Basic Electrical Technology
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Lecture - 4
Sources

Hello everybody, in the last class we had a detailed look at three of the most important elements that is the resistors, inductors and capacitors. We saw that energy forced from the source towards the destination which is the load and in between the energy can get dissipated in the resistor R or it can get stored as kinetic energy in the component called L or the inductor, it can get stored as potential energy in the component called C the capacitor capacitance of the capacitor or it can also get transformed from one type of energy to another type of energy like electrical to magnetic, magnetic to mechanical and so on and so forth.

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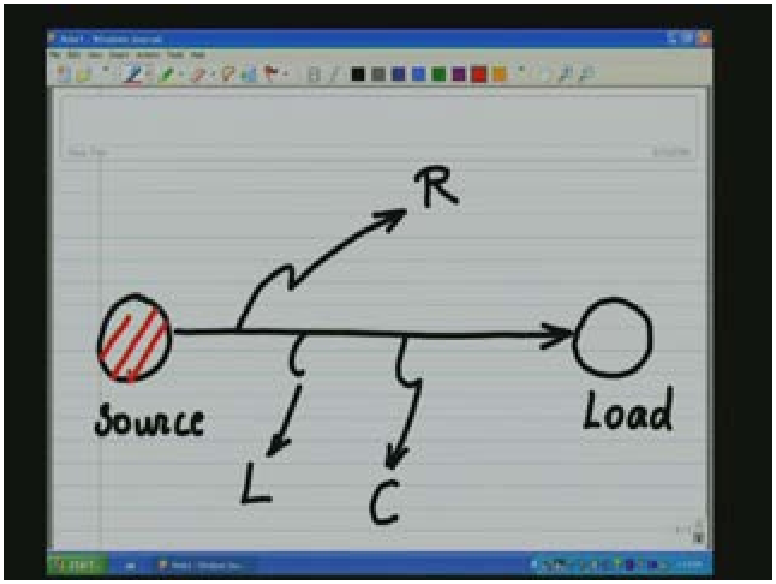

In this session we shall now focus our attention on this block that is the source block; what are the electrical sources, what are the characteristics of electrical sources, what are the non-idealities and we will have some look at real world and practical sources.

If you look at electrical sources the common ones that may come to our mind, one is the wall outlet. Every home will be having this 230 volt AC outlet so we are all familiar with that one that is one of the electrical sources most common electrical sources that you will be using. The second one which you may have heard and probably also used, the batteries. Batteries are DC sources, very common; used in pen torches, used in laptops, used in many of the electrical equipments you cell phones so on and so forth, they are all batteries DC sources. We will have a look at these also later on. You have a third distinct type of source, the solar photovoltaic cell. These are slightly different in concept we will come to it and have a look at it in more detail when we touch up on the solar cells but they are becoming more and more popular in today's equipments and the most common one that you all would have seen is the calculators the solar calculators.

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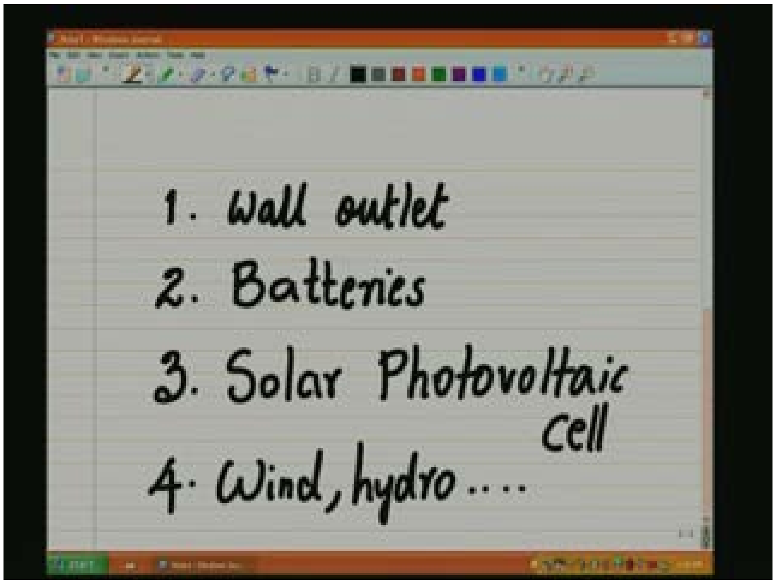

There are also few other sources like generators obtained from wind, hydro so on and so forth which are generated at the remote areas wherever there is a dam or wherever there is lot of wind in a particular location that is through wind mills and then connected to the grid and then routed to individual loads and homes.

These are some of the more common electrical sources which you will be using in almost all of your electrical equipments.

Now if you look at these sources themselves electrical sources themselves they can be broadly classified as voltage source and current source. In the voltage sources the voltage is determined by the source and it is held constant, in the current source the current is determined by the source and it is held constant whereas other parameters like in the case of the voltage sources the other parameter would be the current which is determined by the external circuit and the case of the current sources the other parameter which is the voltage is determined by the external sources.

The sources are further classified as AC sources alternating current sources or direct current sources. Likewise even in the current you have two classifications: the AC and the DC.

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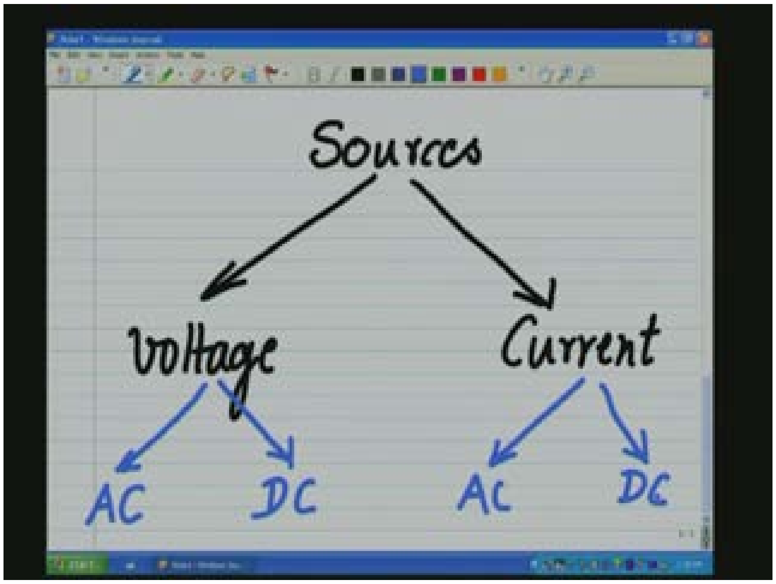

Let us now look at how voltage source and current source is represented symbolically and of course their ideal characteristics. Let us consider a voltage source.

The voltage source is symbolically represented by a circular symbol with two terminal leads coming out of it. It has an arrow pointing….. I will just come to that pointing in a manner I have shown here, this arrow indicates that this potential this terminal potential is measured with respect to this (Refer Slide Time: 8:01) and that is what this arrow indicates and then there is a current going out of one of the terminals and then its circulates and enters the other terminal. This is a symbolic representation of a voltage source. It is also represented in a slightly modify manner in many of the literature; voltage source; instead of the arrow plus or minus mark is used, it does not indicate that this is always positive with respect to this but what it indicates that the measurement of this terminal voltage is done with respect to this. This is the symbolic representation of a voltage source.

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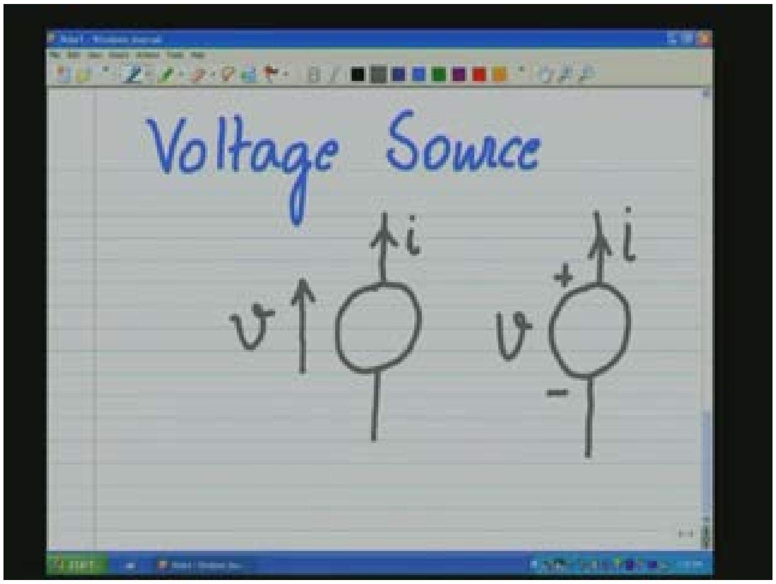

How do we represent the current source?

Current sources are also represented in a similar manner. You have a circular block with two terminals and there is an arrow within the circular block which indicates the direction of the flow of the current and i to indicate that it is a current source.

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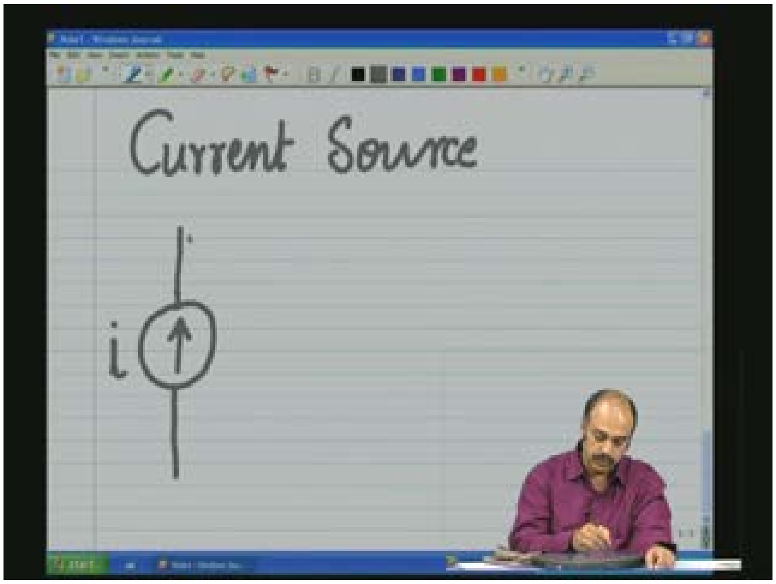

Now this is the terminal and the terminal voltage for the current source is determined by the external circuit. So this is one such representation of a current source. Alternatively you can see a current source being represented in this manner also. A double circle with an arrow indicating the flow of direction of flow of current and an i to indicate that it is a current source and the terminal voltage V T which is determined by the external source.

The important characteristic of a source is its I-V characteristic. The I-V characteristic gives a very nice description of the voltage source in a pictorial form. now we take an empty source a voltage source and look at its I-V characteristics………. so let us draw the X Y plot, the X axis is the load current i, the Y axis is the voltage of the voltage source.

Now if you look at the plot of course you see that in the case of the voltage source the voltage will be a constant with respect to the current i. So whatever may be the current here; this current here is the load current, so whatever may be the load current the voltage will be a constant or some value let us say V 0.

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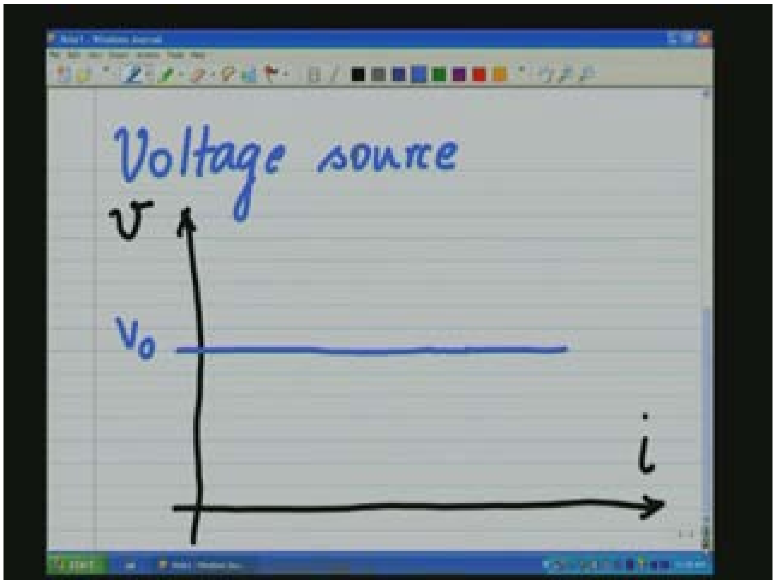

Likewise if we take the current source the current source can also be represented by an I-V characteristic. In the case of the I-V characteristic for a current source the independent variable is not a current but the terminal voltage V T and the dependent variable here on the X on the Y axis will be the source current. So we see that whatever may be the terminal voltage which is the load for the current source the current value will be a constant at some value say I 0. So in the case of the voltage source the voltage is constant with respect to the load or the load current and the case of the current source the current is constant with respect to its load which is the terminal voltage; the terminal voltage being decided by the external circuit.

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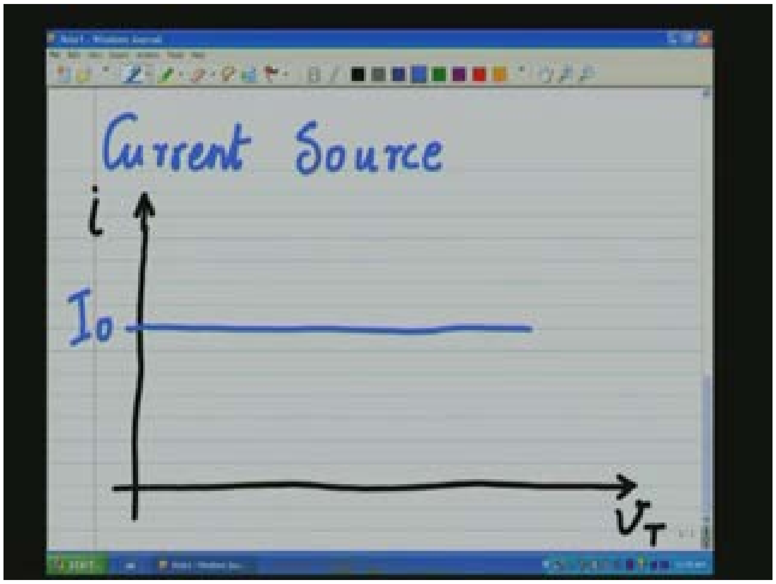

These are ideal characteristics. Only in the ideal characteristic you see the voltage source and the current source I-V characteristic where the waveform is horizontal straight line. But in a practical characteristic it is going to deviate from this horizontal straight line significantly and later on we will see how these non-idealities are going to affect the I-V characteristics of these sources.

Before going in to the non-ideal or the practical sources let us have a look at how an AC source look like; the AC source are the alternating current source. In the case of a DC source, if we look at the waveform of let us say a voltage source with respect to time t voltage with respect to time t you see that it is a constant. So this is the waveform that you would see for a DC source. But if you take the case of an AC source the AC source with respect to time t the waveform need not be a constant but it could be varying in some arbitrary fashion. So this would be an AC source (refer Slide Time: 15:35) this would be an AC source.

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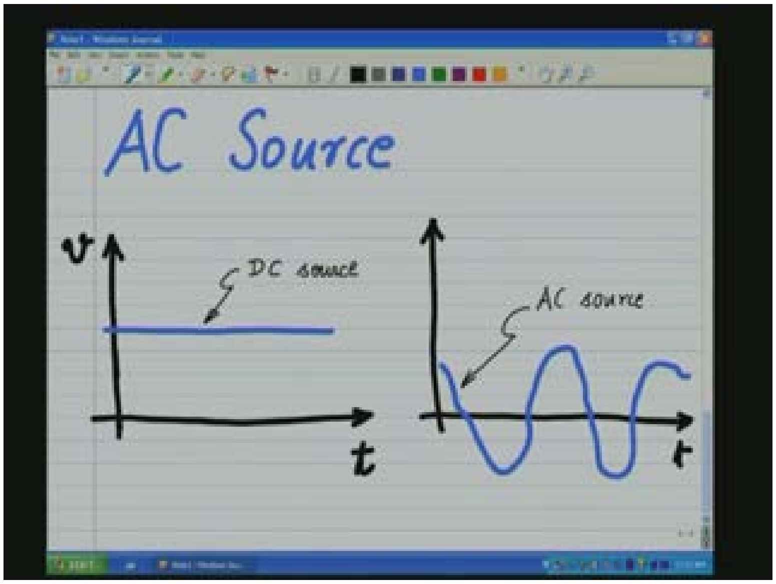

So an AC source the voltage waveform or the current waveform of that particular source varies those positive and negative or has a varying component as a function of time. Whereas in the case of the DC source as a function of time the value of the voltage of the current is going to be constant.

The most common AC source that you would probably have come across is the source that you would see the waveform that you would see when measuring the voltage of a wall outlet. The wall outlet waveform typically is an alternating current waveform. Let me first draw the wave shape with respect to time. It is a sinusoidal waveform and it has a repeating period, it has a repeating period t which means that this portion of the waveform (Refer Slide Time: 17:08) keeps repeating every period of time t.

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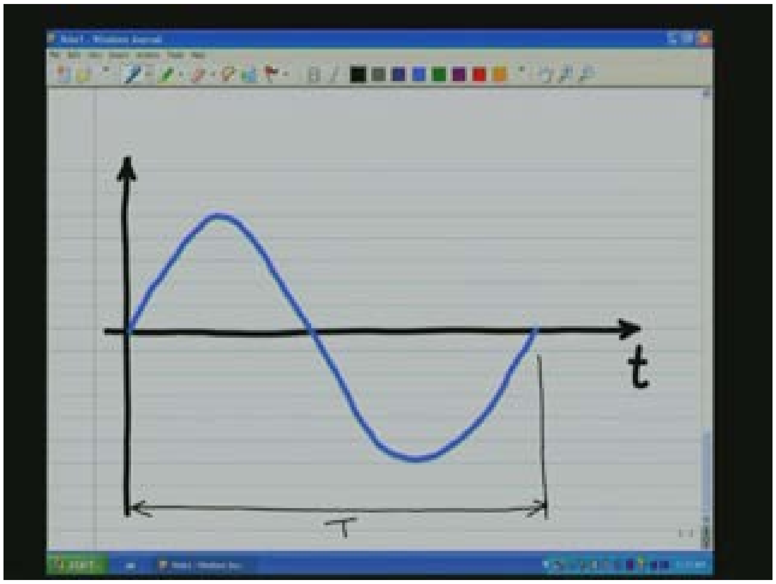

Now this waveform or the sinusoidal waveform is characterised by peak amplitude V m and this whole equation is given as V m sin (2 pi by T) that is the period T into the time. This is the equation that defines this blue coloured waveform which is here and this is the type of waveform that you will see across every wall outlet and in majority of the cases the AC waveforms are you will come across will be of this sinusoidal nature. Now here what is constant? When you say it is a voltage source with respect to load what is it that is constant independent of variation of the load? It is this V m amplitude.

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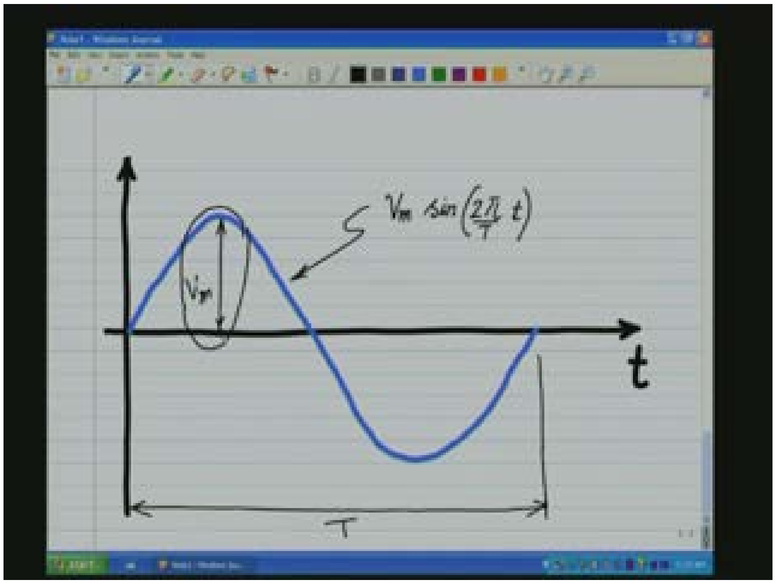

So, if we plot this V m with respect to the load i and this is (Refer Slide Time: 18:50) let us say V m the peak value; you will see that it will be constant; the peak value or the V m of the sine wave is constant whatever may be the value of the load current i. So in this case of the AC sources we have to take one characteristic feature of the waveform like V peak which is the V m or the average value or the RMS value any one of these which will define which will which will define that particular waveform and that will be constant with respect to the load.

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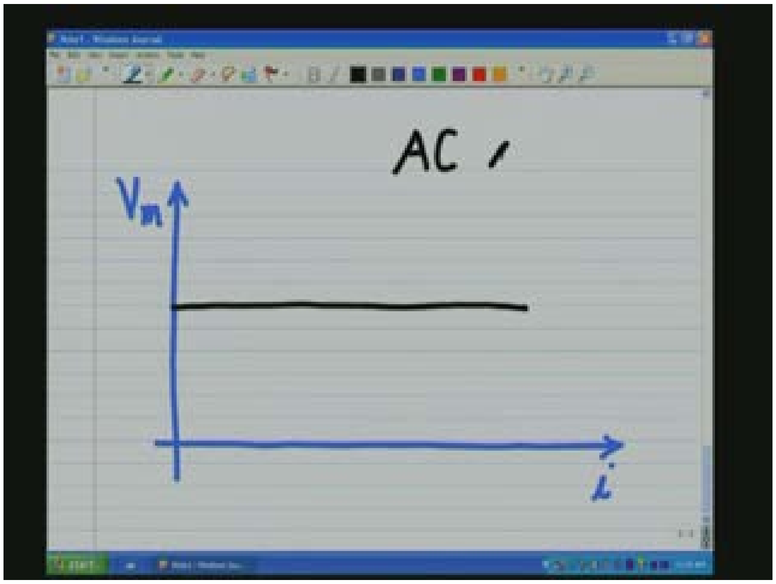

Now we will discuss about some practical sources.

What is it different in a practical source as compared to the ideal source? In the case of the practical source there is a source let us say a voltage source V where we have this following representation that we already discussed and till its two terminals are connected to a component R s or the source resistance and now the load is our external circuit is connected across these two terminals and this is the terminal voltage.

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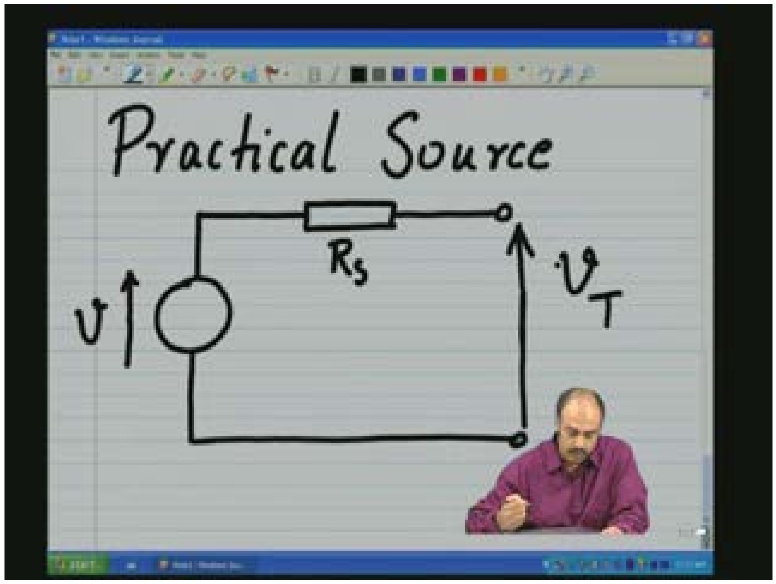

In the case of the ideal source this component was not there; R s was equal to 0 in the case of an ideal source. But in the case of all real practical sources R s is the finite value a non-zero value and it has an effect on the V-I characteristic of the source. So now the V-I characteristic of the source has to be seen with respect to this point (Refer Slide Time: 21:54) so it should be V T versus the current high which is flowing here.

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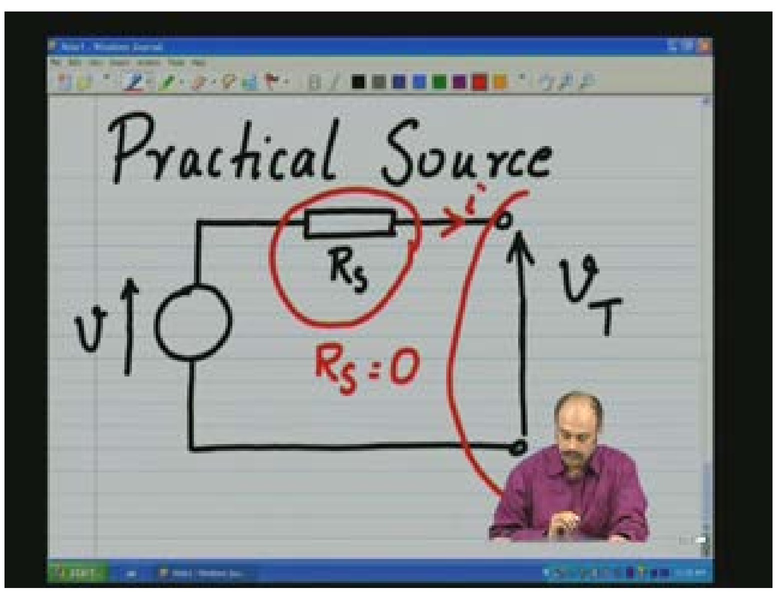

Therefore, now let us have a look at the V-I characteristic of some practical sources. Let me draw a small scale down circuit of a source here (Refer Slide Time: 22:28). Let us construct the source which is comprising of an ideal source V with the non-ideality of series resistance R s and there is the terminal voltage resulting due to connection to the external circuit.

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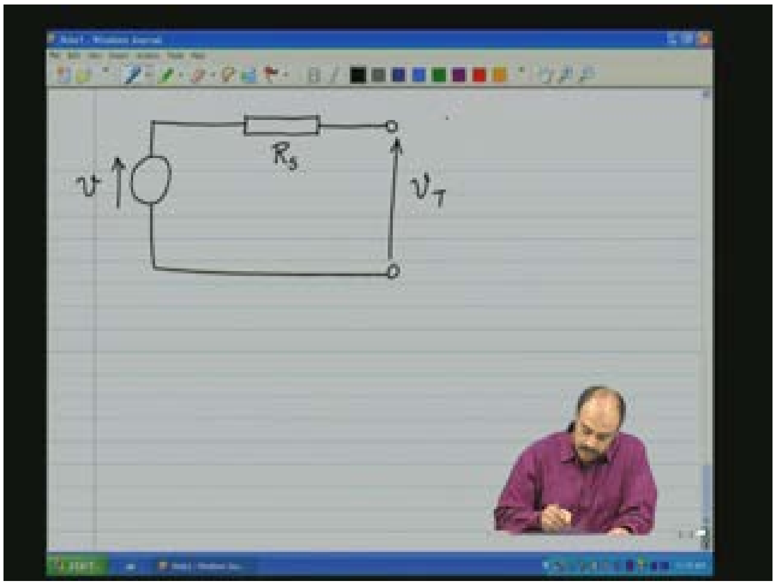

Now there is going to be a current that flows in the circuit here. Due to the flow of this current here there is going to be a drop here across this resistance and that is going to be iR s iR s that is current into Rs is the voltage drop across this.

So if you look at this entire loop you see that V is equal to i into R s plus terminal voltage V T as determined by the external circuit. So now we need to know what is V T with respect to the load current. V T is V which is the source voltage of the ideal source minus i into R s. So this is the load current and this is the terminal voltage.

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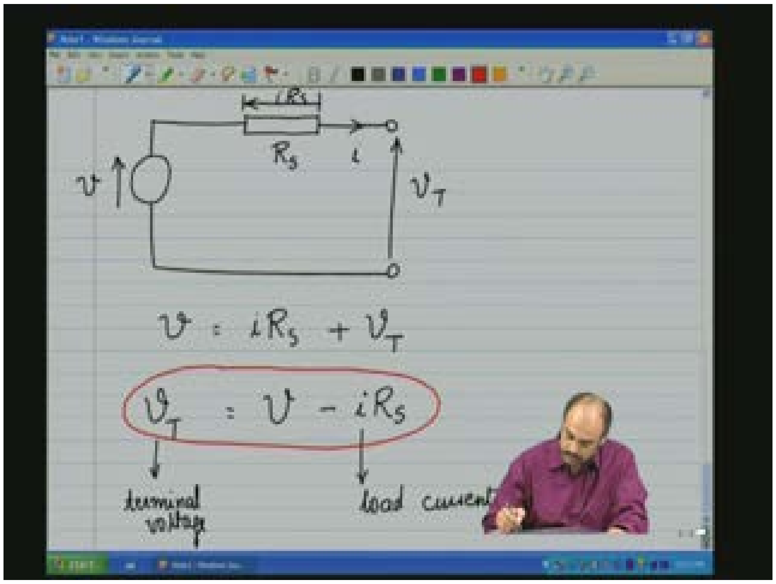

So let us have a look at this equation. Let us picturise it and see how the I-V characteristic looks like. So let me put down that equation here V terminal equals the ideal source voltage minus i into R s. Remember that in the case of ideal source R s is equal to 0 and this component is not there and therefore terminal voltage is same as V. But the practical sources R s is not equal to 0 and therefore this component comes into the picture.

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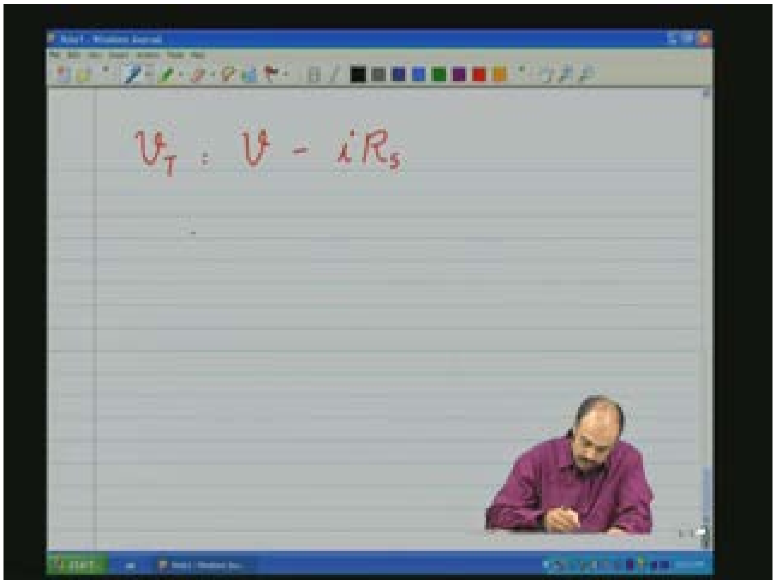

So let us now draw the I-V characteristic of such a practical source. Now the X axis is i of the load current which is the independent variable, the Y axis is V T. Now at zero load……… so by saying zero load it means i is 0 which means there is no current flowing through the output circuit so according to the equation we see that i is equal to 0 this portion is not there (Refer Slide Time: 25:58) so V T terminal voltage is same as V so the terminal voltage starts with V. And if it had been ideal we will have seen that it would have kept going straight horizontal. However, it is not ideal therefore it starts at this point and then as the current increases this negative component keeps increasing that is i into R keeps increasing and subtracts from the ideal component V. So this amount of voltage drop is due to i into R s.

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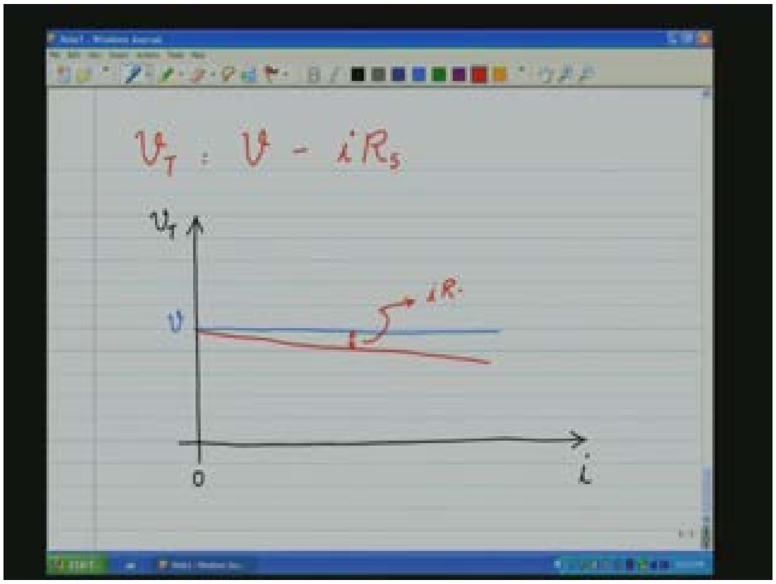

Therefore, in all practical power supplies or all practical voltage sources you will see that in the I-V characteristic the terminal voltage is not going to be horizontal but it will be slightly angled down by an amount which is equal to i into R s where R s is the source internal impedance which is in series and this equivalent series source impedance is zero on an ideal case. Therefore, the goodness of a voltage source can be quantitatively measured by looking at the I-V characteristic; the more horizontal the I-V characteristic the better the source which means the more horizontal it is the iR s drop is small and therefore R s is small and therefore it is a better source compared to one which has a much higher droop.

Likewise even in the case of a current source there is a non-ideality that has to be introduced for practical current sources. So a practical current source is composed of an ideal current source is the current I and this is supposed to be connected to the external circuit which determines the terminal voltage and in the case of the practical current source there is one more component that we are going add across the source and that is called the shunt resistor R shunt.

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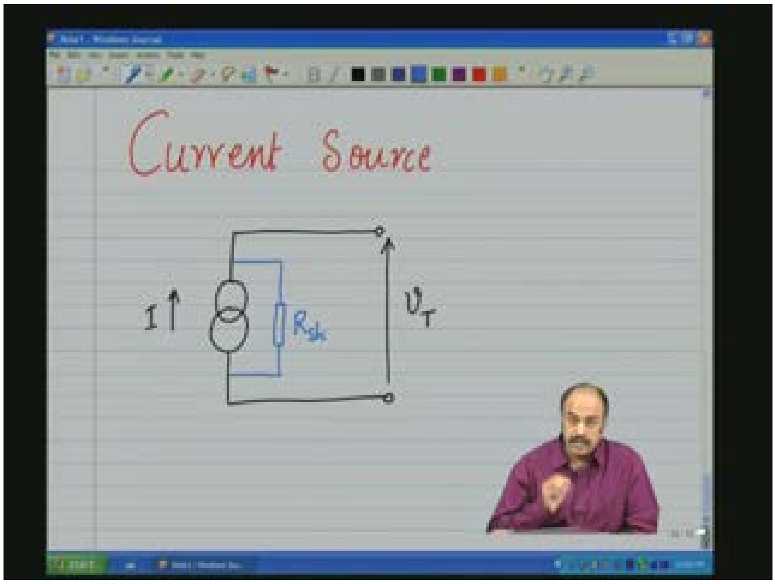

In an ideal source R shunt will be infinite, will be very very high. In the case of a practical current source R shunt is not infinite but a value which is finite but may be in mega ohms and such in that order.

So now if you look at this circuit though there I the current source I flowing here it is now splitting into two parts: one portion of the current will flow in here and another portion of the current flowing here. So if you say this current is i shunt let us say which flows through the shunt path the shunt resistance path (Refer Slide Time: 30:26) and this current is the terminal current where I equals i terminal current plus i shunt. Therefore I equals I T plus V terminal by R shunt.

Or in other words, if we rearrange this we obtain terminal current equals the actual ideal source current value minus terminal voltage by R shunt. So this would be the practical current source equation. Now the terminal current will be same as the ideal current source current if R shunt had been infinite. So in an ideal current source R shunt would be infinite and therefore this time would be zero and I T would be same as I.

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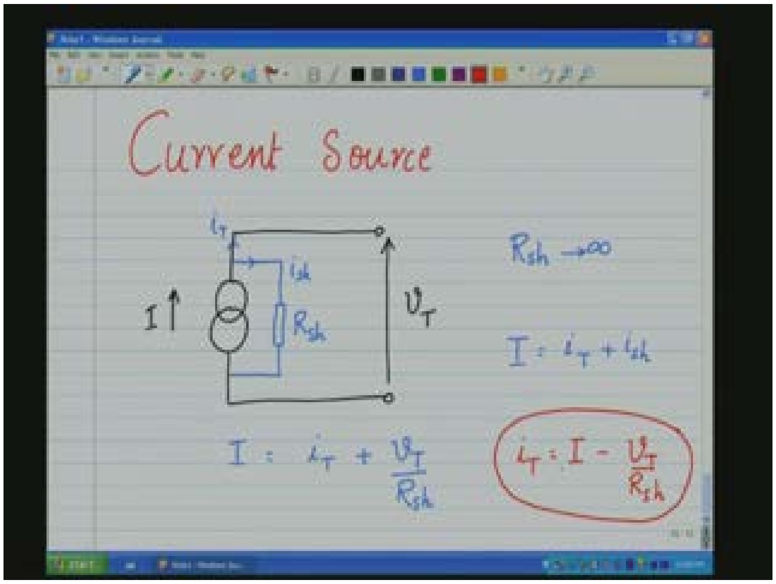

However, in a practical case R shunt is not infinite there is some contribution of this as V T increases from zero to a higher value.

Now let us look at the I-V characteristic of this practical current source. Let me put back the equation. i T equals the actual ideal current source value minus terminal voltage by R shunt value. Let us draw the I-V characteristic. The x axis contains the variable which is V T at the terminal voltage, the y axis is i T and at zero when V T is 0 means this is short circuit; when V T is 0 that is short circuit condition, this portion that is V T by R shunt is zero because V T is 0, i terminal is same as I so it starts from some value I and if it had been ideal R shunt would be infinite and therefore this would have one horizontal straight like that.

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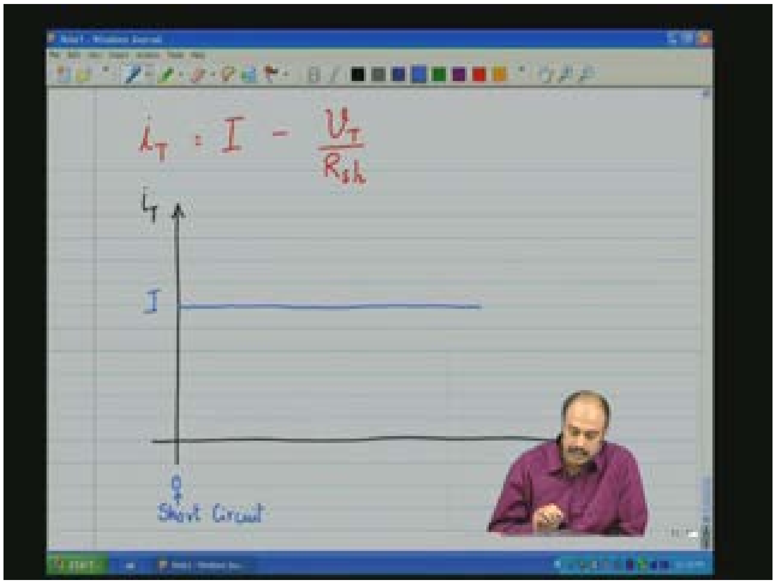

However, R shunt is not infinite in a practical case and therefore we see that this will start drooping as V T increases (Refer Slide Time: 33:43) and this droop amount is V T by R shunt. And here again we can say that the goodness of the current source is seen from this graph here; if this red line matches with the blue line then it is closest to the ideal power source or if the red line starts deviating more and more higher from the blue line then the current source becomes poor and poorer because the R shunt value becomes lower and lower. So this can be used as a guide for comparing two or more current sources.

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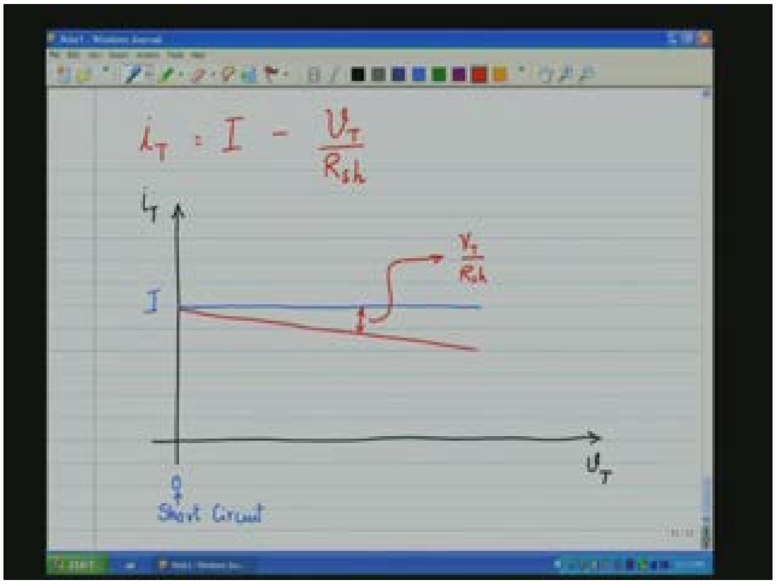

Now let us see some real world voltage sources. The first voltage source that we will be looking at is the battery which is one of the most popular and ubiquitous voltage source that you would have seen everywhere and used probably in many of the electronic equipments and gadgets.

The battery is a DC voltage source; meaning the voltage is a constant independent of the load current and also it is a constant with respect to time.

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A typical battery looks something like this. There are many types and versions of batteries. This is one such battery. It has two terminals: one marked positive which is red in colour, the other one marked negative. We will have a closer look at the battery shortly. Before that we will try to understand how we represent the battery on paper meaning its symbolic representation.

A battery is represented on paper symbolically in this fashion. It has a series of long and short horizontal lines and two terminals here (Refer Slide Time: 36:20) which is the terminals to which the external circuit is connected. The long line is positive or the anode; the short line is the cathode of the negative terminal and we represent the voltage value of the battery by V B.

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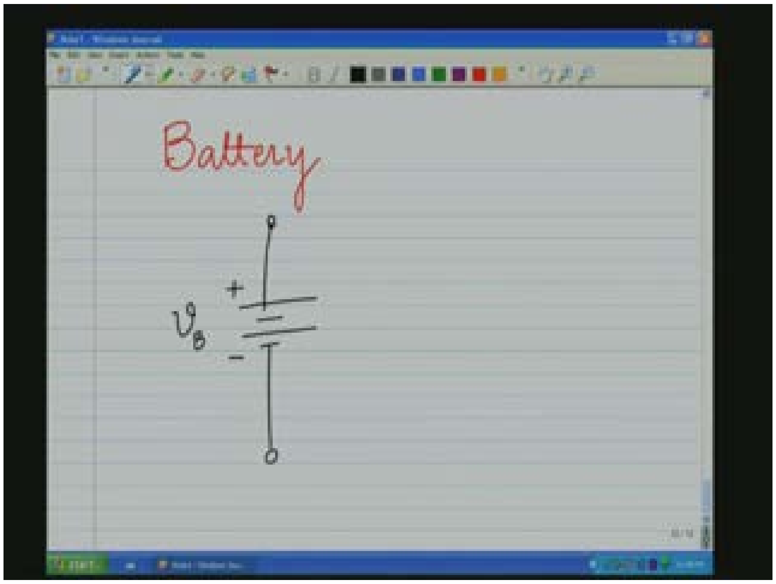

So this is the symbolic representation of an ideal battery. What goes inside of the battery? it is a can let us say, it contains two electrodes: a positive electrode called the anode a positive electrode called the anode and the negative electrode called the cathode and it would have inside an electrolyte it has a electrolyte. These are the three important components of the battery: the positive electrode or the anode and negative electrode or the cathode and the electrolyte.

In the case of the most popular battery which is lead acid battery which you would also have heard used in almost in all the automobiles the positive electrode is lead oxide, the negative electrode is lead and the electrolyte is sulphuric dilute sulphuric acid or should i say H 2 SO 4 this is the chemical symbolic name of sulphuric acid so this compresses typical lead acid battery, the electrons get generated from the cathode, flows on to the anode and from here to the external conductor to the external circuit then back again to the cathode and in the process as far as the lead acid battery is concerned water is generated and it dilutes the battery and the charge goes down. So repeatedly as the charge goes down you will have to recharge the battery again back to its original capacity which means the concentration is brought back and then again it is in the charged condition.

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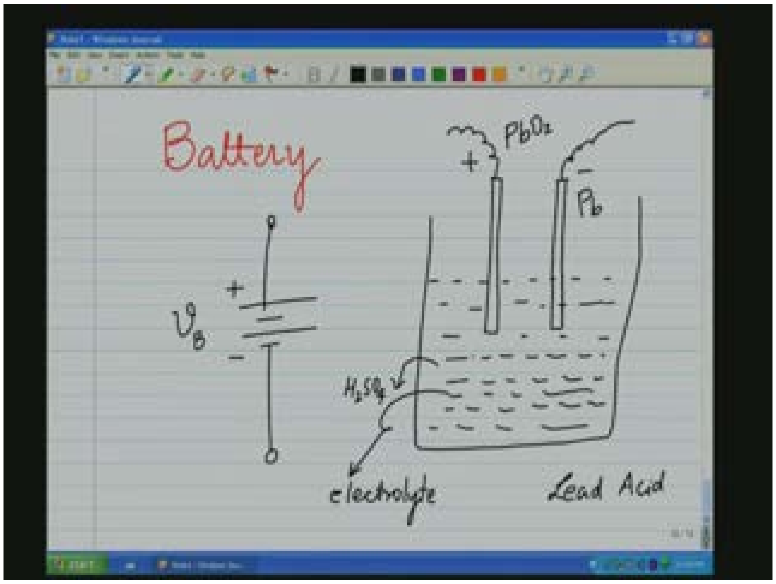

Let us now take a look at the battery which you were seeing in the picture here. This is the lead acid battery that I have been describing (Refer Slide Time: 39:21). This is a sealed maintenance free lead acid battery; the electrolytic is in gel form. This is the positive terminal or the anode; this is the negative terminal or the cathode. Whenever you see a practical battery there will be some name plate readings which are of importance to you.

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You will see here something is written on the side. Two of the most important things that you will have to see in the case of the battery is the terminal voltage. You see that it is 12 volts. that is across these terminals you will get a nominal DC voltage that you would get across these two terminals and next to it there is something else written called 7AH; it means 7 Ampere Hours which means you could draw 7 amps for 1 hour but in natural practice you cannot do that but that is what it implies. Each battery has maximum discharge current capability. So, for example; this is a C10 battery let us say then you can draw 7 by 10 that is 0.7 amps for 10 hours so it means 7 Ampere Hours something like that. So these two numbers you will have to bear in mind while designing batteries or choosing batteries that this 12 volt into 7 ampere hours turns out to be 84 watt hours. So 84 watt hours is the energy capacity of this battery.

Now, coming back to the screen here, there the ideal battery has a symbol which is like this as I explained earlier. A practical battery will have one more component introduced in the series which is the series resistance or in this case let us call is as R B, this is V B this is the positive terminal and the negative terminal and this is V T the terminal voltage.

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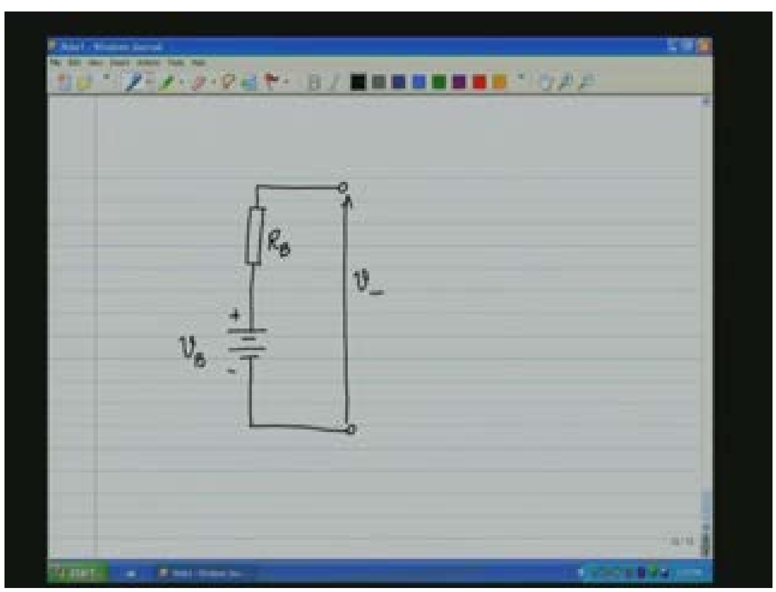

So you see that R B will have a finite value in all practical batteries. If a battery had been ideal RO would have been zero but it is not so unfortunately so you will have some value. And further, in the case of the batteries R B is not constant; R B is a function of state of charge of the battery state of charge of battery. What this means is if the battery is fully charged R B is low, if the battery is fully discharged RB is high. Therefore we cannot take R B as a constant value also like in the case of some of the sources. So how does the I-V characteristic for a battery a practical battery such as this look like.

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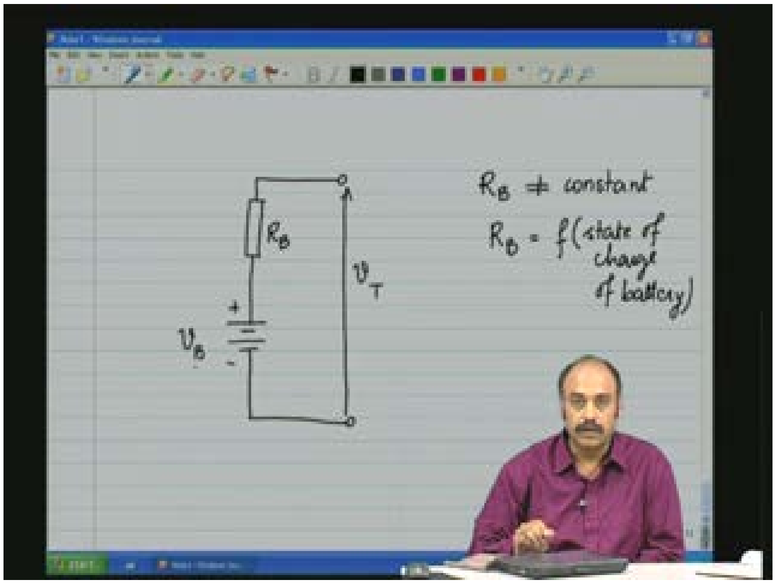

Let us now draw the I-V characteristic of this practical battery that we have been talking about; a battery which is composed of an ideal voltage source DC voltage source in series with the series resistance R B. So the Y axis is the terminal voltage, the X axis is the load current i so this point is load current of 0 amps or open circuit.

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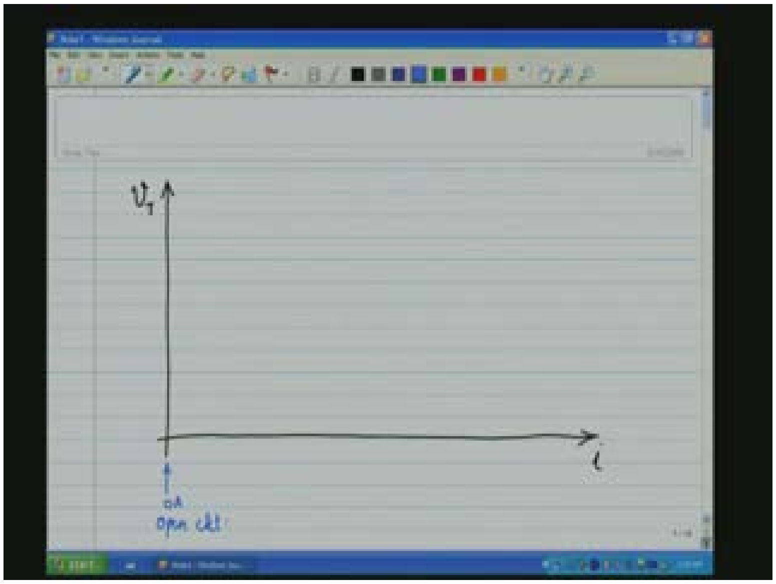

Now, one: there is no load, there is no i B R B drop and therefore the terminal voltage is same as the battery source voltage under ideal conditions which is V B itself and if they have not been i B this battery terminal voltage would have gone horizontal as shown here (Refer Slide Time: 44:29). However, due to the presence of R B as the load current increases there is going to be an i B R B drop which will make the terminal voltage to droop as shown here and this droop is nothing but i B into R B. So, if R B is less then such a battery is fully charged or it is a good battery, if R B is high then such a battery is either fully discharged or in poor condition.

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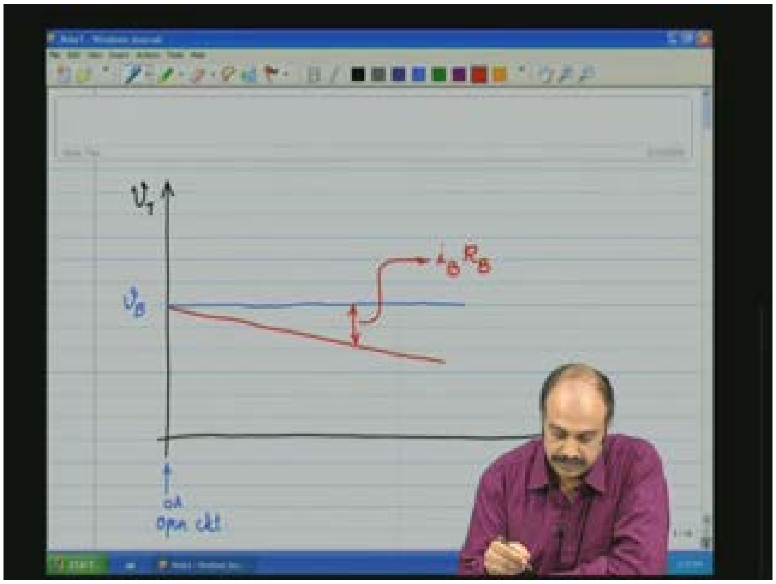

You should know that the battery I-V characteristics that we just saw is more of a general nature. The exact IV characteristic will differ from battery to battery, from the type of the battery to type of the battery, from manufacturer to manufacturer, from ampere rating to ampere rating and so on and so forth. So you should actually take the I-V characteristic data from the manufacturer's data sheet for much more specific details.

Now we shall go into another type of source called the solar photovoltaic cells the solar photovoltaic cells. As the name suggests here photovoltaic, the source is based on the principles of photoelectricity. It basically means that there is a pn junction and M-type material on a P-type substrate. So when sunlight falls on such a material the valence electrons are excited and they move into the conduction band and these conduction band electrons move in the external circuit and complete the circuit and if there is a load like a light or a lamp that it will get lighted up. This is the principle of the photovoltaic cell the most basic or simple or in its most simplistic form.

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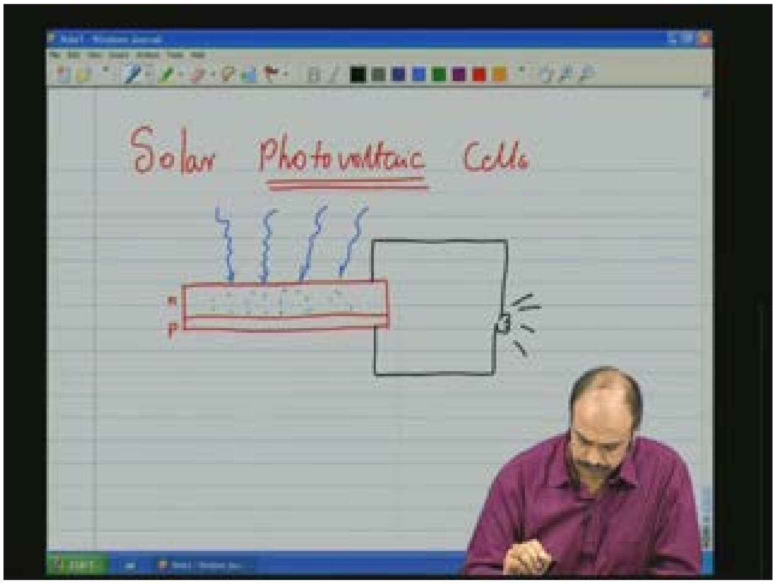

How do we represent the photovoltaic cell on paper?

It is like this. We have a rectangular block like this and a small triangular mesh layer up; looks like a post cover and it has two terminals, so this terminal is the positive end and this terminal is the negative end and we get the terminal voltage across these terminals.

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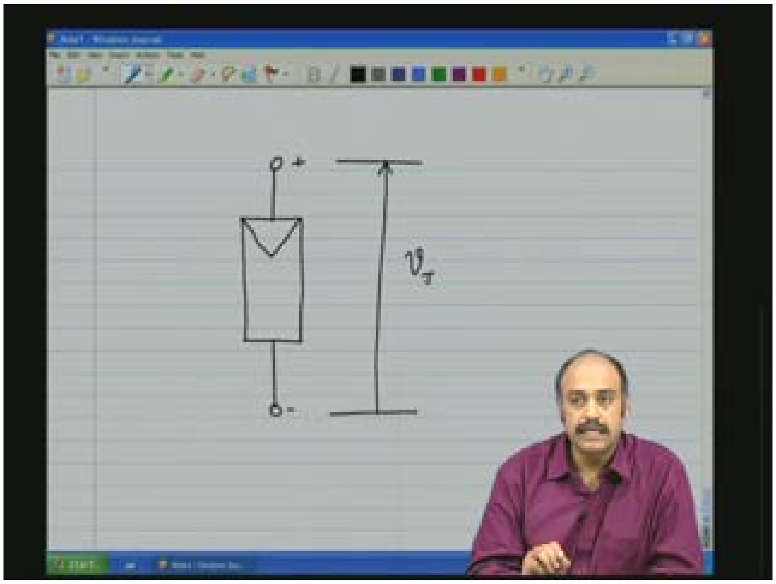

This is the symbolic representation of a photovoltaic cell.

Now we will see how a real world photovoltaic cell looks like.

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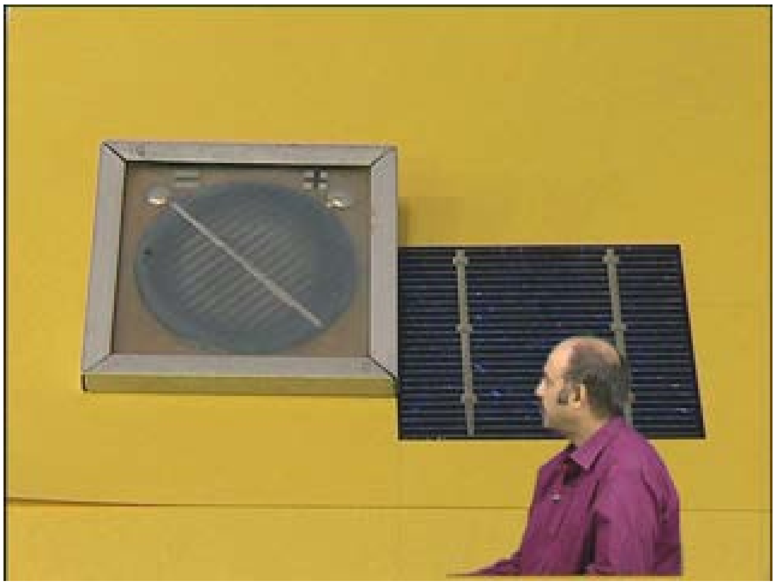

Typically a photovoltaic cell looks something like this. This is one such photovoltaic cell which is a polycrystalline cell (Refer Slide Time: 48:26), the one alongside is a monocrystalline cell. Let us have a closer look at this photovoltaic cell. You see this is actually a pn junction, the top layer would be a N-type layer and the sun rays would fall on this and on this there is metallization which are soldered on it on one layer and on the back side also you see the metallization so that we can solder one lead on this and one lead on this side and pick it up and that would be the two layers of the photovoltaic cell.

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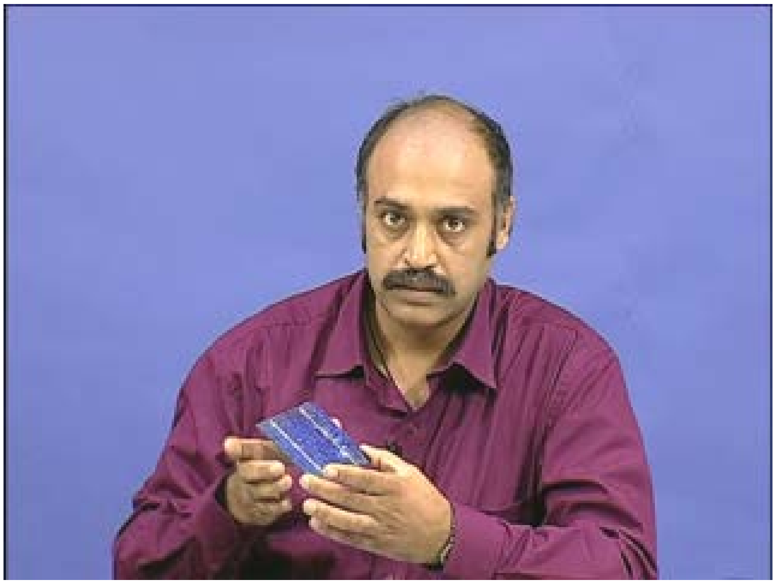

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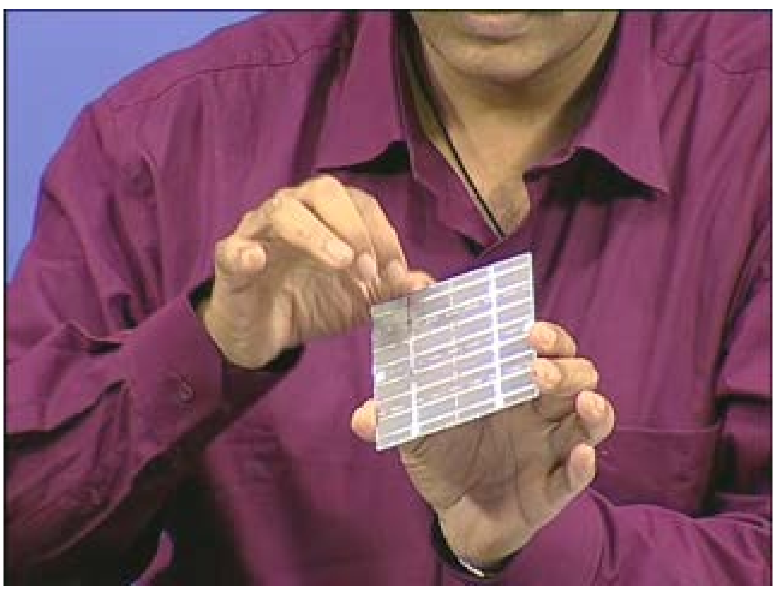

Typically the efficiency of this cell would be around 10 to 12 percent which means if you have 1 kilowatt of energy falling on this terminal power that you would get the electric power that you would get out of this cell would be something like 120 watts. So that is what the order of efficiency would be for any typical photovoltaic cell.

Now coming back to the slide general sources were categorised into two types: one is the voltage source and the other is the current source. However, the photovoltaic cell does not fall into either, in fact, it falls into both of these categories; it is a combination of both voltage source and the current source. This is the unique feature of the photovoltaic cell which is special to these types of sources.

So how does it behave both like a voltage source and also like current source? Internally if you look at the photovoltaic cell its equivalent circuit it consists of a current source so I am drawing an ideal current source which is like this. This is shorted by a……… bypassed by a diode like this and the terminals at this go on towards the output terminals and they result in the terminal voltage.

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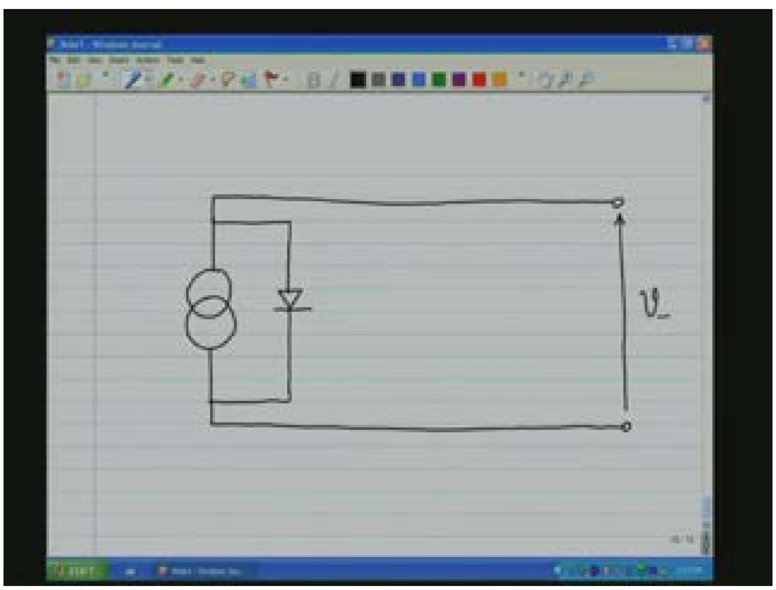

Now to this there are two components or non-idealities which get added: one is the shunt resistor which is the non-ideality of the current source and there is a series resistance which is the non-ideality of a voltage source. So you see there is a current source, there is a non-ideality of the current source which is the shunt resistance, non-ideality of the voltage source which is the series resistance and then the terminal voltage V T coming up there. So these are the equivalent circuit of a typical solar cell that would look like.

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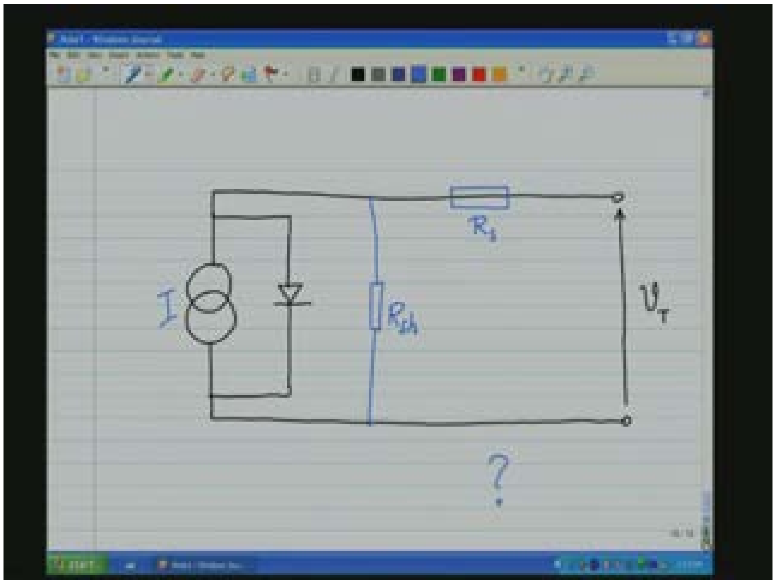

Then what is the V-I characteristic of such a cell or such a source.

So let us have a look at the V-I characteristic of such a source. Let us first draw the axis. y axis represents the current i or the terminal current of the photovoltaic cell. Now I told you just now that the photovoltaic cell or the solar cell behaves both as a current source and a voltage source which means a current source implies that I should have a horizontal line like that, a voltage source implies that I should have a vertical line something like that. So a photovoltaic cell an ideal photovoltaic cell will fall within this square template that I have right now drawn here. But there are some non-idealities in the solar cell that is it also has shunt resistance which is finite, it has a series resistance which is also finite non-zero.

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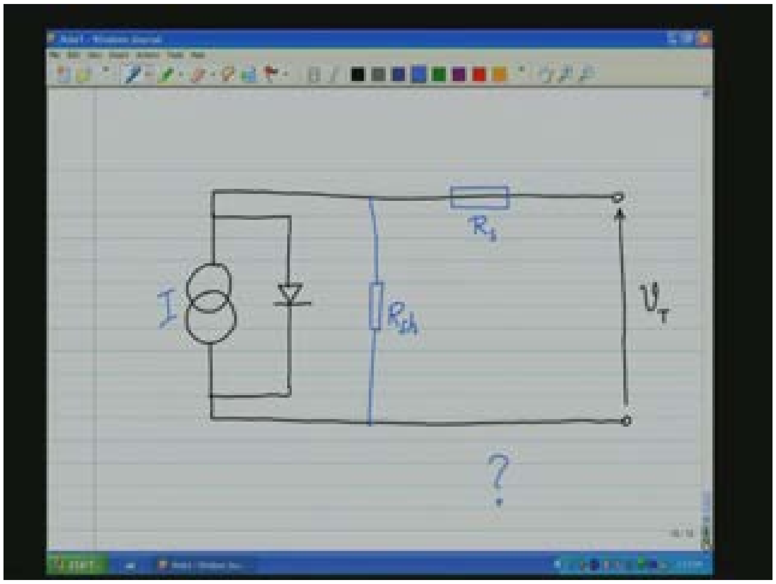

The series resistance we know affects the voltage source parameter. So instead of being vertical like that the voltage source is going to deviate from the vertical because of this series resistance or should I say the iR s drawn. The shunt resistance is going to affect the current source parameter. So because of the shunt resistance it is going to deviate from the horizontal current source effect due to the non-idealities of the R shunt and that is V by R shunt where V shunt is the voltage across the R shunt. So to that effect to that amount that much current keeps decreasing. So a typical real world practical solar cell will have an I-V characteristic as shown here in the red line; an ideal solar cell will have a characteristic as shown by the blue square; as blue squarish or rectangularish pattern there.

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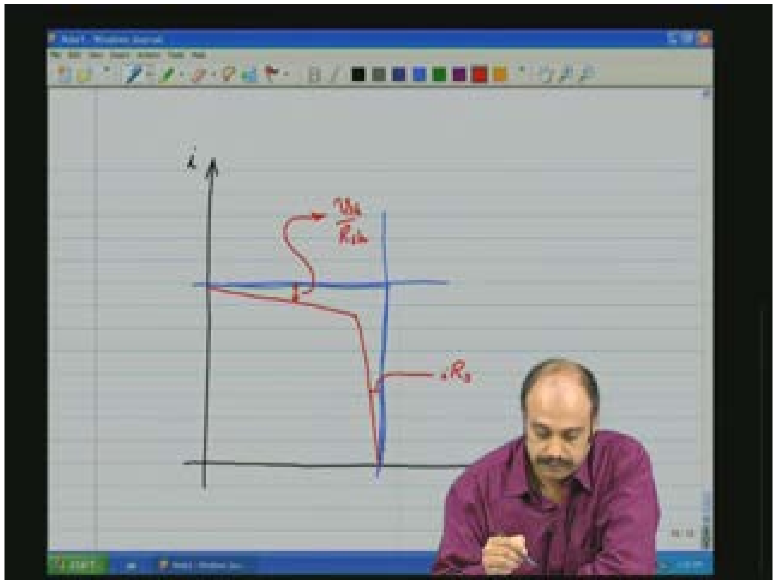

There are two critical points that you have to note in the case of a solar cell. One is this point and another is this point. This is called the short circuit current I SC point and this is called open circuit voltage V OC point. In fact, these two parameters of the solar cell are data sheet parameters where you may have to choose when you want to choose the solar cell for design. Another point that is of interest also is an operating point around here around the mean which will give you the peak power. This also is a data sheet point.

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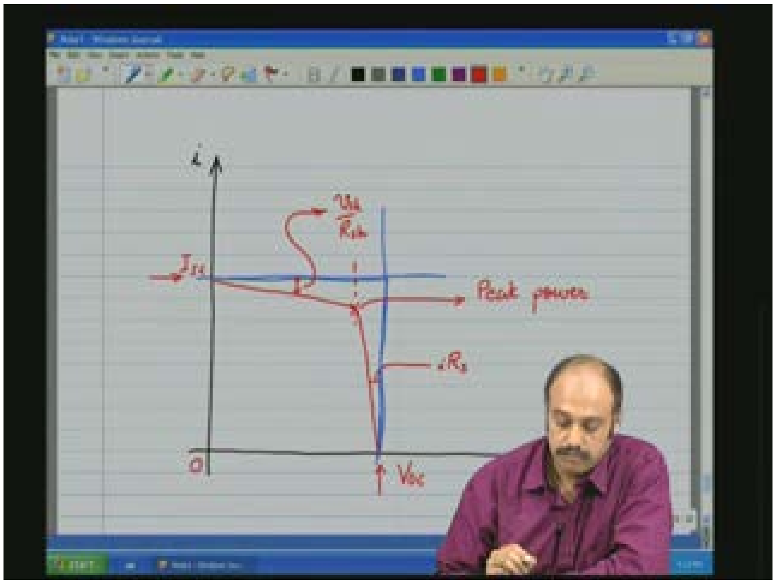

Summarizing for now, we saw that electrical sources are of two categories: the voltage source and current source. The voltage source has a non-ideality which is the series resistant R s because of which the voltage is not going to be truly horizontal but drooping. The current source is having a non-ideality R shunt. R shunt is supposed to be infinite in the ideal case but it is some large finite value in the practical case. And then we saw few real world sources that is the battery and the solar cell.

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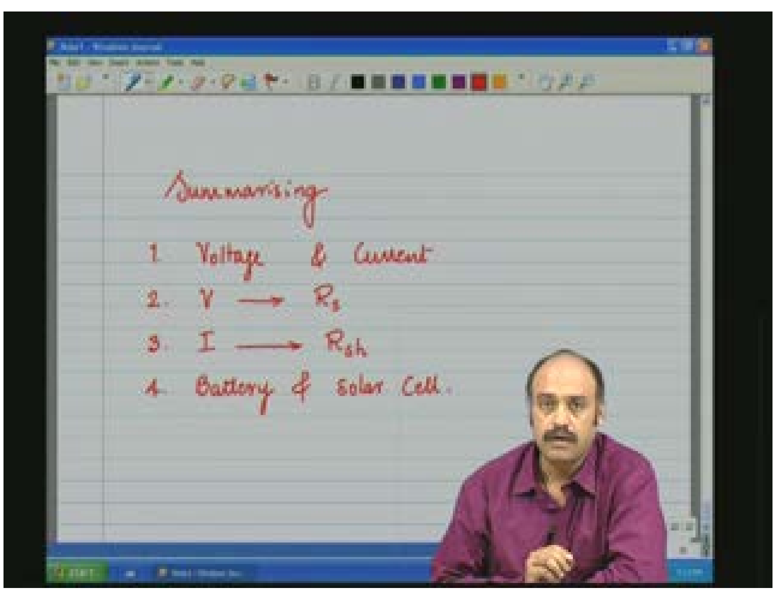

You should keep in mind that the internal resistance R s and the R shunt that we have seen in the discussion of today need not be purely resistive; it could also be inductive or could also be a combination of resistive, inductive and capacitive that is it could be an equivalent series impedance instead of just an equivalent series resistance in the case of the voltage source or an equivalent shunt impedance instead of a simple equivalent shunt resistance in the case of the current sources. And of course we did have a close look at these sources here; the lead acid battery and the polycrystalline, the monocrystalline solar cells.

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These two sources are DC voltage sources DC voltage and current sources in the case of a solar cell, a DC voltage source in the case of the battery. In the next class we will see the characteristics of the AC source one of the most important sources which is the wall outlet which comes from the wall outlet which is a 230 volt mains.