparent.

3.4.4 Frame

A final structural component of the module is the edging or framing of the module. A conventional PV module frame is typically made of aluminium. The frame structure should befree of projections which could result in the lodgement of water, dust or other matter.

3.Parameter extraction

4.1.1 Determination of the ideality factor

The ideality factor, also known as the diode quality factor, is a parameter used to describe the deviation of a diode from ideal behavior. It is typically denoted by the symbol n and is a dimensionless quantity that ranges from 1 to 2.

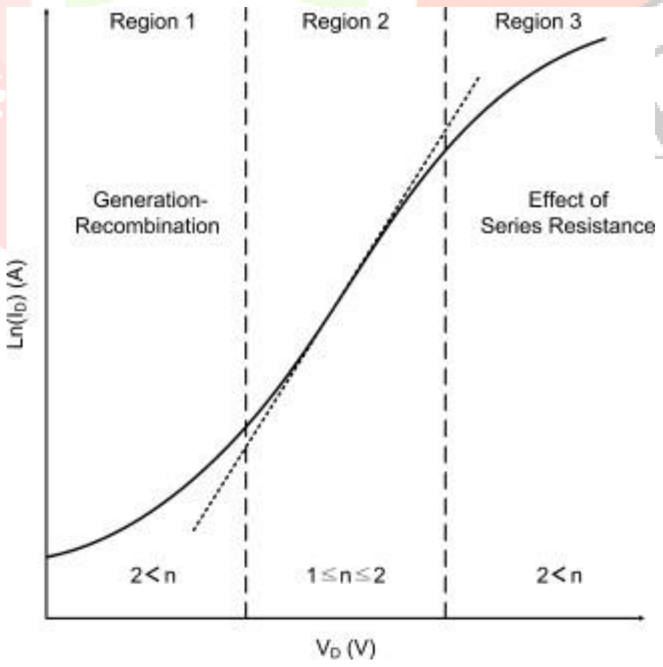
The ideality factor can be determined experimentally by measuring the current-voltage (I-V) characteristics of a diode at different temperatures and fitting the data to the following equation:

$I = I0 \exp(qV/nkT)$

where I is the diode current, I0 is the reverse saturation current, V is the applied voltage, q is the charge of an electron, k is Boltzmann's constant, T is the temperature in kelvins, and n is the ideality factor.

By plotting ln(I) versus V, a straight line can be obtained, and the slope of this line is equal to q/nkT. Therefore, the ideality factor can be determined from the slope of the ln(I) versus V plot.

It is important to note that the ideality factor can vary depending on the type of diode, its manufacturing process, and other factors. Additionally, it is an approximation of the real behavior of the diode and does not take into account all the physical mechanisms that may affect its performance.



4.1.2 Determination of the reverse saturation current

Reverse saturation current is the asymptotic limit of the reverse dark current for an infinite reverse bias. Its origin is the diffusion of carriers through the space-charge zone even against an unlimited electric field. It is a unique value decided by manufacturing conditions of the diode and is not influenced by the reverse bias voltage.

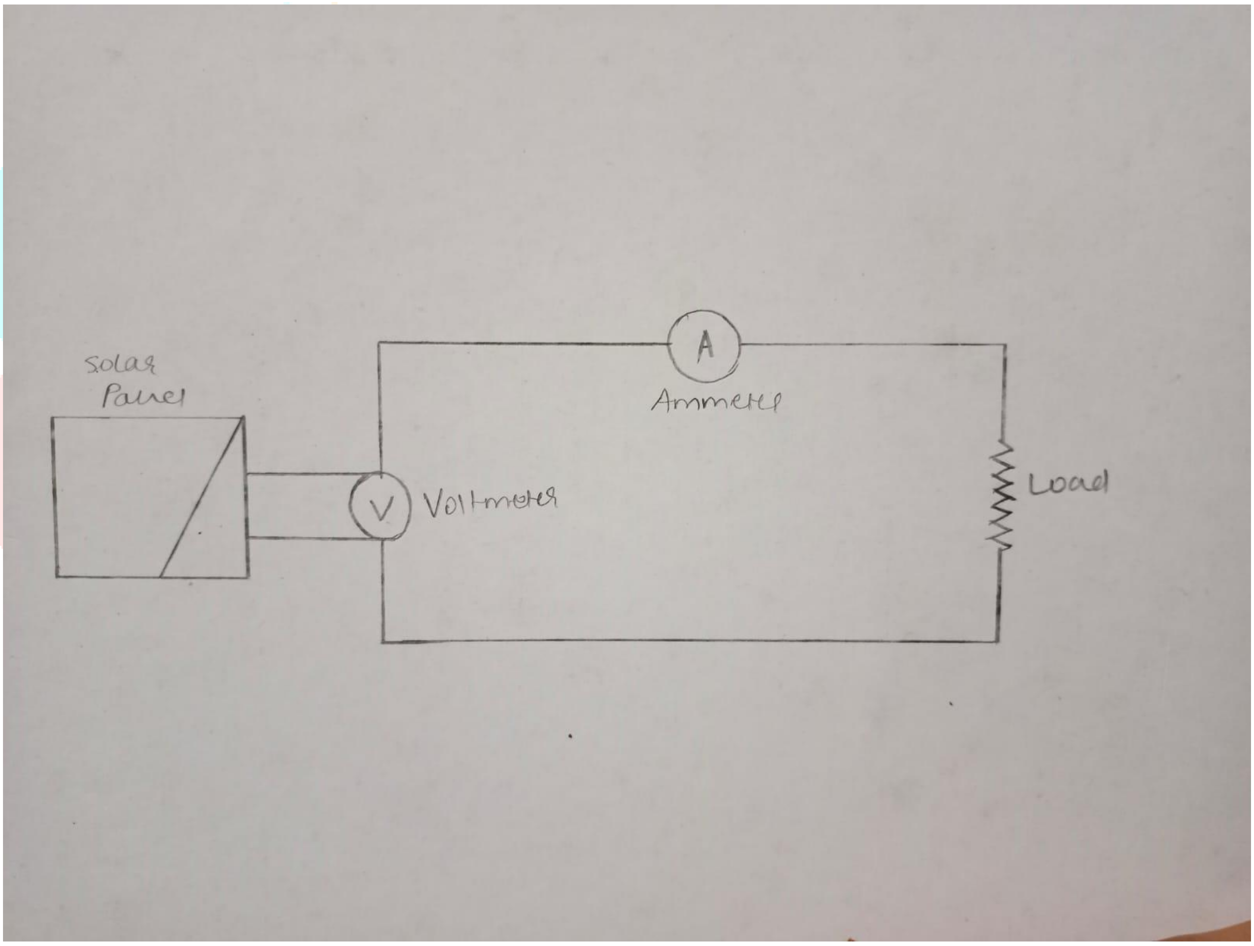
Accordingly, the value of the reverse saturation current differs according to the I–V curve data.Since diode current is greatest under the open circuit condition of the solar cell, the influence of reverse saturation current is also greatest under this condition. Therefore, the accuracy of the reverse saturation current calculated using data at this point is highest

4.1.3 Determination of resistance

Using the ideality factor and initial value of the reverse saturation current, the data of the I–V curve with ideal Rs and Rsh can be obtained. As shown in Fig. 2, the series resistance Rs reduces the output voltage in the voltage source region of the I–V curve by the difference between the voltage from the ideal I–V curve (Videal) and the voltage from the measured I–Vcurve (V).

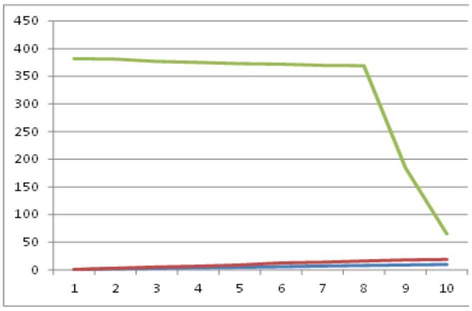
4.2 Experiments

The I–V curve of a 40W 12V module having cells 36 connected in series was measured under standard irradiation at standard temperature (25 C). The curve on the datasheet was converted to digital data.

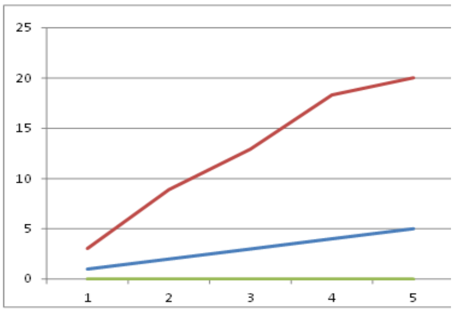


(Circuit for measuring I-V values)

Reading	Voltage (V)	Current(mA)
1	0.76	382
2	2.9	381
3	5.31	377
4	6.7	375
5	9.07	373
6	12.86	372
7	14.06	369.6
8	16.21	369.2
9	18.08	184.7
10	19.05	65.3



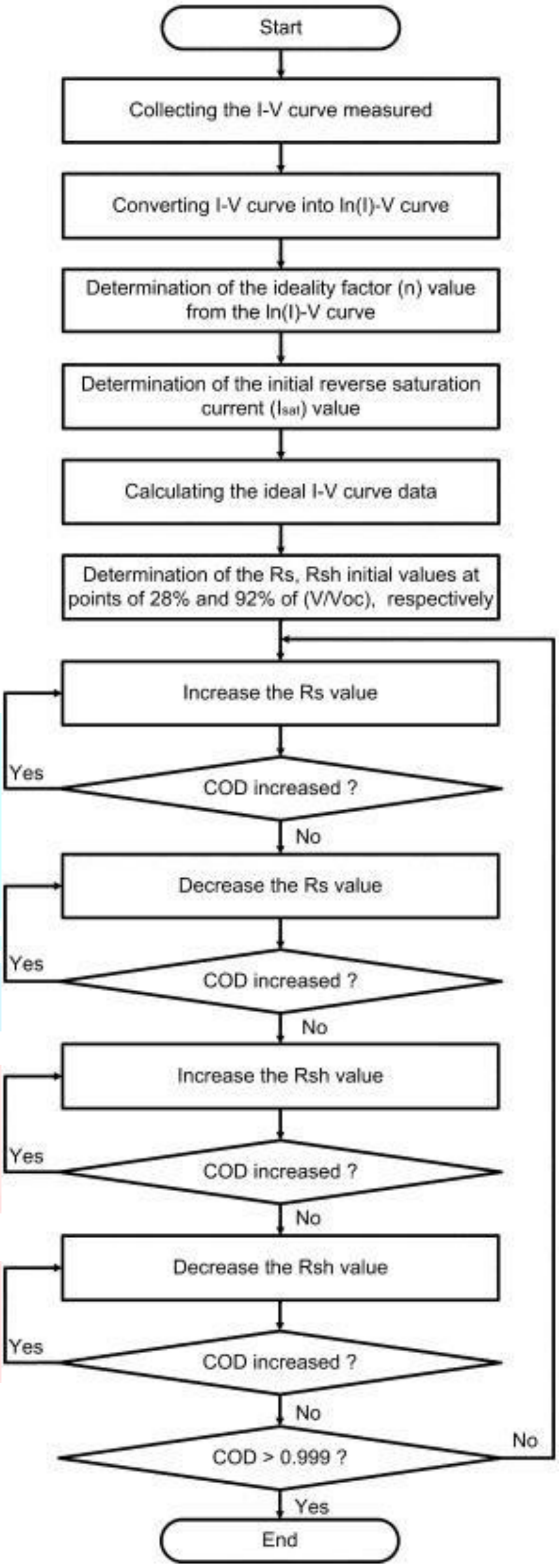
Reading	Voltage (V)	Current(mA)
1	3.05	0.013
2	8.9	0.014
3	12.93	0.015
4	18.32	0.01
5	20.03	0.004



These are the two readings we take at two different time with different light condition, fromthese reading we get this I-V curve.

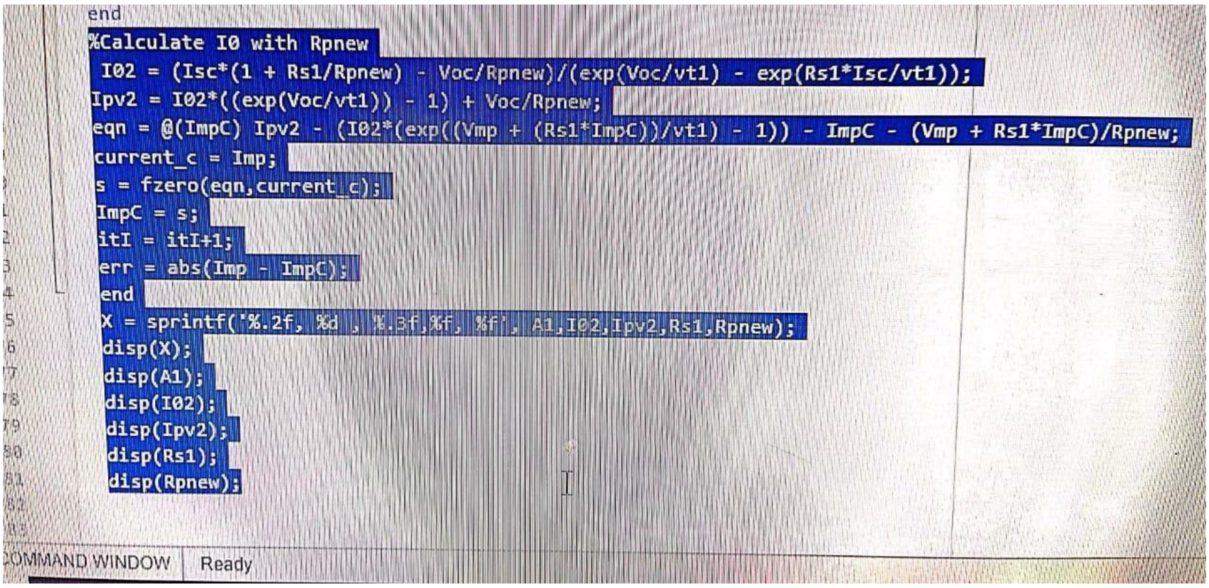
4.2.1 Flow chart

As per further flow chart we followed procedure in MATLAB and we get five different parameters value.



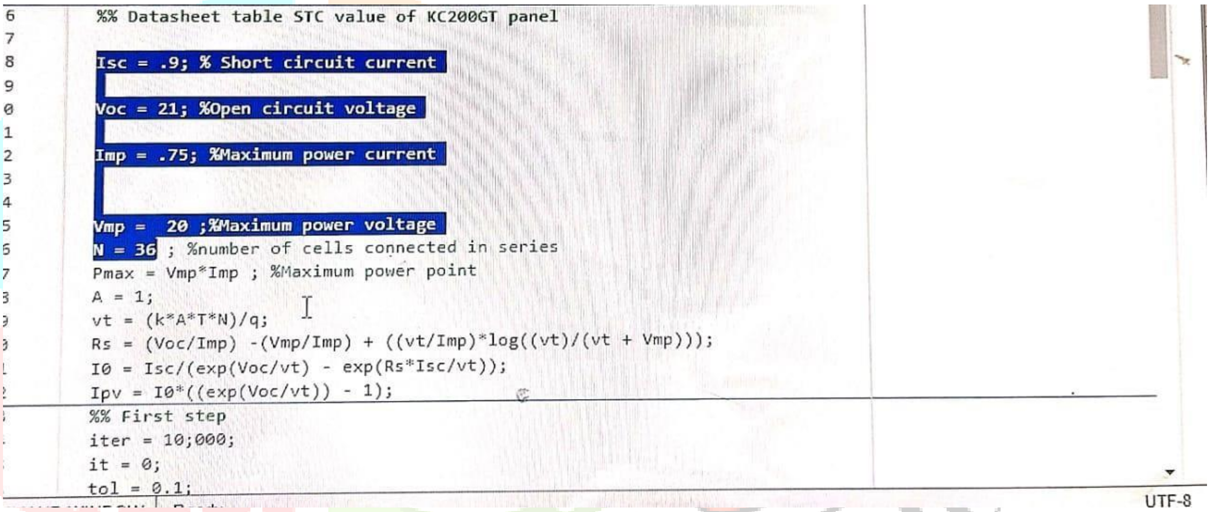
This is the flow chart for getting different values from the I-V curve that we measured at different light condition .

By using following MATLAB



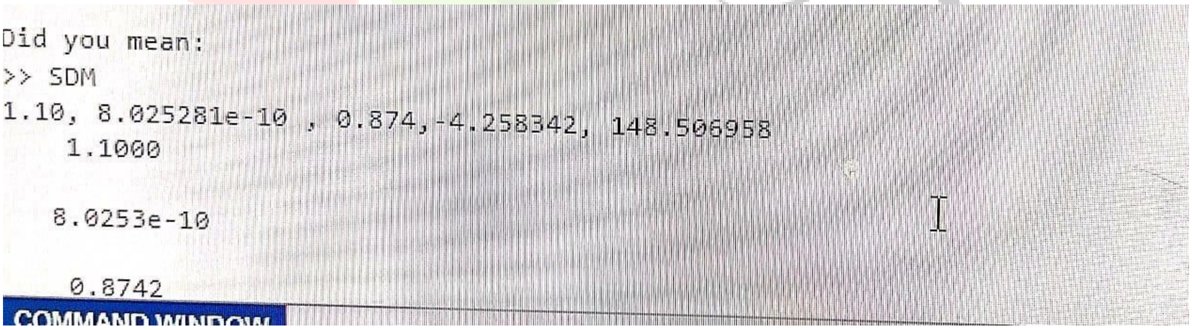
```
end
%Calculate I0 with Rpnew
 I02 = (Isc*(1 + Rs1/Rpnew) - Voc/Rpnew)/(exp(Voc/vt1) - exp(Rs1*Isc/vt1));
Ipv2 = I02*((exp(Voc/vt1)) - 1) + Voc/Rpnew;
eqn = @(ImpC) Ipv2 - (I02*(exp((Vmp + (Rs1*ImpC))/vt1) - 1)) - ImpC - (Vmp + Rs1*ImpC)/Rpnew;
current_c = Imp;
s = fzero(eqn,current_c);
ImpC = s;
itI = itI+1;
err = abs(Imp - ImpC);
end
X = sprintf('%.2f, %d , %.3f,%f, %f', A1,I02,Ipv2,Rs1,Rpnew);
disp(X);
disp(A1);
disp(I02);
disp(Ipv2);
disp(Rs1);
disp(Rpnew);
```

Calculating saturation current with Rph



```
%% Datasheet table STC value of KC200GT panel

Isc = .9; % Short circuit current

Voc = 21; %Open circuit voltage

Imp = .75; %Maximum power current


Vmp =  20 ;%Maximum power voltage
N = 36 ; %number of cells connected in series
Pmax = Vmp*Imp ; %Maximum power point
A = 1;
vt = (k*A*T*N)/q;
Rs = (Voc/Imp) -(Vmp/Imp) + ((vt/Imp)*log((vt)/(vt + Vmp)));
I0 = Isc/(exp(Voc/vt) - exp(Rs*Isc/vt));
Ipv = I0*((exp(Voc/vt)) - 1);
%% First step
iter = 10;000;
it = 0;
tol = 0.1;
```

Datasheet table



```
Did you mean:
>> SDM
1.10, 8.025281e-10 , 0.874,-4.258342, 148.506958
    1.1000

   8.0253e-10

    0.8742
```

4.2.2All extracted values of five parameters

The following are the values of five parameters :-

1) Ideality factor :- 1.10

2) Photon current:-8.025281e-10

3) Saturation current:- 0.874

4) Series resistance:- -4.258342

5) Shunt resistance:- 148.506958

4. Conclusion

a simple and powerful method of extracting parameters of a solar cell model was proposed. The proposed method is useful for the accurate and easy extraction of solar cell parameters from the I–V curve provided by the manufacturer or a measured I–V curve. Experiments wereconducted with modules having different capacities and a unit cell made by different manufacturers. It was found that in obtaining the series and shunt resistances from the difference between the ideal curve and measured curve after extraction of the ideality factor and reverse saturation current, optimum values were obtained at specific points of the curves. The proposed method directly calculates the ideality factor and reverses saturation current from the I–V curve. Parameters were extracted with high accuracy by letting resistance values converge to the actual value through repeated calculations. The proposed parameter extractionmethod is expected to be useful in the development of an accurate solar cell simulator, performance evaluation, degradation diagnosis, and the development of new MPP tracking algorithms.

5.pveducation.org

6.Referance

1) A novel parameter extraction method for the one-diode solar cell model Wook Kim, Woojin Choi

2) Parameter extraction of solar photovoltaic modules using various optimization techniques:a review B Maniraj, A Peer Fathima

3) Characteristic output of PV systems under partial shading or mismatch conditions JianboBai a,b,⇑ , Yang Cao a , Yuzhe Hao a , Zhen Zhang a , Sheng Liu a , Fei Cao a