Indian Institute of Science

Design of Photovoltaic Systems

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We shall try to study the photovoltaic cell from the electrical engineers point of view from the electrical engineers point of view most of the devices like the diodes BJT, MOSFETS, IGPTS or black boxes there without items and the design is performed based on the datasheet parameters likewise we would like to study the photovoltaic cell from the terminal characteristics without going into the physics of the PN Junction of the photovoltaic cell we would like to study the terminal characteristics and develop a model an electric circuit equal and model for the photovoltaic cell. This model we would later on like to use it for analysis and design of photo light based systems.

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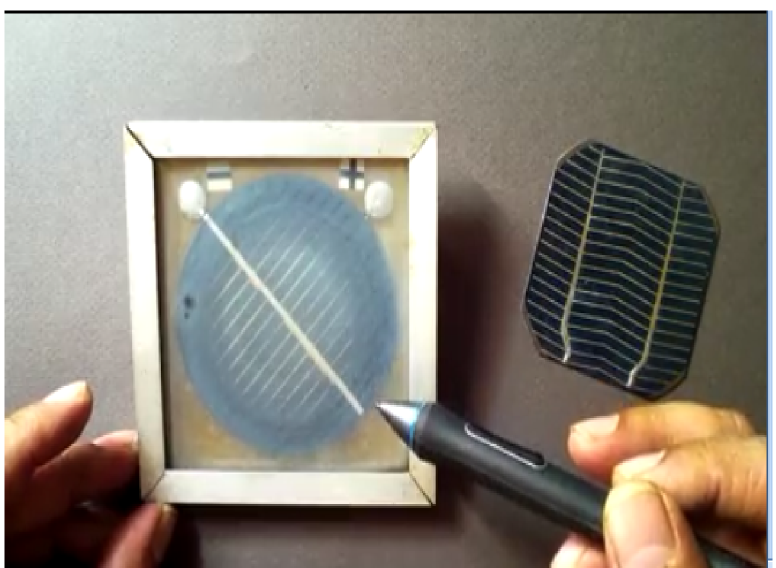

Here is an example of a poly crystalline photovoltaic cell this is the top layer which is the N type part of the PN Junction the bottom layer is the p-type and the p-type substrate metallization so normally what you would see is that then-type metallization are joined together and then that would be connected to the minus terminal and the p-type metallization would be connected to the plus terminal.

Another example of a PV cell which is knotted and camps encapsulated is this is again another poly crystalline PV cell something that is encapsulated with glass and that you can use for lab purposes is something like this you see here the plus terminal and the minus terminal this is a mono crystalline cell the top yin substrate is kind a is connect it through the metallization to the minus terminal and the bottom substrate is connected to the plus terminal.

So this is nothing but like a diode a PN Junction this is the anode and this is the cathode so this is brought out as terminals on the backside and then students can perform experiments on this very simple encapsulated PV cell the operation is pretty simple light falls on this glass surface the top surface of the PN junction which is a n-type and the valance electrons get excited and get move into the conduction band and through the stop metallization moves into the negative terminal.

And then flows out into the election circuit and into the anode terminal and comes back to the P substrate through the bottom metallization. So it is important that the exposed part covered by glass here has to be perpendicular to the incident radiation coming from the sun only then this particular PN Junction will act as a generator to understand the photovoltaic cell.

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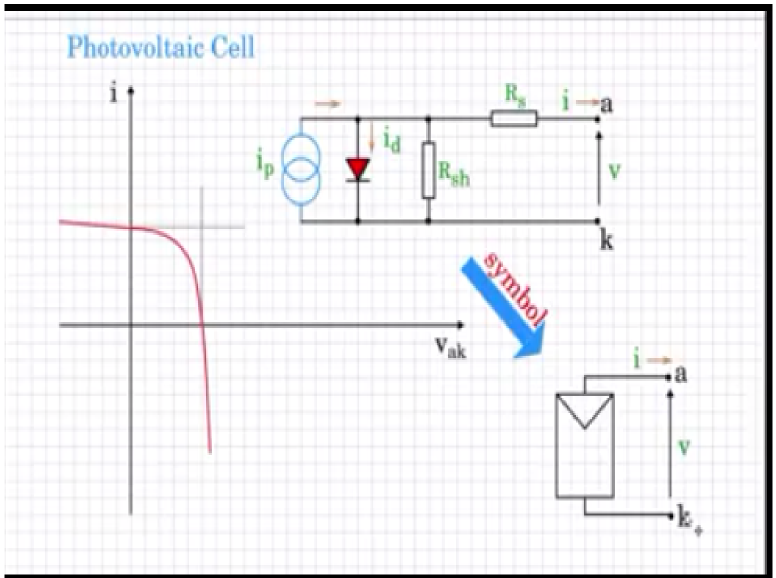

Let us start with another PN Junction the well-known diode let us connect this diode in a circuit a typical circuit for this would be something like this where the diode is part of a much more complex external circuit as shown here let us put in some terminals so this portion of the circuit the diode with along with these terminals is of interest and let us study its characteristic before we try to understand the photovoltaic and cells characteristic.

Let us call this terminal as A for anode and let us call this terminal K for cathode and we know that the current always flows from the anode to the cathode indicates the diode we call this as the current I another parameter terminal parameter of interest is the voltage across the terminals A and K we call that VaK so it is of our interest to study the diode PN Junction in terms of the current through the diode and the voltage across its anode cathode terminal Vak.

So with this polarity of voltage Vak being taken as positive that is the non arrow end as a common point for probing and the arrow end as the positive terminal for probing to the voltage and the direction of the current I have showed here as positive then we say that the power flows into the device the device is acting as a sync and the power flow is into these one port terminals the object of interest now is the diode part.

So we will bring the focus to the diode and this diode in its present representation as it is drawn in this circuit with the current flowing into the terminals anode terminal and with the voltage indicated asked us and the power flowing into the diode terminals they diode acts as a sync which means it receives power and only dissipates it cannot generate so this particular portion of the diode a portion of the diode circuit is now a sync circuit and not a generator circuit.

We will gradually see how we make it into a generator circuit and what extra components we need to add in order to bring about the model of the photovoltaic cell let us now make some space for drawing the characteristic we will reduce this portion and keep it that let us have the x-axis and we shall mark it as Vak this is the voltage axis and then we have the y-axis we shall mark it as i and draw the iV curve of this particular diode is very familiar to all of us we will stick to drawing mainly the forward portion of the characteristics which of course things like this.

So this is a familiar static curve of the diode and we know how this has come about now from this how do we develop the photovoltaic cell model we see that the first quadrant is involved in dissipation and is the dissipation mode or of components basically things where in the current flow is into the terminals are shown the fourth quadrant is a generation quadrant here the voltage is still in the same direction and only the current has become negative or current as reverse direction here in which K in which case the power flow also reverses direction which means the power is flowing out of the terminals and therefore acting as a generator.

So this portion of the IV characteristic is of interest to us because we would like to see how this diode can become a PV cell and also a generate let me track this here a copy of it here and increase the size so as to make it more legible so in this quadrant we see that the current is negative with respect to what we have represented here if this was supposed to be the positive direction of the current flowing into the terminal negative would be direction of the current flowing out of the terminal.

And the object here the diode in this case plus something else will act as a source and the power is actually now flowing out of the terminal because the product of these two will result in a negative value which means negative power so in this quadrant fourth quadrant this component or object is behaving as a source but how does the current here flow in this direction because we all know that the diode can handle current flow only in the direction from anode to cathode.

How can one make the current flow in this direction out of the terminal across the diode we add a current source IP in such a direction the current is flowing in this fashion as shown only under this condition you will see that this current splits at this node into the diode ID as shown here and into the terminal I as indicated here. Therefore, you see that through the diode the current distance lowing from the anode to the cathode but at the terminal the current is flowing out of the terminal.

So if you look at this whole block as a whole the current flows out of the terminal voltage is still retaining the same polarity the power is flowing out of the terminal and therefore this whole block acts as a source this is actually the principle of the photovoltaic cell this current source IP is actually the photocurrent which is dependent upon the solar radiation intensity more the solar radiation intensity higher is the value of the IP larger will be this current.

And larger will be the current flowing or to the terminal. And therefore, the power there are a few other components and no idealities also that will come into the model but this basically will indicate how the photovoltaic cell is behaving as an electrical source from an electrical engineers point of view let us study it just a little bit further before we develop the equations for that.

IP is the photocurrent which is directly proportional to the solar intensity the solar power that is incident on the surface of the panel if IP is zero that is under dark condition the characteristic is like this with the bias at the x-axis line ask the light intensity increases the photocurrent IP increases and this whole characteristic starts coming down by amount equivalent to the photo current.

So increasing IP would mean the shifting of the characteristic like this higher the incident power incident solar power the more the characteristic will shift towards the fourth quadrant so any operating point on this part of the curve would mean that the photovoltaic cell is operating in the generating mode so normally the photovoltaic cell is considered to be a generator and the one would like to see that it is in the first quadrant.

Therefore, we now redefine the current the voltage remaining the same but the current the direction of the current we will take it as positive for this axis when the current goes out of the terminal as shown here and that not like what it was defined before for the case of the simple diode so we would not like to have this but would like to use this as a reference now and this we would like to bring it to the first quadrant which would mean we have to flip the current axis.

And that is done by just simple flipping of the y-axis because the current has just flipped the direction so this here forms the characteristic the IV characteristic of a photocell a photovoltaic cell. Consider the IV characteristic of a typical photovoltaic cell observe that for some portion of the IV characteristic the photovoltaic cell behaves as a constant current more or less constant current for this portion of the characteristic the photovoltaic cell would behave like more or less a constant voltage source so the photovoltaic cell has the unique feature of being both a combination of a constant voltage source and the constant current source.

Let us draw a line is the constant current line let us draw another line with a constant voltage line the constant current line if you take. It gives an idea of the slope or the constant current portion and therefore, it implies existence of a shunt resistance a high value of shunt resistance across a constant current source so we can include a non ideality or shunt a higher value of shunt resistance across the constant current source as shown.

Here likewise the voltage line the slope of it to the voltage portion of the characteristic would imply a series impedance in series with the terminals so it would appear as though we have a series impedance at the terminals like this so let us include this non-ideality also to the existing model minor redrawing and relocation of the components this forms the equivalent circuit model of a photovoltaic cell.

This has a symbol which looks like this envelope like symbol is the symbol of a photovoltaic cell it represents either a photovoltaic cell or a photovoltaic model there are two terminals the anode terminal the cathode terminal this is the terminal voltage and the terminal current generally flowing out of the anode ton so here we have the entire photovoltaic cell with a characteristic the equivalent circuit model and the simple you.