Basic Electrical Circuits
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Lecture - 4
Controlled Sources: Determining the characteristics of a two terminal element; Realizing a resistor using a VCCS or a CCVS

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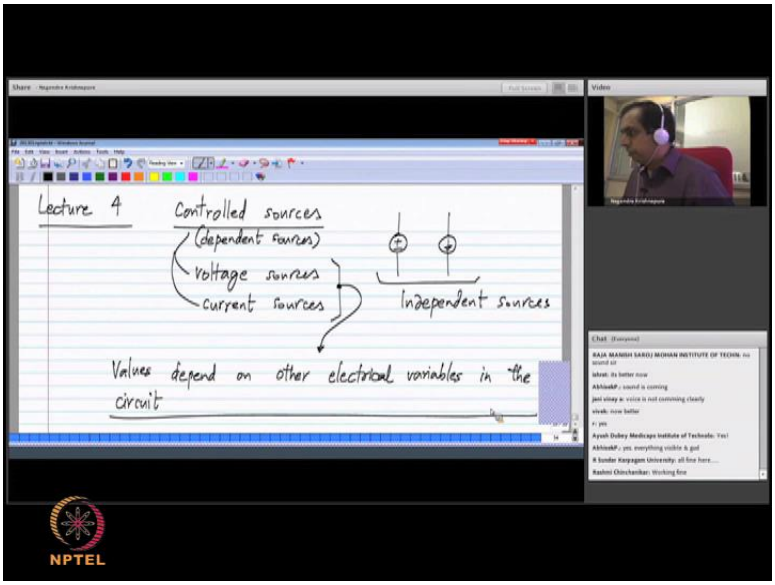

Now, we can get back to we can get back to earlier are you able to see, you might see the windows start up screen; I am starting the fourth lecture of basic electrical circuits and in the previous lecture we looked at what happens when you connect components in series and parallel. So, it was rather settled, but we tried to do it rigorously that we get all the sine conventions correct and in case anybody had doubts we also try to do rigorously so that all those doubts are cleared. In this lecture, what we will do is to discuss what are known as controlled sources. Now, when I say controlled sources what I mean is there are either voltage sources or current sources.

But the difference is the voltage sources and the current sources that we discussed so far denoted by these symbols are known as independent sources; that means, that the balance amount is dependent on anything else in the circuit the values will be given and they will be fixed. I do not mean necessarily that they will be constant with time; they have been considering sources that are constant with time later; we will see independent

sources, which can change with time. But here is what is meant by independent is that it is independent of any other electrical variable in the circuit.

So, consequently these controlled sources which are also sometimes known as dependent sources when I consider these things their values will depend on some other electrical variable of the circuit. So, determine what the controlled by we have four different types of sources; we have two types of sources there is voltage source and a current source and each of these can depend on either a voltage or a current, so that basis four kinds of controlled sources.

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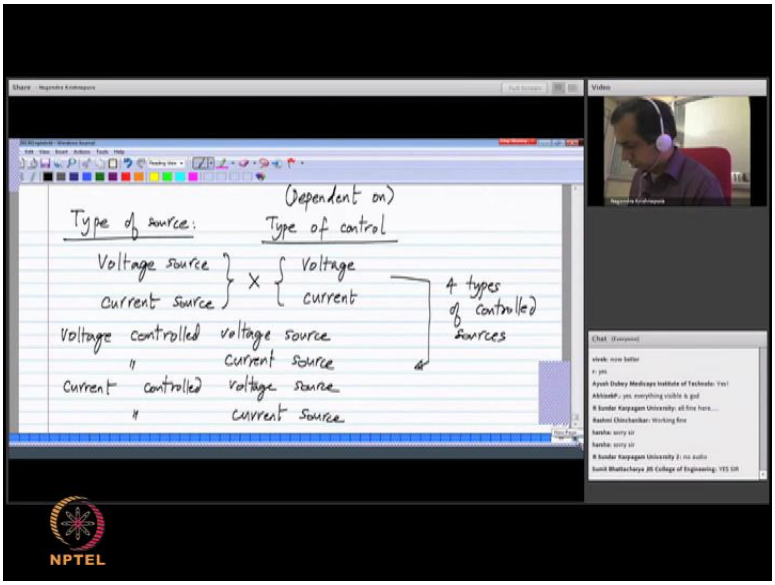

There are two types of sources a voltage source and a current source and they can be controlled by a say type of control or say dependent on they can be dependent on your voltage or a current. So, these two sounds these two possibilities give you four types of controlled sources: voltage controlled voltage source and the voltage controlled current source. Similarly, we can have a current controlled voltage source and the current control current source.

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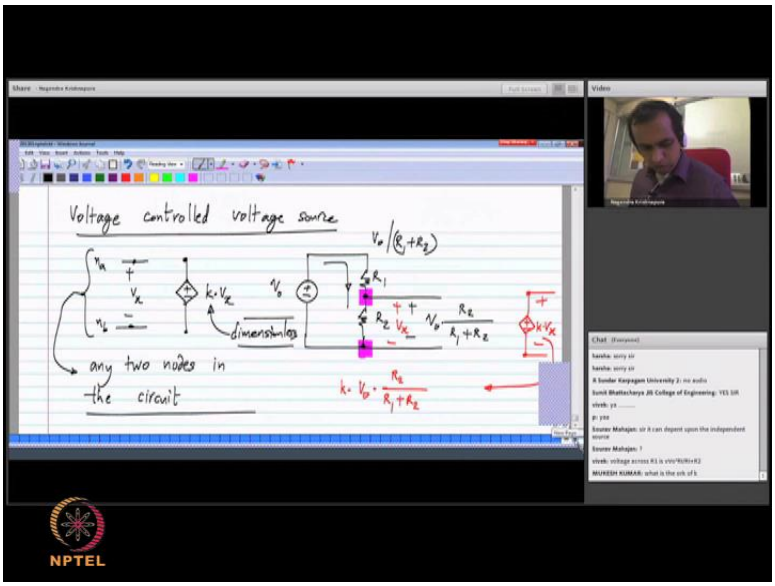

Now, what is a meaning of a voltage controlled voltage source? A controlled source is denoted by this symbol this you have the rhombus and this you have the circle just to distinguish it from independent sources and make sure you understand right of way that the controlled sources. The value of this would be k times v x, where v x is the voltage between some two nodes in the circuit. Now, it is very important to understand that this v x is not something that I applied from outside, but it is any voltage in the circuit. I will called these n a and n b and these two are any two nodes in the circuit.

Now, what we will do also give you an example that is why I have v naught connected to two resistors R 1 and R 2; the current flowing here would be v naught divided by R 1 plus R 2. Because the series combination of a the current source series combination of the resistors results in a semi resistors, which is the sum of the resistances and the voltage across this is v naught times R 2 divided by R 1 plus R 2. Now, I could have a current source controlled I could have a controlled voltage source in the circuit, which I will show in red that is k times o x and v x could be defined to be this one; v x is the example that is given to you in the definition of the circuit.

Now, in this case where it says the voltage across these points would be k times v naught times R 2 by R 1 plus R 2. So, it very much depends on what is v x s and v x s the voltage is being these two nodes in this particular circuit. So, in general v x could be defined to be anything that depends on the circuit and the voltage of the voltage

controlled voltage source will depend on v x. So, that is what is meant and also this k is the constant a property of the voltage controlled voltage source and it is dimensionless some left and you can as you can easily guess; it is a dimensionless constant.

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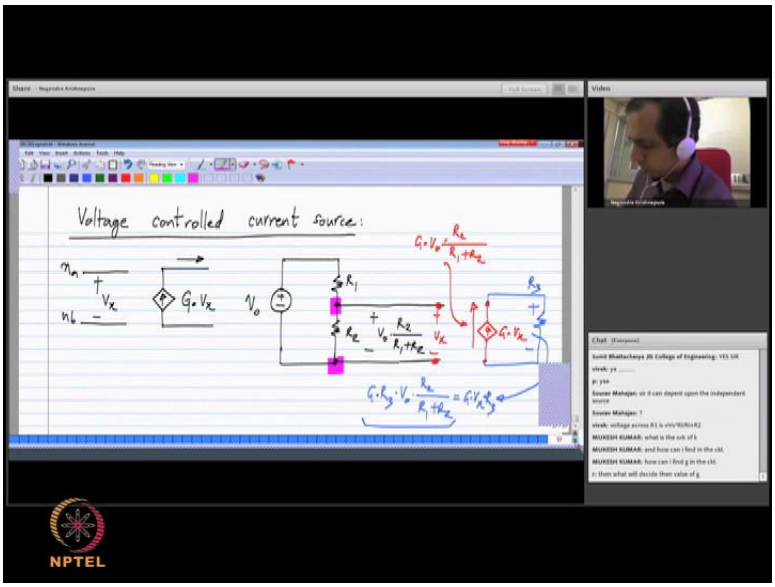

Now, the next slide of a controlled source is a voltage controlled current source. Now single to it similar to that of a current source, but it is round of to the circle and what it deals is the value of this will be some G times v x having v x is the voltage between some two nodes of the circuit. So, left side we have n a and then n b; v x is the voltage between n a and n b. So, what this means is this is the maintenance flow of current, which is dependent on the voltage between n a and n b. So, again as I was saying into to the example perhaps v naught, where v naught R 2 by R 1 by R 2 across the resistor R 2. I could have controlled current source, which is G times v x where v x happens to be defined like this in the circuit v x is the voltage between these two nodes.

So, what this means is this will the controlled current source will close the current, which is equal to G times G naught times R 2 by R 1 plus R 2 . So, if you let us say you connect the resistance for this R 3 really you cannot have a current source nothing connected to it those sometimes; we draw like that in a circuit our case is to be satisfied current source has always has to be connected to something where the current can flow. So, here let us say it is connected to R 3 what happens is that voltage across R 3 would be G times R 3 times v naught R 2 by R 1 plus R 2.

Basically, it is equal to G times v x the current source value times R 3 and that in turn equals this one. So, this is what voltage controlled current source does. It looks at the voltage between some nodes and this is a current that is related to related to this v x; the v x is the voltage between certain nodes. So, again what is most important to understand is that I am not connecting the voltage source v x to this whole thing; v x happens to be some voltage in the circuit, which is defined appropriately.

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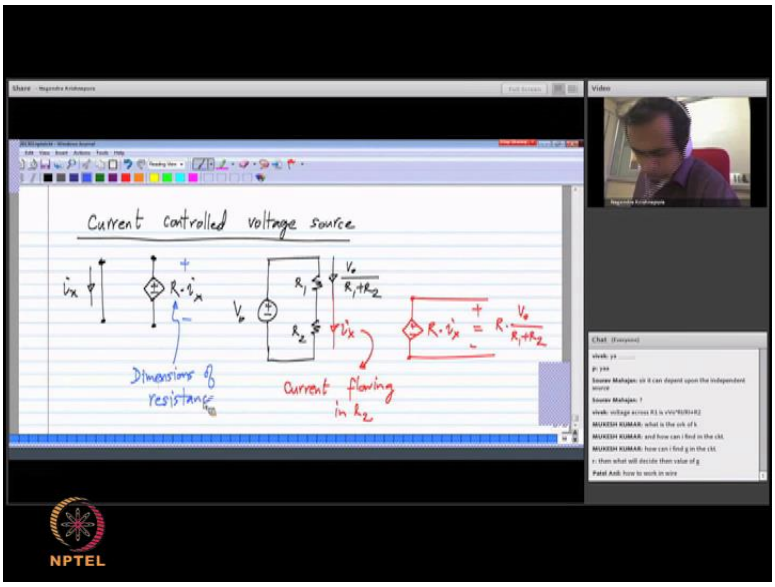

Next, we can consider current controlled voltage sources. Let us say I have a current controlled voltage source; what it means is that it is a voltage source its value depends on some current in the circuit. What is this current i x? There is some wire or some branch in which certain current i x is flowing and the value of this voltage source depends on the current i x. So, again I will take the same example v naught R 1 R 2; the current flowing here is v naught divided by R 1 plus R 2. Let us say I will have a current controlled voltage source and the current controlled voltage source is defined to have value R times i x.

This case let us define i x to be the current flowing in R 2, i x is the current flowing in R 2. What it means is, then the voltage across this would be R times i x. So, this happens to be equal to R times v naught divided by R 1 plus R 2 in this particular circuit. Now, one thing I have to point out here it will be a dependent voltage source and the voltage depends on the current and it is directly proportional to current and this constant of

proportionality; if you multiply a current and giving you a voltage the voltage across this is R times i x. So, the constant of that constant of proportionality has to have dimensions of resistance.

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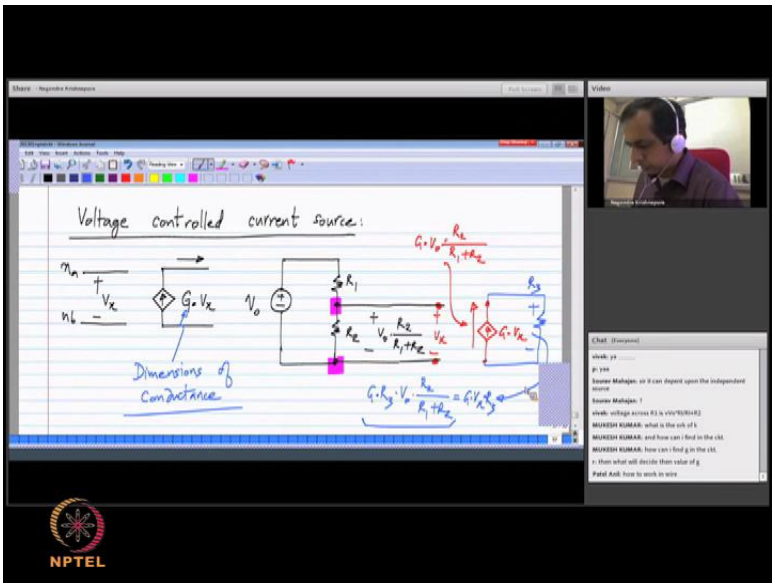

Similarly, in the previous case this constant of proportionality multiplies this voltage v x to give you a current. So, this has to have dimensions of conductance.

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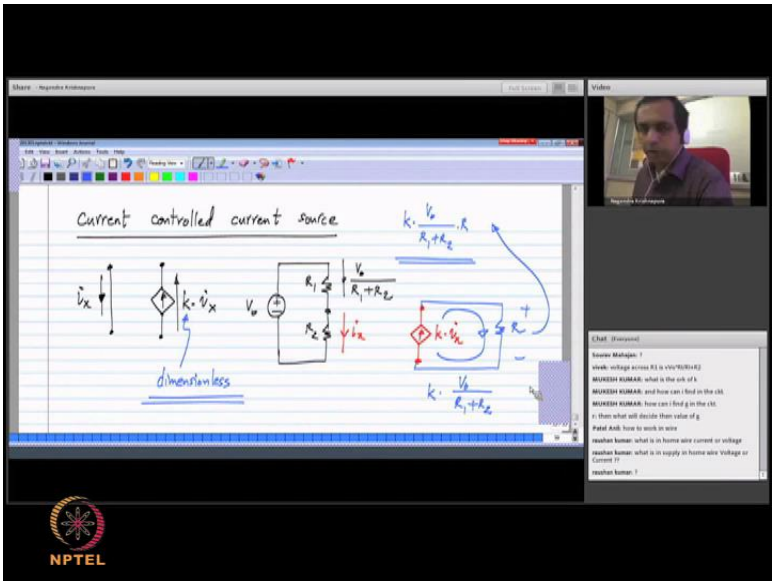

Finally, you take the last of the dependent sources which is a current controlled current source. Again, it is a current source that the value depends on another current that is the

current being posed by this current source; it was k times i x and i x can be any current in any part of the circuit. So, i x is going through this wire in general we would define the current to some branch to be i x. I will literally take my voltage divided example R 1 R 2 the current flowing here is v naught divided by R 1 plus R 2; if this voltage is v naught and let me define a current controlled current source to be some k times i x, where i x is the current through R 2 this is something that I would define.

Now, what it means is that this current source here will force the current, which is k times v naught by R 1 plus R 2 meaning; before I connect a resistance to it this will force a current k times v naught by R 1 plus R 2. It means that the voltage across this would be current times the resistance k times v naught by R 1 plus R 2 times R. So, that is a definition of a current controlled current source. So, that is the definition of an all the four controlled sources. Now, this constant of proportionality it is multiplying a current with your current say it is dimensionless in this case.

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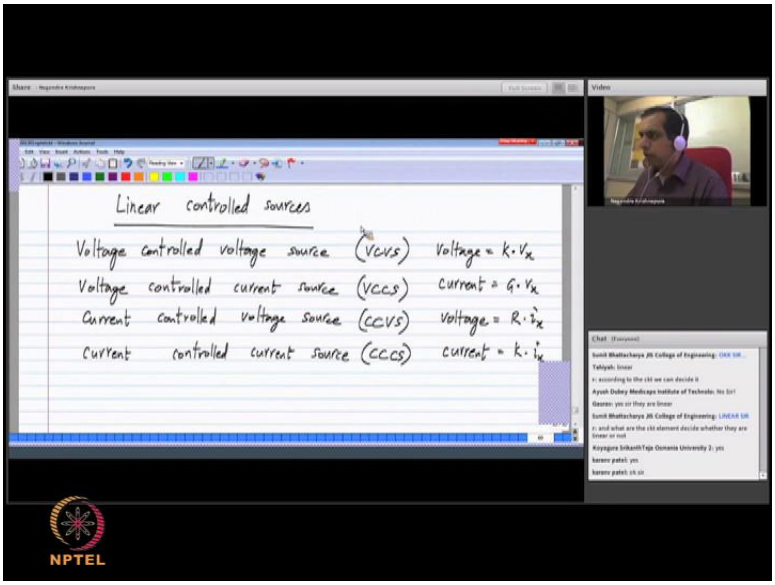

So, just a required summary you have four types of controlled sources: voltage controlled voltage source, voltage controlled current source, the current controlled voltage source and a current controlled current source. This is abbreviated to VCVS and this is VCCS, CCVS and CCCS. A voltage controlled voltage source is the voltage equals k times v x, where v x is some voltage in the circuit and voltage controlled currents source this is a current G times v x, where v x is some voltage in the circuit.

Current controlled voltage source, where it is a voltage across its terminals which is some R by times i x, where i x is some current in the circuit. Similarly, current controlled source poses a current rate it is k times i x. So, that is the one of the basic definitions. Now, I went through all the four definitions because they are sort of routing; now I will take all the questions any question that you have regarding controlled source or anything else.

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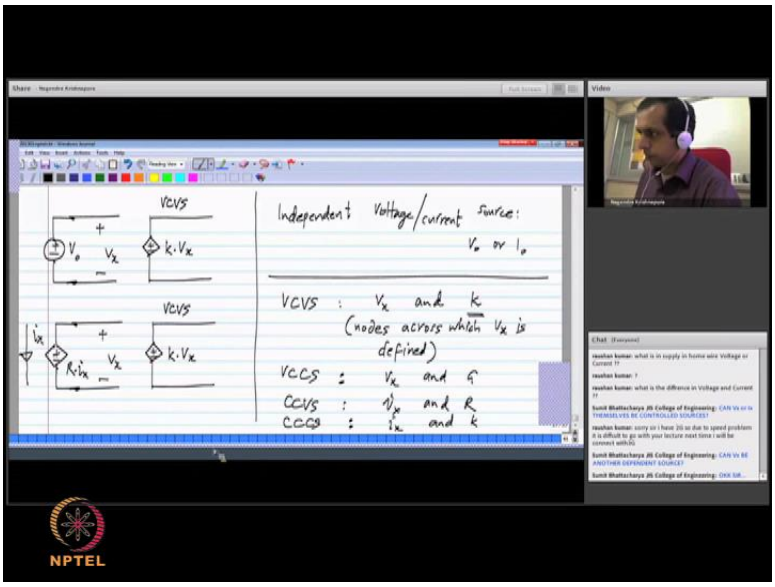

There are the two questions, one is can the controlled source be dependent on some value that is given by an independent source. That is also I have a VCVS that is voltage controlled voltage source and this says that it is k times v x. Now, v x is defined to be the voltage between these notes plus this voltage can very much be given by some independent source to this is entirely possible; it depends on the circuit. Now, this v naught, I mean basically this voltage controlled voltage source is this part this is voltage, which is k times this voltage minus that voltage.

Now, that can be any logic it can be given by any voltage source it can be a result of some other computer circuit all you have to do is define these two notes across, which v x is measured and that can very well do across an independent voltage source. So, that is possible and it is also possible that it comes from later on dependent source. So, let us say this v x could be the result of a current controlled voltage source, where this i x is current showing somewhere and this voltage source is R times i x. All of this is possible,

but v x can be anything it has to be some voltage defined properly in the same circuit that is all.

Now whether v x comes from an independent source or a dependent source all that is all does not matters that is only the details of the circuit. It can be a voltage across a resistor or in case of current controlled case; it could be current from an independent current source or a dependent current source whatever it is. The other question was how to find the value of k and so on? Now, these are given to you. Normally, if you have an independent voltage or a current source all you have to do is to specify the value of the voltage or current.

Now, if you have a dependent source let us say voltage current source you have to specify v x that is the nodes across, which v x is defined and again v x the voltage has a polarity. So, it says which is plus and which is minus over h and the value of k that is a given just like we wrote a value of a resistor or an independent voltage source we have to give the value of k. Similarly, if we have a voltage controlled if it is a voltage controlled voltage source you give v x and k voltage controlled current source you have to give v x.

G always will be given to you current controlled voltage source you have to say what i x is with i x it is and some R, which is the proportionality constant and the current controlled current source i x and G. Now, it looks like they are finished with the entire question. Now my question for the participants is are these sources linear. We discussed four types of controlled sources are they linear or not according to the definitions I have given.

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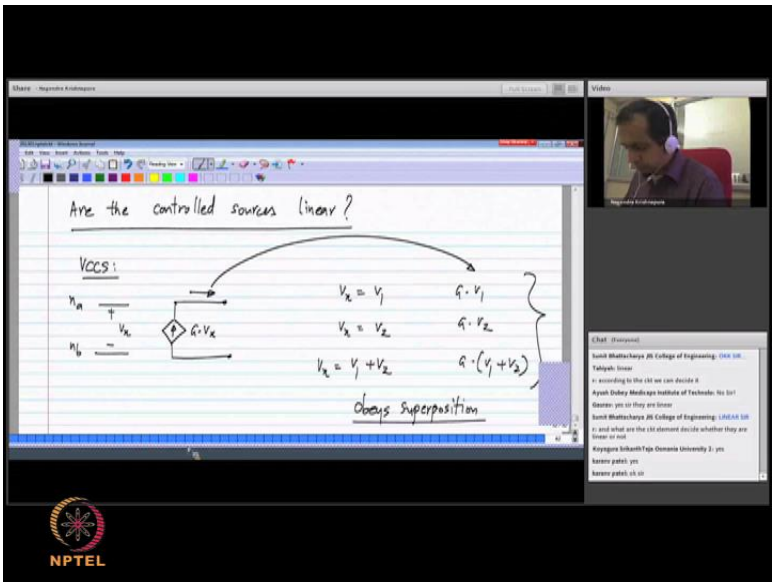

So, question is the controlled sources are linear here the way I have defined them. I think many of you have responded and you said that they are linear; some said that it is non-linear I am not sure why here it is very much linear. I will take the example of a voltage source current source, but exactly is the same that applies to all of them. If I have a voltage controlled current source; let us say this is defined to be the voltage between these nodes n a and n b and the current source value is some G times v x. So, what is the value of this current let us say if v x equals v 1 it will be G times given v x equals v 2 it will be G times v 2 and v x happens to be v 1 plus v 2 this will be G times v 1 plus v 2 and so on.

So, it has to be superposition length because the current will be G times whatever the voltage is and so from this relationship it directly it comes out with many other. This is this denotes proportionality through v x the current is proportional to v x and such a relationship is very much linear. So, it obeys superposition so that means that they are linear. In fact, the four types of controlled sources we discussed are linear controlled sources. So, all of these are linear controlled sources. Are there any other questions about controlled sources? Right now I will not use them I showed very simple examples.

But controlled sources later when we come to full fledge analysis we can allow the circuits, which include this controlled sources. Are there any other questions about controlled sources? So, another question which asks can a circuit be made up of entirely

controlled sources. It is entirely possible that is you can have a circuit, which has only controlled sources and nothing else. We will not look at how to realize controlled sources of course, that depending on circuit technology there are different ways of realizing controlled sources. But yes there are circuits, which can be made completely of controlled process. In fact, I have shown example of them.

About those of who came late controlled sources or the linear controlled sources we were discussing are either voltage sources or current sources, whose value depends on some other voltage in the circuit or some other current in the circuit. Now, all these lectures are going to be recorded. So, you can go back and watch the entire lecture. The hopefully we will put up soon today or tomorrow and you will be able to watch them. Is audio not clear is the audio not clear it looks like for some people audio is not clear, but for other it is perhaps you can check the settings at your end and see if audio gets better.

Now, some people have raised their hands; I will ask them to ask questions or the name is just is that how is the day.

Hello.

Hello yes

Hello

Vasu please go ahead.

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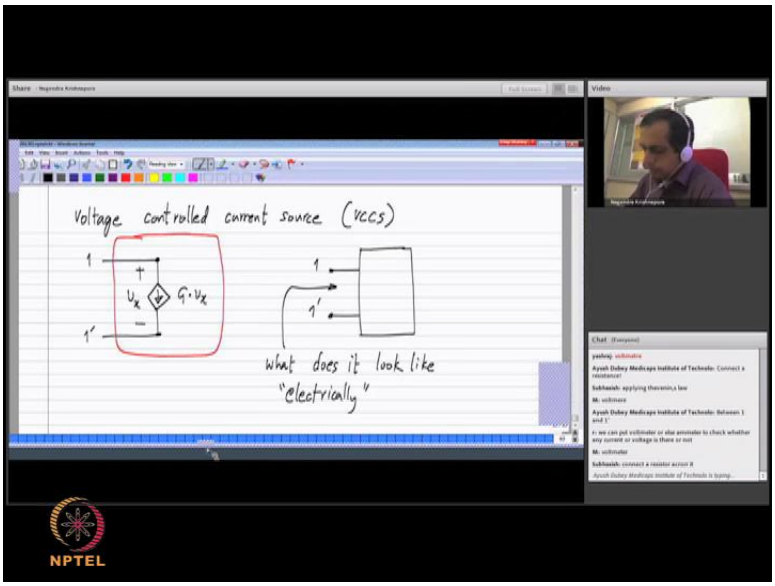

Now, somebody raised the question of whether a circuit can be entirely made of controlled sources I will show the example. Right away, I was thinking of doing it later. So, let me show an extremely simple circuit it is a voltage control current source I am using here are my just VCCS please mind the direction. Now, this is a VCCS and its value is G times v x and ideal data and the voltage to be across the voltage current of itself v x and let me call this these two terminals one and one point.

Now, this is very much a legitimate circuit now if i give this to you in a black box and asked you to find out, what it is what it looks like electrically between these two terminals one and one point what do you do. I would like answers from participants. That is I gave you a black box with two terminals and you have to find out what it is by making some electrical measurements what will you do. The question is and this comes as repeatedly right many times what happens is you can have a complicated circuit and you have two terminals coming out of the circuit.

You have to find out what it looks like when I say looks like looks like electrically from those two terminals. Now, we have while discussing series in the parallel elements it has two terminals and I have find out electrical characteristics or in general this could be electrical characteristics of a two terminal element. What should I do? What is the experiment I would do or what experiment that I would do that is the question. I have a

box here two terminals one and one point and I have to find out what it looks like and what is say I mean electrically.

The question for the participants is what experiment I should do or what analysis should I do to find out what it looks like electrically from those two terminals. Clearly, you cannot touch any other part of the circuit the only things that are accessible to you are those two terminals. I have not got any correct answers so far. So, please try it again the question is very simple I have box with two terminals; however, I just have a two terminal element you have to determine what it is that is; obviously, when I say what it is it is highly characteristic and your numbers before .

So, what is it that I should do to find out what element it is or what characteristics it has? Unfortunately, i did not get any correct answers. So, i am going to explain that. This is very simple right how do we distinguish one element from another? How do we know that something has a resistor or voltage source or a current source? Also we have told in many cases, but I am saying you have not told. You have to evaluate the I-V characteristics to find out what it looks like in the I-V plain. So, where there is current and time voltage and you vary that voltage and find the current and from the resulting characteristics you can figure out what it looks like electrically.

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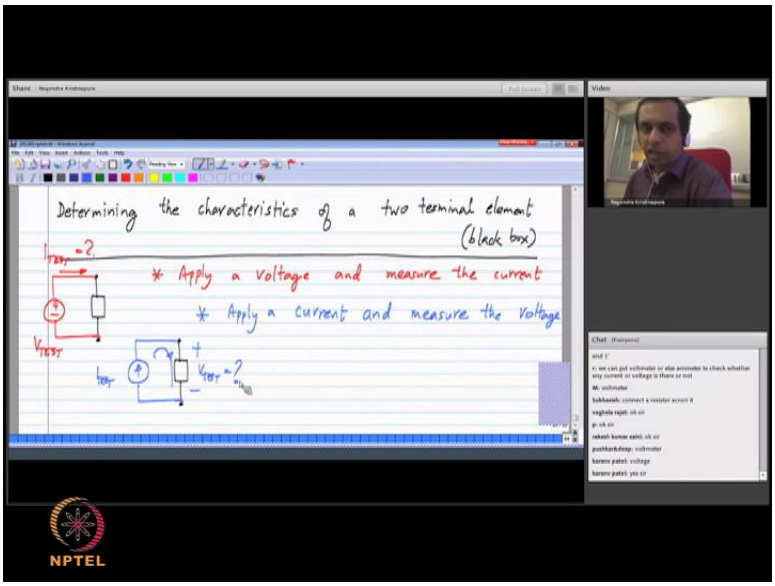

In two terminal elements it could be two terminal elements or a black box and it is understood that you would not get to know you would not know what the element is. So,

you are just given a box like this and there are two terminals. So, all can do is you apply a voltage let us say V TEST and you measure the current. Alternatively, you could apply I TEST and measure the voltage; now this measures the voltage across the elements. You apply a current and measure the voltage. Now, in a lab you are given a two terminal box this is what you have to do and also on analysis this is what you have to do. You either apply a current or measure the voltage or you apply a voltage and measure the current with the terminals.

You apply the voltage across the two terminals and measure the current through the terminal. Similarly, you push a current into a terminal and measure that voltage across the terminals and you use the appropriate sign convention, which is the passive sign convention by this is what we use when I say will apply and measure. It could be either a measure or calculate or you vary the value of I TEST and you make a clot any of these things is the same I will just call it measure and it could be any of these things is that part clear. Wait for the very simple elements we have and see what we get.

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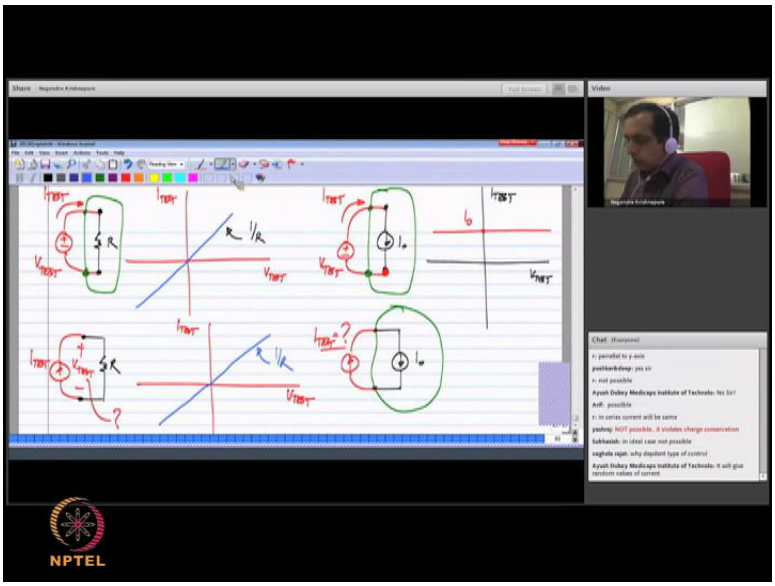

So, let us say I have a resistor R now we can pretend as we do not know this that I will do the experiment we need not know; what the characteristic was that or the resistor was put up in a box and apply V TEST and measure the value of I TEST what am I going to get. Because every V TEST what will happen to I TEST the question is in this experiment if I vary V TEST and go on measuring the value of I TEST what will happen

to it how will it vary. As many of you obviously, guessed I TEST would be V TEST by R and like I said we do not know; what is in the black box that if there was a resistor in the black box what we would find is let us say V TEST would measure I TEST.

I cannot plot it that is why I vary V TEST from our negative value zero to positive values and plot I TEST having got a straight line passing through the horizon and it will have some slope. So, result to find the straight line passing through the horizon. Then, I know it is a resistor it is equivalent to resistor the inside the black box let me mark the stop there is the box and I cannot see inside the box, but I will just write measurements at these two terminals. I seek characteristics like this; I know that this is a resistor or equivalent to a resistor what is inside or whatever is there inside is equivalent to resistor that it follows ohm's law, where current is proportional to voltage.

From this slope I can also calculate what the value of the resistance is. What is the slope of this line? Read again a question for the participants what is the slope of this line. So, clearly the slope would be 1 by R. So, again if you think about black box you do not know what it is you make this measurement you find that you get a plot, which is a straight line passing through the horizon and you take the inverse of the slope that to in a resistor and you take the inverse of the slope and that gives you the value of the resistance. Now, similarly let me say I have a voltage source that is my element I do not know the value.

Now, let me say a current source I naught what I will do is again in the black box. So, I will apply a test for this and measure this current I TEST what I will say in this case. Now, this is what you will see in the black box I am telling you that and I may turn measurement only at these two terminals I am not looking inside and this case; what is the kind of plot that I am going to get. My question is inside a black box is a current source or I make this measurement at the terminals what is the kind of plot I will get. Obviously, it is a constant current the current will not change we can change later what we want that the current is not going to change.

So, the plot that you will get we will do a straight line parallel to the horizontal axis that is basically a horizontal line and the value of that when it cuts the vertical axis that gives you the value of the current source. So, with I naught this will be I naught. Similarly, I can instead of using a voltage source let us say that the black box and the resistance or I

cannot use a current source instead and in that case I measure the voltage I measure the voltage. So, it is very clear that if I plot I TEST versus V TEST you know that in this case I am varying I TEST and finding the V TEST the instant plot is I versus V because that is what we have been doing all along.

So, it is very clear that I got a graph that is exactly the same as this one that is I will get a straight line passing through the origin and the slope of that would be l by R. Now, let us say I have a current source currently the same earlier I said that if you have two terminals you can either apply a voltage and the voltage current or apply a current and measure the voltage. Now, let us say my black box consisted of a current source. Can I now apply a current and measure the voltage? Is it possible? This is question for the participants, earlier I have said I apply a voltage and measure the current or apply the current and measure the voltage now is that possible in this case and the black box contains a current source.

Now, some of you said it is possible and some of you said not now this is not clearly possible; because we are talking about a case of ideal current sources and this is not possible. You can say in practice what happens if I do not connect it the answer is in practice you will never have an ideal current source. So, it is very much possible. So, now in principle you can either apply a voltage and measure a current or apply a current and measure a voltage in practice one of them may not be possible; especially it should have ideal elements, but in principle either of the I mean in principle one of them is always possible and you will be able to do that.

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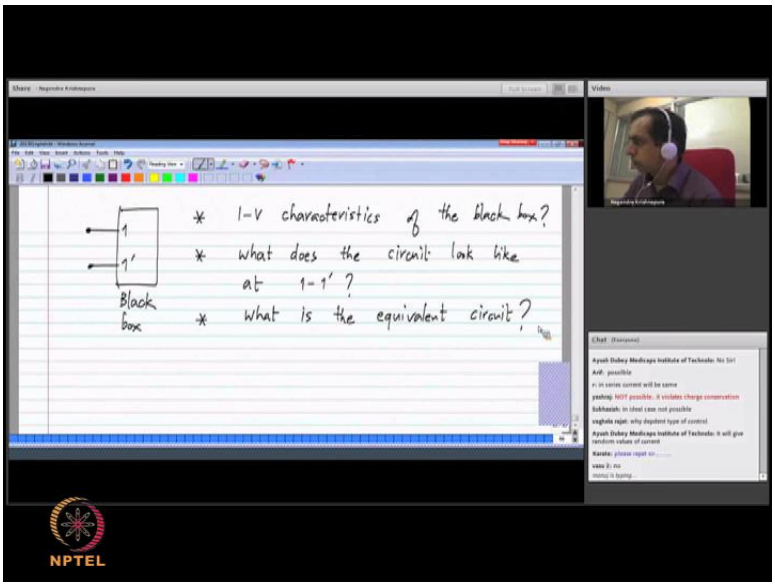

Now, this question is asked in many different ways. You could be asked or this is one main terminals one and one prime this is a box black box. You could be asked what is the I-V characteristics; what are the I-V characteristics of the black box; how does the circuit look like at the terminals one and one point or you could be asked what is the equivalent of this circuit. In all these cases the total experiment or the experiment or the analysis you do is this you either apply a voltage or measure the current and from that you figure out or what is inside when I say what is inside it is equivalent to what is inside. For instance, let us say you have a black box in consists of two resistors in series.

What you can measure from the terminals is the combined value of the series combination? You will not be able to tell that there are two resistors or twenty resistors in series, but what you will be measure is the equivalent resistance and that is going up. Because when you have twenty resistors in series it acts like a serial resistor because value is the sum of twenty resistance values that is number one. So, this is the analysis you have to do. Secondly, sometimes you may not be able to either apply a voltage source or apply a current source, but then you find that you get stuck with analysis. Then, you switch to the other one then go ahead with the analysis.

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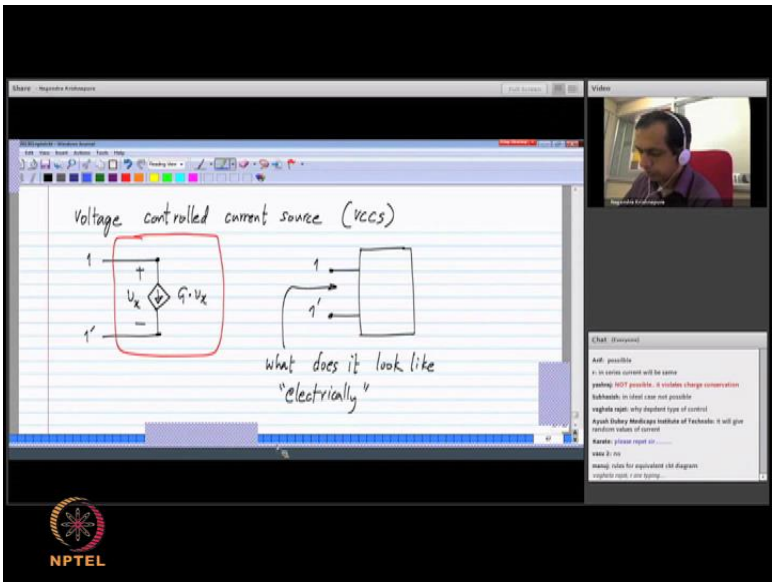

Now, with this diagram let me go back to my earlier question, which is I have this circuit and it is inside this black box and it has two terminals one and one point. Now, my question is what do this look like electrically, what are the I-V characteristics working into one and one track. So, you have to do as I said earlier you either apply a voltage and measure the current or apply a current and measure the voltage. So, please do that and give me the answer the relationship between the voltage across these two terminals and the current through the terminal one or in any other way you seek it please give me the answer to this.

What does this black box look like at terminal set one in one point was the question. So, again there is no random guess work or anything that is necessary. Many times some students resort to that well what you have to do is to approach it systematically; you either apply a voltage and measure the current or apply a current and measure the voltage. Let us see and see what we get.

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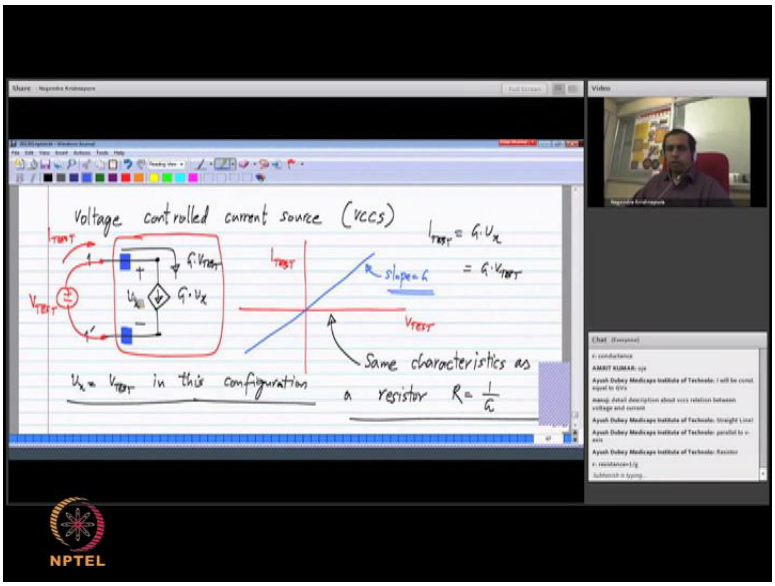

I will apply a voltage source V TEST. Now, the value of this current is v time v x where v x is the voltage between these two nodes; whatever the voltage applies there this v x would be the difference between those two nodes. Now, this difference between these two nodes when we connect this V TEST it is exactly equal to V TEST. In this particular circuit in this configuration v x equals V TEST in this configuration. So, clearly the current flowing here will be G times V TEST. So, if I plot let me call this current I TEST if I plot I TEST versus V TEST what I see would be; what kind of state will I get; what is the state of this plot?

Clearly, it is going to be a straight line because I TEST is G times v x is the current of the voltage controlled current source and that is G times V TEST. So, it will be a straight line and the slope of the straight line will be G. Now, what are the two terminal elements that we know which has these characteristics; we know some two terminal elements, which have these characteristics what is that. So, clearly that is a resistor the resistor has I TEST versus V TEST it is a straight line passing through the arc origin that is these characteristics are the same as a resistor, whose value is 1 by G.

So, then we can say that whatever is inside is equivalent to resistance or value from 1 by G. Now, I came to the circuit because somebody asked the question about circuit consisting of only of controlled sources well like; I said you can have many full circuits consisting of only controlled sources and this is one example. Now, in this case this is a

voltage controlled current source and I have defined the controlling voltage to be across the voltage control current source across the same element. So, in that case the current will be proportional to the voltage; that means that it behaves like a resistor.

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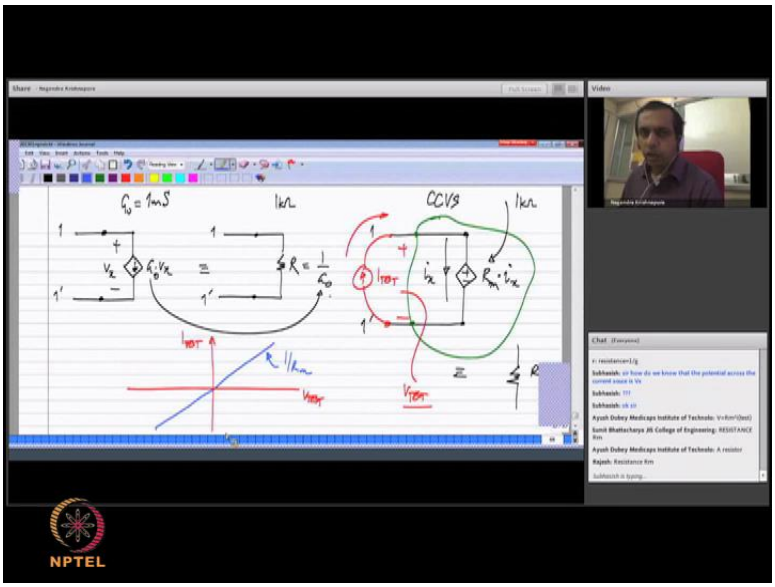

I have G times v x, where v x is defined across this. So, that is the special part about this circuit this could be anywhere; in this circuit it happens to be across the same element. I can say this is exactly into a resistance R, whose value is 1 by G where G is this one if I call this G naught just to distinguish it from a general G that is used for conductance R will be 1 by G naught. So, between the terminals one and one point it looks like a resistor any questions about this.

Hello.

Yes.

Hello sir.

Speak.

In the last question,

Yeah.

In the last question you treated the black box there was a current source inside the black box.

Yeah.

But when we plotted the I-V characteristics there was characteristics of similar to resistor.

No, it was not where I have told that in this one are you talking about.

Yes sir.

Are you talking about the voltage controlled current source?

Yes sir.

Yeah. So, in that case here that is correct. So, in this case the characteristics come out to be similar to that of a resistor that is because the controlling voltage is determined to be across the controlled source; v x is defined like this. The characteristics that we would say is depend on what v x axis is in this case v x is defined to be the voltage in one and one point. So, this is how the characteristics will.

We will not be able to decide that there was a current source sir, but we will not be able to decide there is a current source inside.

That is right. You will not be able to decide because this looks like a resistor. So your voltage controlled currents are dependent that a voltage controlled current source is dependent current source is not the same as an independent current source. So, its characteristics will depend on the controlling quantity and it can be different in different contacts. So, that is what is going for equivalent; that is data resistor in a black box or a controlled source connected to this like this in a black box or it could hundred resistors in series in a black box. All you will be able to measure is that you will have a resistance of some value exactly what is realizing that resistance you will not be able to measure.

So, that is what is meant by a black box. Now, there is there is another question how do we know the voltage across this is v x as the definition of v x; when you give a voltage controlled current source you have to say v x is in the circuit. In this particular circuit and we have defined v x to be the voltage between these two terminals. So, that is the

definition of v x and i also have to give the value G, which is the proportionality constant between this v x and the current. Let us start with the definition of the voltage controlled current source. There is a question from Vasu please go ahead.

Like, I was saying you cannot distinguish you cannot figure out what is inside the black box what is the meaning of the black box; what we can say is that the terminal characteristics that is the characteristics looking in from the two terminals one and one point in this case we will be live something. So, in this particular configuration it looks like a resistor any other questions about this. Similarly, you can work out this example for yourself I will take a current controlled voltage source, which means that it is a voltage source having current having a voltage source which is some R, I will say R m just to distinguish it from a resistor R m times some i x.

I have to define what i x is and I will define i x to be through the same source that is i x in this case is through the current controlled voltage source. Then, I call these terminals one and one point and I will say this is the black box now please tell me what this black box looks like from the terminals one and one point. Earlier, I worked out the example with a voltage controlled current source; I think now you should be able to work out the example of a current controlled voltage source by yourself. Also now you should understand what is meant by what does the element look like or what does the black box look like between a pair of terminals on a one and one point.

I think now you got the idea and in this case you have to apply a current and measure the voltage because you have another voltage inside voltage source inside you cannot connect the voltage across it. You have to measure a current like I have said sometimes you have to do that you push a current I TEST and you measure the voltage V TEST and if you do that you clearly see that V TEST will be R m times I TEST or if I plot I TEST versus V TEST i will get. I will get a plot like this a straight line passing through the origin whose slope is 1 by R m. So, these are the characteristics which I am going to get. So that means it also looks like a resistor of value R m.

So, again let us say in the first case here I adjust G naught to be 1 milliohm or I take a 1 kilo ohm resistor or in this case I adjust R m to be 1 kilo ohm and define i x to be current through this branch or in this case define v x to be the voltage across this controlled current source. In all these cases if I enclose all these things inside a black box and give

you only the two terminals what you will measure is the resistance of 1 kilo ohm and you cannot distinguish one from the other. So, that is what is meant by equivalent. So, all things are equivalent to each other.

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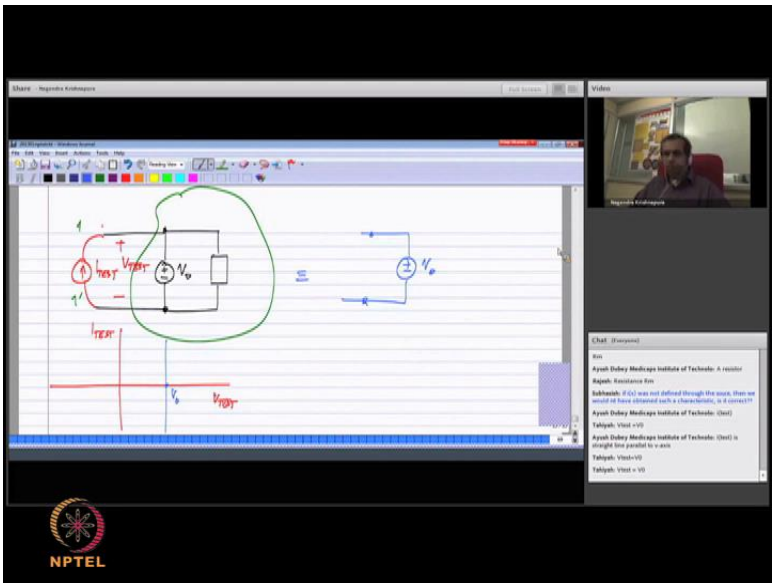

Now, earlier I discussed this already, but in the same sense that if you have a voltage source in parallel with something it could be anything. Obviously, you cannot connect another source in parallel, but anything other than that is fine and I put this inside black box terminals one and one point again. So, now if I measure I versus V let us say I apply a current and measure the voltage across it what will I see I TEST versus V TEST I apply a current and measure the voltage across this element and I plot I TEST versus V TEST what am I going to get.

So, the question is I have a voltage source let us say v naught in parallel with something it could be anything; it could be a current source; it could be a resistor or it could be some complicated interconnection of hundred components. What is it going to be what will be the I TEST versus V TEST. There the meaning of the question is I go on varying I TEST and I go on measuring the value of V TEST for every value y test and then I have got I TEST versus V TEST what is the plot that I will see. So, somebody said it is parallel to the v axis that is not correct; in this case it is parallel to the y axis because whatever I TEST you have you have a voltage source here.

So, V TEST will have to be v naught. So, whatever the value of I TEST you will simply get a plot like this where this point is v naught. I have assumed the positive v naught if it is negative it will be on the other side, but that is the plot. So, this will look like a voltage source that is the point I was trying to get across so; that means, that a voltage source in parallel with anything is a voltage source itself. So, this we discussed earlier. Similarly, if you have a current source in series with a resistor or something like that it will this will be a current source. Because you measure the I-V characteristics it will look like that of a current source so; that means it is a current source.

Now, there was another question from Subashini asking if i x was not defined to be like this if i x was not the current flowing through the controlled source; then we would have not get this straight line characteristics and that is correct. So, depending on where i x is we have to define it in somewhere in the circuit; if it not through this we are assuming that it is more complicated circuit and i x is somewhere else. So, in that case i x would the characteristics I TEST versus V TEST would be something else and it will depend on the details of the circuit and any other questions.

We are nearing the end of the session. So, if there are no more questions we can end the session now and in the next lecture we will look at certain other quantities, which are derived from voltages and currents that is the power and energy in elements. Go through all the elements that we know and how a power and energy are in the behavior of power and energy in each element. Then, from there we will take the discussion forward to another kind of element and go on.

Thank you, I will see you in the next lecture.