Basic Electrical Circuits
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Lecture - 10
Thevenin and Norton (Theorem and) Equivalent Circuits
Power Conservation in a Circuit

Now, when we were looking at some general representations of linear circuits, which can be used more widely. So, we are in the middle of sort of generating an equivalent circuit for a complicated circuit. So, in the meanwhile if you have any questions about what we did in the previous class or anything before that please go ahead. Any questions about things we were discussing in the previous class? So, let me get back to what we were doing.

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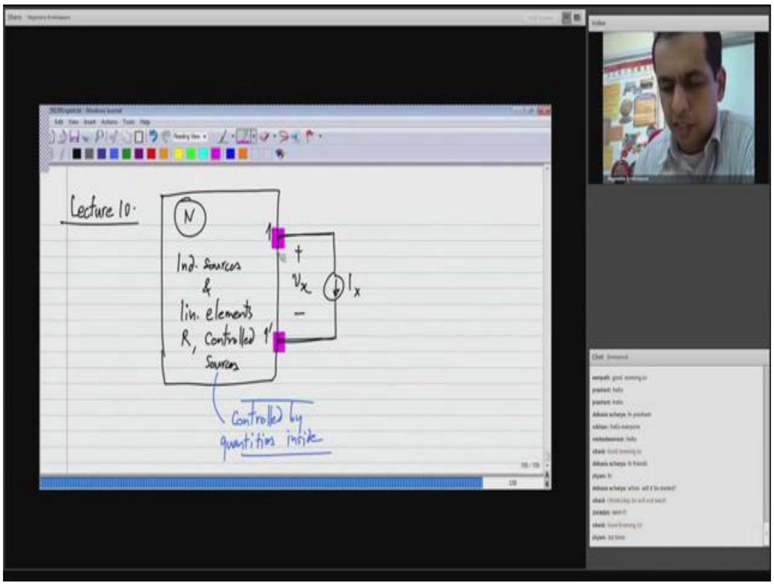

Now, what we are looking to do was to take a circuit of this sort which consists of linear elements and linear controlled sources which are controlled by quantities inside. This is this network N and then it is loaded by current source I x, which could be a current source or it could be the equivalent to any other load or complicated network that is connected. We know from substitution theorem that if you had some other network here, we could replace it by the current, current source that it is drawn. Now, what we did was this is a linear network so super position applies and we can analyze this in two steps, which is what I have shown here. Let me copy this stuff over.

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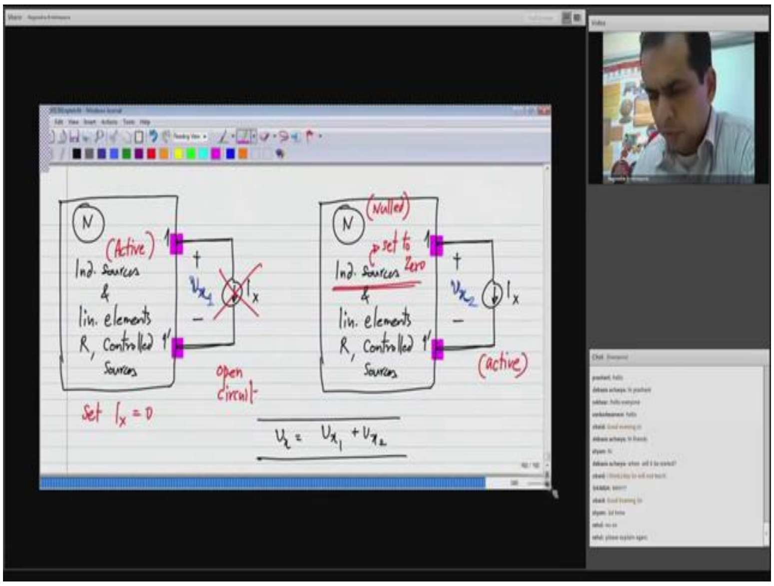

So, I will do a two-step analysis of this. I have a number of independent sources inside and I also have this independent current source I x, which could be a current source or it could be a substitution for some other element or some other load. So, first I will deactivate the current source that is I x is equal to 0 and analyze this circuit that is at these terminals 1, 1 prime. I will define the voltage V x 1. Next, I will set all the sources inside, all the independent sources inside to 0, so that is known as nulling the circuit. Then, I will analyze the circuit with I x alone. So, I x is active in this case. So, clearly by superposition, in this case when everything is acting, that is when you have the load or it is represented by I x plus when you have all the independent sources inside the circuit, you will get a certain value V x.

And this V x which is the solution you are looking for is nothing but V x 1 plus V x 2. What you calculate from this step by setting this I x to 0 and then this step by setting all the independent sources in the circuit to 0 and that is nulling the circuit and finding the voltage. Is this part clear splitting of the circuit like this? Any questions about splitting of the circuit in this manner? That is first I will activate all the current sources inside deactivate this I x, then I will null the circuit and have only I x active.

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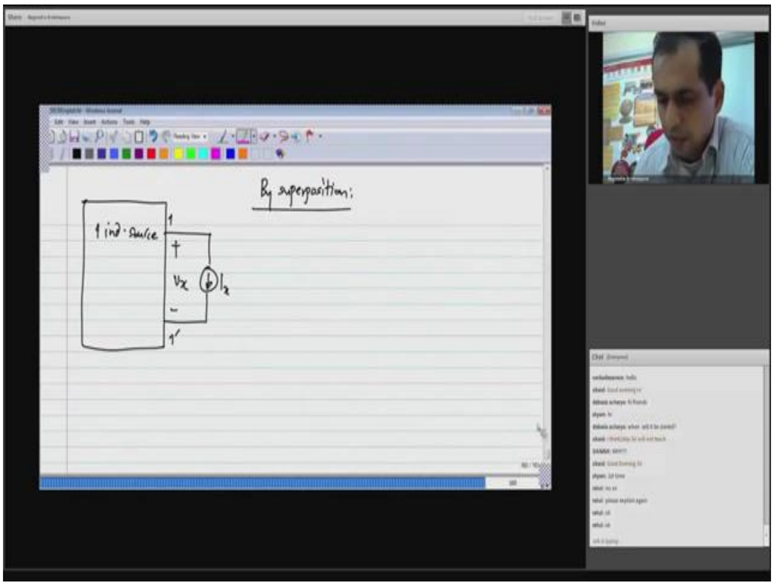

So, let me just imagine that I have only 1 source inside and 1 independent source outside which is I x. So, clearly by superposition. What is the meaning of superposition? if you have a number of independent sources in a circuit? We can and then let say, you want to find a certain quantity let say this V x at this terminals 1, 1 prime. Then, what you can do is analyze the circuit with each independent source activated at a time.

So, here are number of independent sources, you set all the independent sources to 0 except 1 of them. You find the value of V x from that 1 and next you take the next source and set that 1 to a non zero value and everything else to 0 then find the V x from that. Do this for all independent sources you will get a number of different values of V x and you add all them up, that will be the value of V x with all the sources active. So, now I do not have to do it one by one, let say you had five independent sources. You could take three of them once and then two of them the other time or four of them once and 1 of them the other time and so on.

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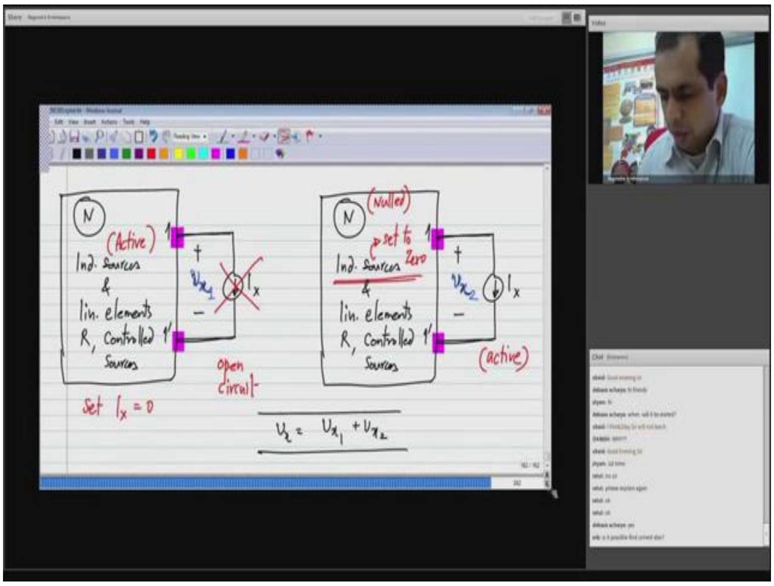

So, here what I will do is I will first deactivate this I x which corresponds to the load which can be substituting for the load and find this voltage and then I will null everything else that is null the circuit and find the value of V x 2 from this. I hope that is clear. Now, one of the questions is that is it possible to find the current instead of that voltage? Yes, it is very much possible, it is not a problem at all. Later you will see that.

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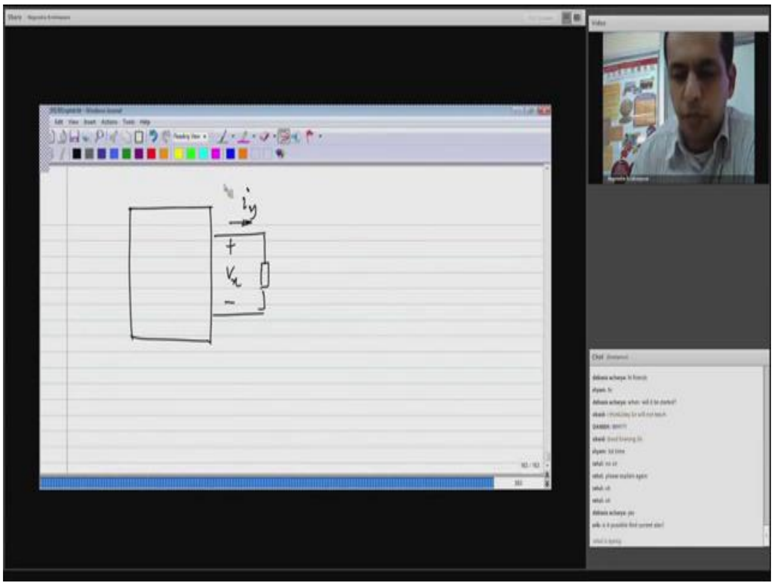

First of all let me call this V x and then there is certain branch, and then that is i y or something. Now, if this circuit is linear then this V x and i y any of these quantities can be found from superposition that is any branch voltage or any branch current can be found from superposition. So, that applies to any quantity that you would like to find. Now, let me look at the first part of this, that is V x 1. Now, you see that V x 1 is nothing but the voltage that appears across 1, 1 prime when it is open circuited.

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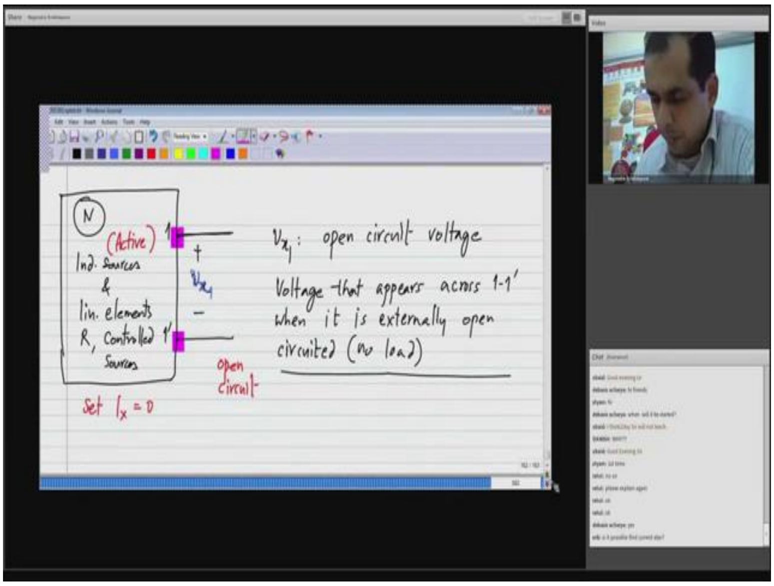

It is a open circuit voltage or the voltage that appears across 1, 1 prime when it is externally open circuited, that is no load is connected. That is the idea. So, one part of this is the open circuit voltage. Now, remember what we are trying to do is, we have a very complicated circuit and only these terminals 1, 1 prime are accessible to us and this may be connected to taken over circuit. Now, what we would like to do is to have instead of analyzing this complicated circuit N every time, we would like an equivalent representation of N that is simple.

So, that is our goal that is what we are driving at because we are not interested in the internal details of N. We have only this 1, 1 prime and this will be driving the other circuit. So, we are only interested to what happens to this terminals 1, 1 prime and in the other circuit. We do not need to analyze all of N every time. That is the idea. Now, that is the first piece of the puzzle, the open circuit voltage. Now, the next part is with N being nulled that is all independent sources inside N are set to 0 and they have only a single independent source in the circuit.

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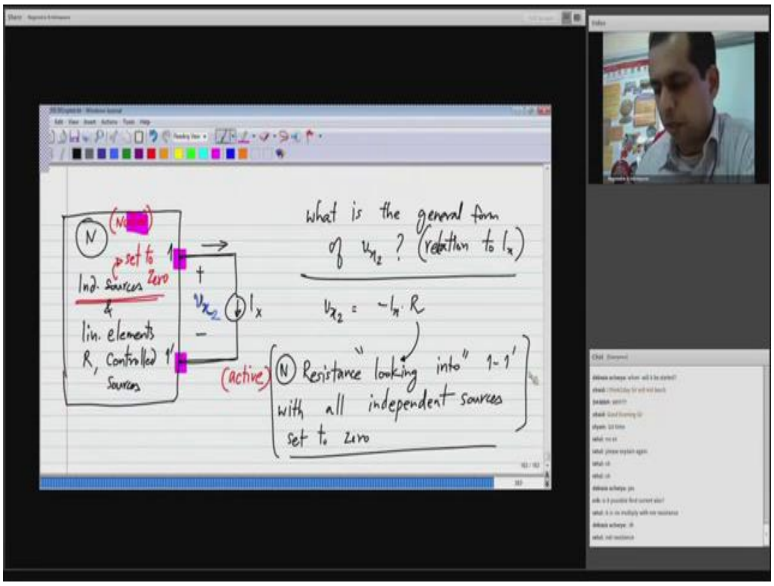

We have single independent source I x in the circuit. Now, we will have this V x 2. So, my question is please try to answer this. What is the general form of V x 2?, What is the general form of V x 2? That is we are now talking about a circuit, which has only linear components and all the independent sources are set to 0. So, we have a single independent source I x. What I would like you to answer is what will be the general form of V x 2 in, in meaning how it will be related to I x.

Yes, I think many of you are able to answer it. V x 2 will be proportional to I x and if the polarity is given, it will be of the form minus I x times some R, where R is a property of this circuit. R is basically the resistance looking into the terminals 1, 1 prime. Because we have single independent source here I x and then all the other sources are nulled and all the other components are linear. So, every quantity in this every branch voltage and current will be just proportional to I x and that will operate V x 2 also.

And with the sign that I have taken because I x is flowing outwards. I will say V x 2 is minus I x times R because the passive sign convention 1, 1 prime if I x would be flowing that way, then I would, if I were flowing that way I would take V in that polarity. In this case I and V are in the opposite polarity to this convention. So, will say it is minus I x R. And what is this R? It is the resistance. Let say looking into 1, 1 prime with all independent sources set to 0.

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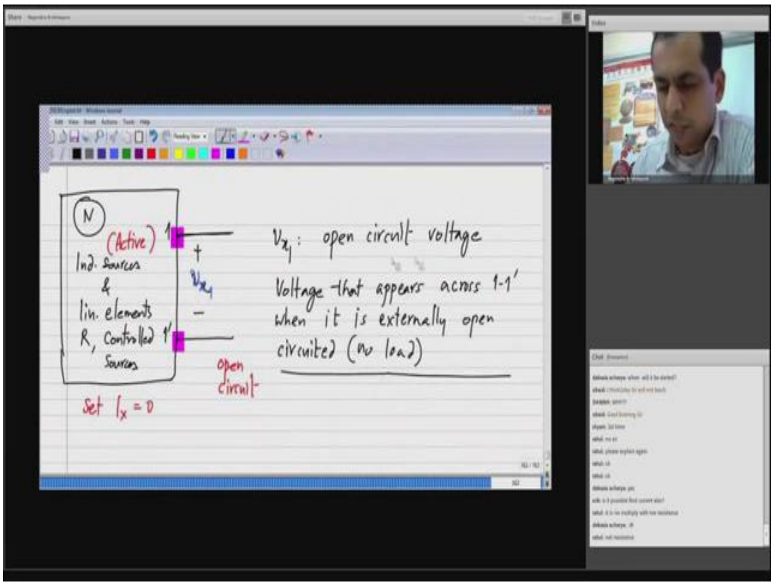

So, that is the resistance of the network N looking into the terminals 1, 1 prime and this, what is V x 1 is the open circuit voltage. I could also call it VOC or let me call it V t h. The reason for this will become clear.

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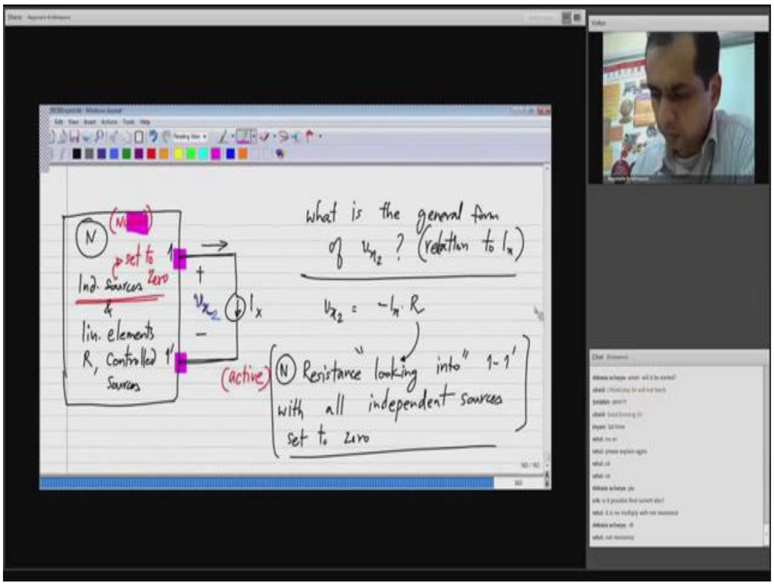

It is open circuit voltage is called V th what I told I simply measured the voltage across 1, 1 prime with nothing connected to 1, 1 prime. And this R, I call this R th again the region will become very clear. So now, so this quantity is called what I called V th.

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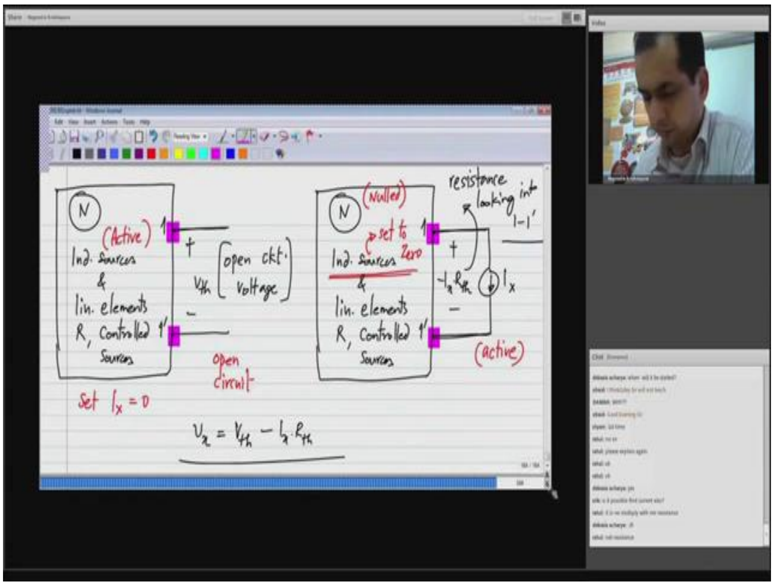

The open circuit voltage and then here this quantity will be minus I x, R th where R th is the resistance looking into 1, 1 prime. So, the total voltage V x will be equal to V th minus I x, R th. Where V th is the open circuit voltage and R th is the resistance looking into 1, 1 prime with all the independent sources set to 0. So, this is the voltage that will be present when this network is connected to a load current of I x.

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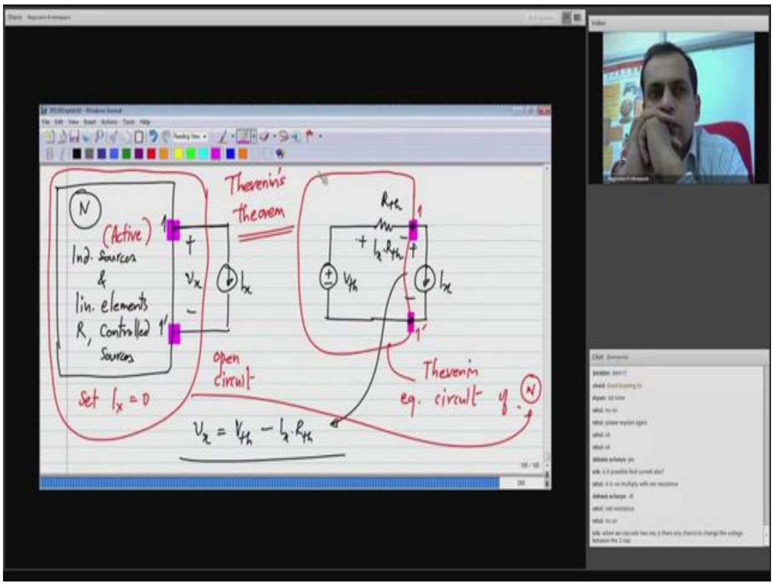

So, this is V x in the complete circuit. Now, the network is active and the load current is connected to it, this I x. Now, because V x is in this form it is very easy to say that this can be generated by having a voltage source V th and resistance R th in series with it. So, if I connect a resistance I x, a current source I x here, you very easily see that all of this I x will flow through R t h. So, the voltage drop across this is I x, R th and the voltage between these 2 terminals will be V th minus I x, R t h. So, the voltage here will be exactly the same as that one.

So, this entire thing here this is terminal 1, 1 prime the whatever is inside this red box is equivalent to the original complicated circuit N between the terminals 1, 1 prime. So, it is only that that is equivalent internal details of this we do not know. The internally here we have only a single voltage source and a single resistance, but as far as the terminals 1, 1 prime are concerned the voltage across this and the current through this will be exactly same as in the original network N.

Now, this is regardless of what is connected to it because we did not make any assumptions about I x. So, I x is some current which could be a current source or which could be a substitution for some other load, but whatever it is this entire thing which is a set of independent sources and linear elements can be replaced by a voltage source V th in series with the resistance R t h. And this particular representation probably many some of you know this already, this is known as the Thevenin circuit or the Thevenin equivalent circuit of this part.

So, now as I said earlier if you are not interested in the internal details of this, so let say you design a very complicated circuit with hundreds of resistors and control sources and many independent sources. And you want somebody else to use it, but you have only 2 terminals that are brought out and which is what they want to use. So, in that case they do not need to know all the internal details of this. All you have to do is to give the Thevenin equivalent.

You give the value of V th and R th, because you know the internal details you can calculate this things. But once this is done as far as the terminals 1, 1 prime are concerned this very simple representation and whatever stuff you had inside this are completely equivalent. And this the idea that any circuit can be reduced to this is known as Thevenins theorem.

So, any questions about this? What we did was we just use linearity of the circuit N and prove that, it can be represented by a voltage source in series with the resistance. That is actually, we proved what is known as Thevenins theorem. So, any questions about the proof or idea of Thevenins theorem?

There is a question on when we cascade two networks is there any chance to change the voltage between the 2 networks? Actually this question is not clear to me which voltage or what is being referred to. So, I have to either draw a figure and email it to me, then I will discuss that. So, am not clear about what is meant by cascading of two networks and what is the voltage between two networks. So, any other questions about this, Thevenin's theorem and its proof? So, actually the proof is quite simple, what we use was linearity. Any questions that you have, if you want to send something in detail please use the forum, discussion forum given for this course on the NPTEL website.

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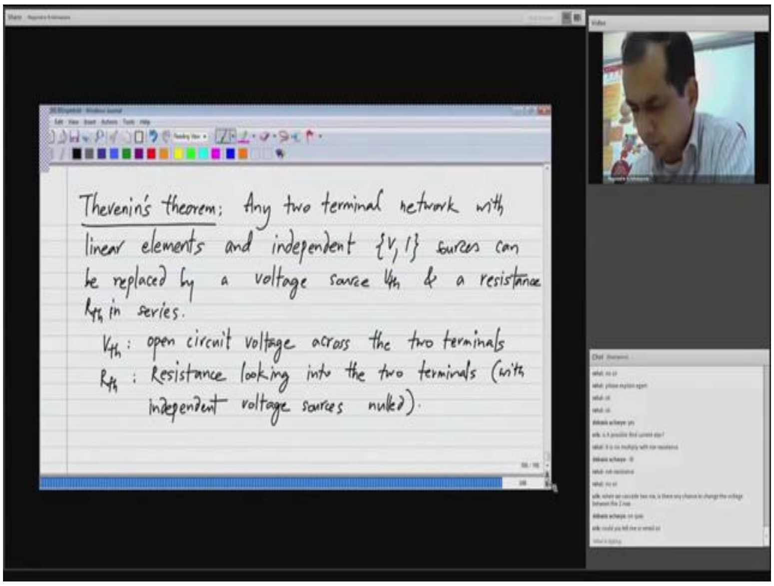

So, the voltage V th is open circuit voltage across the two terminals and R th is resistance between the 2 terminals. So, looking into the two terminals with independent voltage sources nulled.

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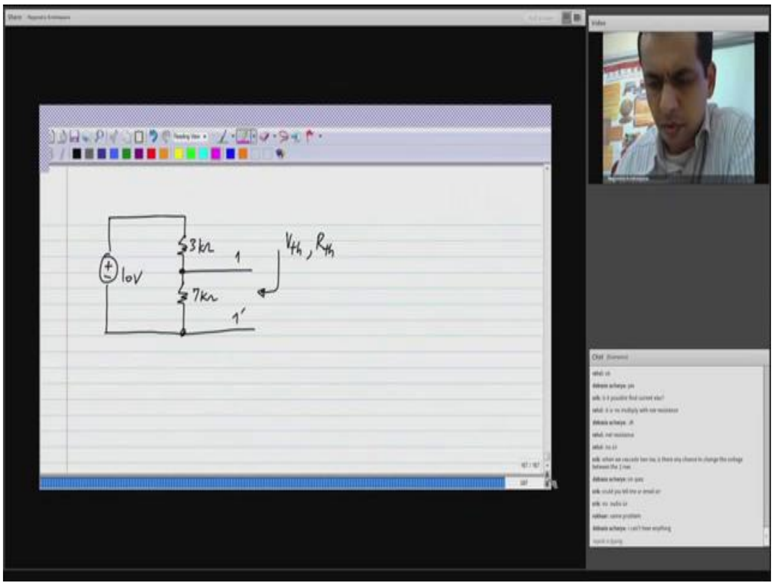

It appeared that because of some network problem the connection broke and also the audio and video went away for a while. I hope it is all now. Are you able to hear me? If there is no audio then again let me know.

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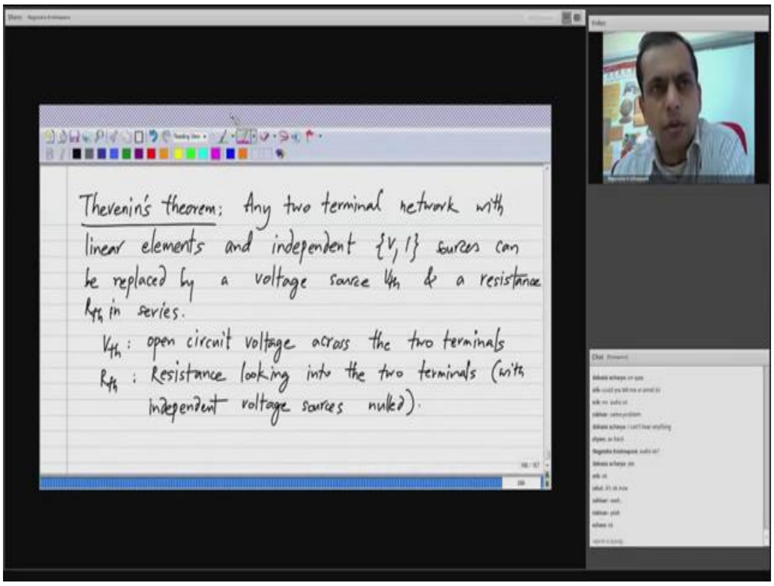

So, as I repeat what I had said, I was just saying that Thevenins theorem says that if you have a 2 terminal network with independent sources and linear elements inside. At the 2 terminals, it can be equally represented by series combination of a voltage source and a resistance. The voltage source is formed by determining the voltage across the 2 terminals with nothing connected to them. And the resistance is formed by nulling all the independent sources in the network and finding the resistance looking into the 2 terminals.

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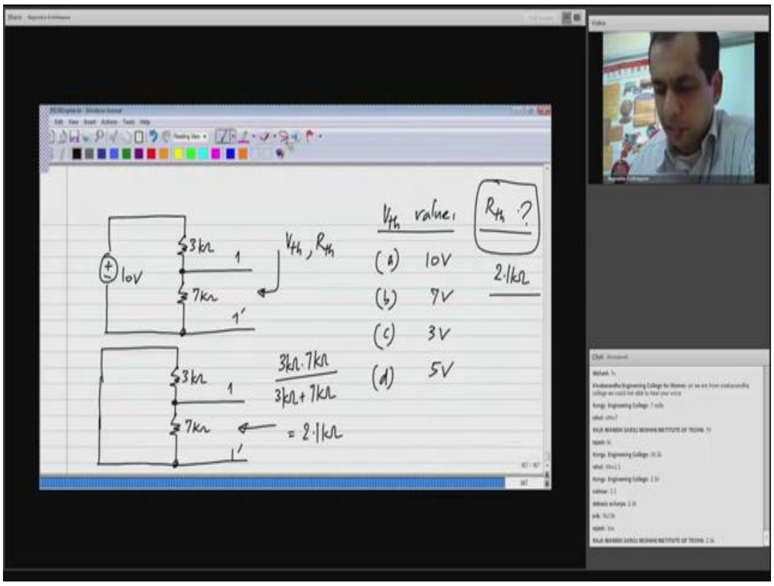

So, as I said we will work out an example and the example circuit I took was this very simple circuit and I have a 10 volt source where 3 kilo ohm resistor in series with 7 kilo ohms resistance and these are the 2 terminals at which I want to find the Thevenin equivalent. This is very important. I mean what is equivalent when you say its Thevenin equivalent of a circuit. The Thevenin equivalent applies only to some 2 terminals specified. In this case, it is this 1 and 1 prime.

So, now my question is what will be the Thevenin voltage across 1, 1 prime in this circuit? Please try to answer this. I think all of you are able to immediately recognize that it is this resistor divider, 7 kilo ohm divided by 7 plus 3 kilo ohms times 10 volts. So, it is 7 volts. That is the right answer. Then again there are some complaints that audio is not ok, but it seems that many other people are able to hear. So, the problem may be with your set up. You please try it again.

So, now the next thing is what is the value of R t h? What is the value of R th looking into these terminals? Again what you should do is, you should take the independent voltage source in this circuit, make it 0 and find the resistance looking back into the circuit. So, I have to make this 0 volts or short circuit and I have to look at the resistance here. Again the answer is very simple, this is a short circuit and you will be able to easily see that the 3 kilo ohm and 7 kilo ohm are in parallel. So, the answer is 2.1 kilo ohm. Again, I have got some answers like 2.1 and so on, please do not do this. Always specify the units for any quantity that has dimensions. Now, somebody said 7 k parallel 3 k. That is correct, so I was looking for the numerical value.

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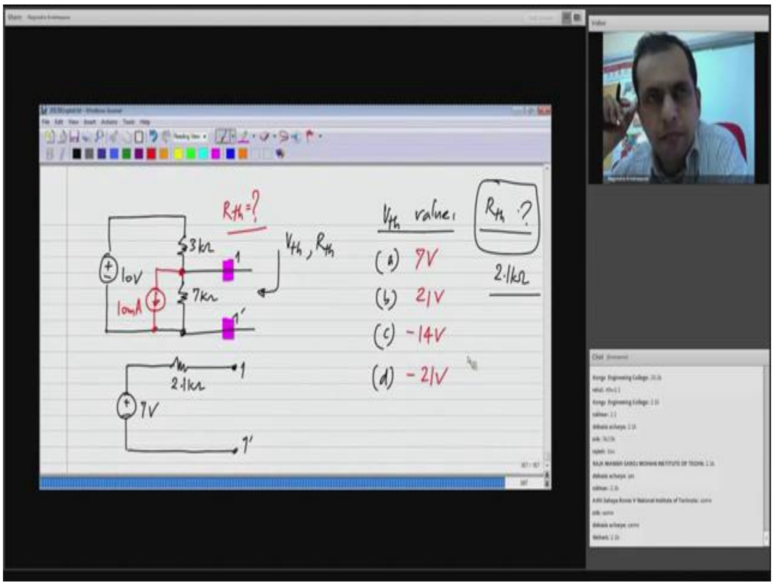

So, what it means is that this entire circuit can be replaced by a 7 volt voltage source in series with a 2.1 kilo ohm resistance. Is this part clear? So, now let me make the circuit more complicated. I will add a 10 milliamp current source as shown in red. So now, we have to find the now of course, according to Thevenin's theorem at 1, 1 prime or by the way I should have marked the terminals here this is 1 and 1 prime. At 1, 1 prime I can represent this new circuit also with a single voltage source and a resistance.

Now, my first question is what will be the value of the resistance in this new circuit? What is the value of R t h? Again, as many of you are able to recognize, it is exactly the same because when you null the voltage and the current source you short circuit this and you open circuit the current source. You are left with exactly what you had before so value of R th does not change at all.

Now, what will be the value of V th, the Thevenin voltage source? What is the value going to be? What will be the value of the V th, voltage source V th? With the new, with the current source added, what is the value of V th? So, we already seen many ways of doing it. We can redo the circuit analysis with the voltage and current source together you can also use superposition here to calculate V th as well because after all it is a linear circuit with independent sources. And superposition means you have to find the total V th due to 10 volts and the voltage V th due to the 10 milliamp current source. Voltage due to 10 volts have already found previously.

So, the only thing you have to do is to find the voltage due to the 10 milliamp current source and added to the voltage due to the 10 volt voltage source. So, the question is about the V th value with this new circuit which has the 10 volt voltage source, 10 milliamp current source and the 2 resistors. Now, also given some choices so please do the calculation and let me know what this value V th is. Can either indicate it on the pearl or just give me the value. I think again many of you are able to do it correctly although 1 person said 0 volts, I am not sure why that is the case. So, let me do it and show it. Although this also is quite simple.

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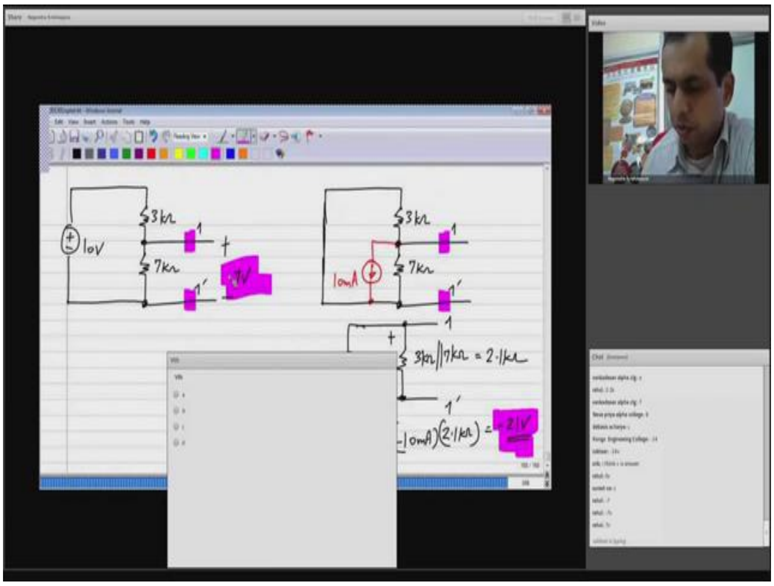

I will do this with superposition which means that first I will set the 10 milliamp source to 0 which is an open circuit and then I will set the 10 volt source to 0, which is a short circuit. Now, this one we have already done before. So, I am simply going to write down the answer. So, the answer here is 7 volts and this other 1 you should be able to see that, this 3 kilo ohm and 7 kilo ohm are in parallel and they are in parallel across this current source.

So, we have an equivalent picture like this. This is the 10 milliamp source and this is 3 kilo ohm and 7 kilo ohm in parallel which is 2.1 kilo ohm. Now by the way, this is 1 and 1 prime. So, the voltage across this from 1 to 1 prime that is with 1 being positive is minus 10 milliamps times 2.1 kilo ohms because of this polarity of the 10 milliamp current source. So, 10 milliamps is being drawn like this. So, this voltage is minus 10 milliamp times this 2.1 kilo ohm which is minus 21 volts.

So, again if you have got some different answers, please look at the, look at this and then figure out where have you gone wrong. So, the total voltage is the sum of this due to 10 volt source and this due to the 10 milliamps source. So, clearly minus 21 plus 7 is minus 14 volts and this is the correct answer.

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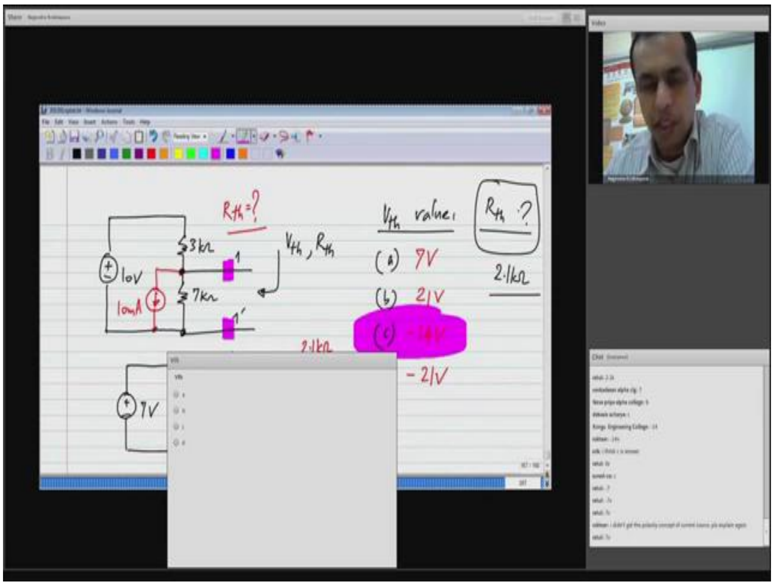

So, with the current source added what we have is minus 21 volts and sorry minus 14 volts and 2.1 kilo ohm in series 1, 1 prime. So, what I tried to demonstrate is that here if you make the circuit more complicated, you can represent it equivalently. Now, this before equivalent circuit regardless of what you connect to 1 and 1 prime. This hopefully you understood this point that I connected some I x here and that I x can be either a current source or a representation for any kind of load.

So, whatever you connect between 1 and 1 prime that does not matter. This part, what we are utilizing is this part here that can be represented by this minus 14 volts and 2.1 kilo ohms in series. In fact, what you connect to this can be non-linear. The part that you are converting to Thevenin equivalents that has to have only linear elements and linear elements and independent voltage and current sources.

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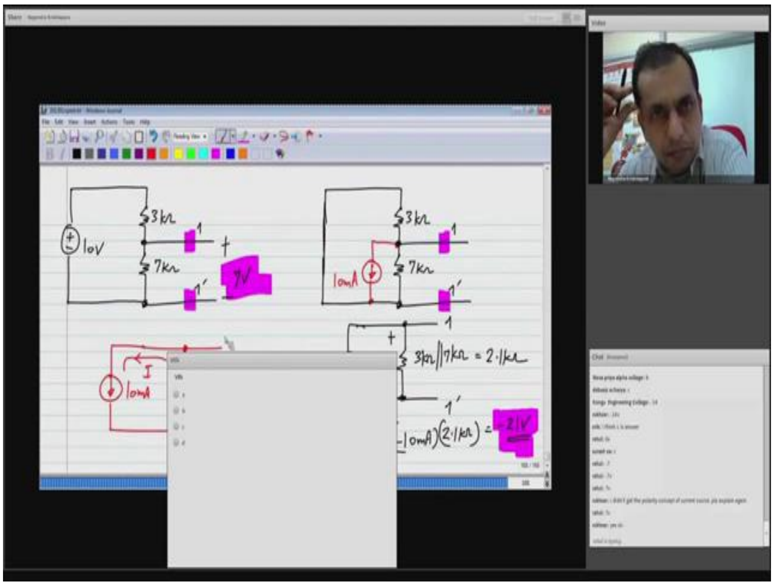

Now, there is a question about the polarity of the current source. I think you got the answer right anyway. So, what I am saying is that if you have a current like this and then you have resistance. So, the voltage measured with this polarity will be minus I times R. So, if the current was flowing like that the current I is flowing like that the voltage in this polarity will be I R. Now, if the current is in the opposite direction, which it is, if I is like that it will be minus I R that is all I said. Is that clear?

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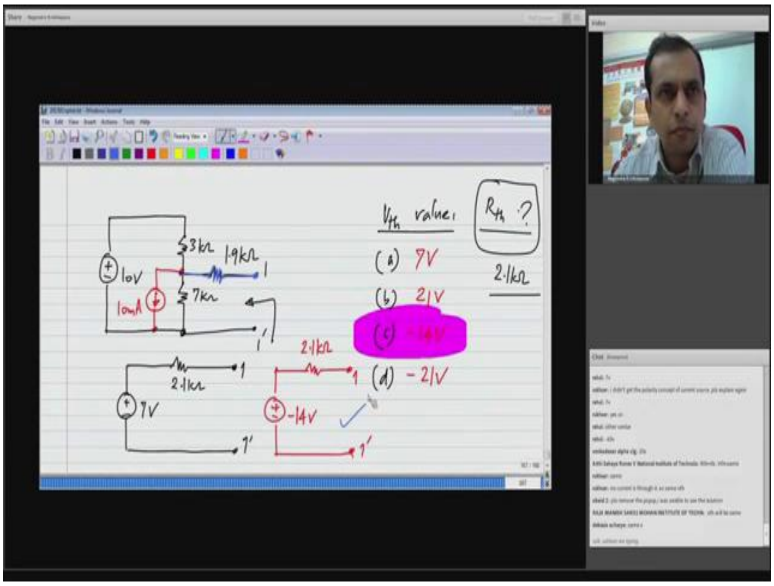

So now, just for we will take it just a small step further. Let me add another resistance like this which is 1.9 kilo ohms. I will take some value and again at 1, 1 prime. I have to find V th and R th. Now, please tell me how will V th and R th change? For this new circuit with this 1.9 kilo ohm resistance. What will be the value of V t h? Previously, when we did not have this. This was the value of V t h. So, what is the value of V th when we have that 1.9 kilo ohms?

So, I think many of you recognize that V th will be the same because when this is open circuited that is how you find V th. The 1.9 kilo ohm is floating and no current is flowing through it. So, whatever voltage appears here will be the same as what appears there. So, this is a special case with the way I have connected this 1.9 kilo ohms, but when I open circuit this, no current is flowing through that. So, whether you have this 1.9 kilo ohm or not you get the same voltage. What will be the value of R th?

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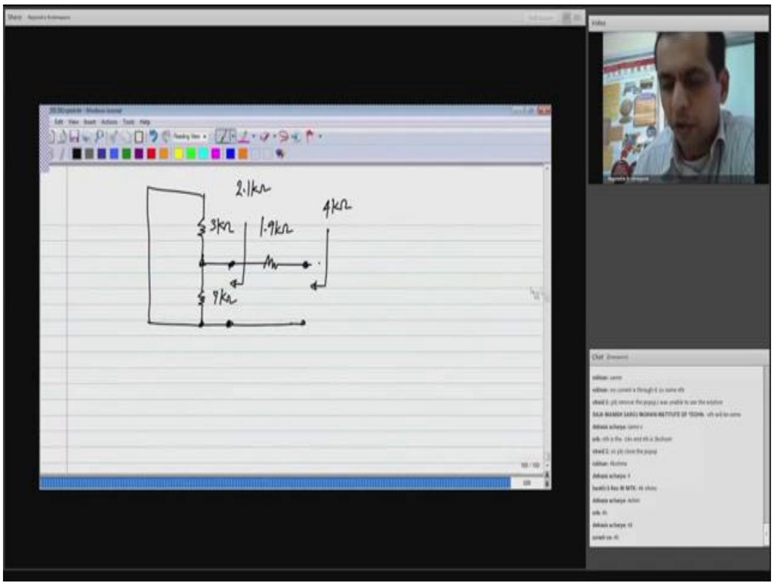

So, again this is simple because we have the 3 kilo ohm and 7 kilo ohm in series and this 1.9 kilo ohm like that. So, we know that looking here between these terminals we had 2.1 kilo ohms and this 1.9 kilo ohms is simply in series with that. So, looking this way it is 4 kilo ohm that is 2.1 plus 1.9.

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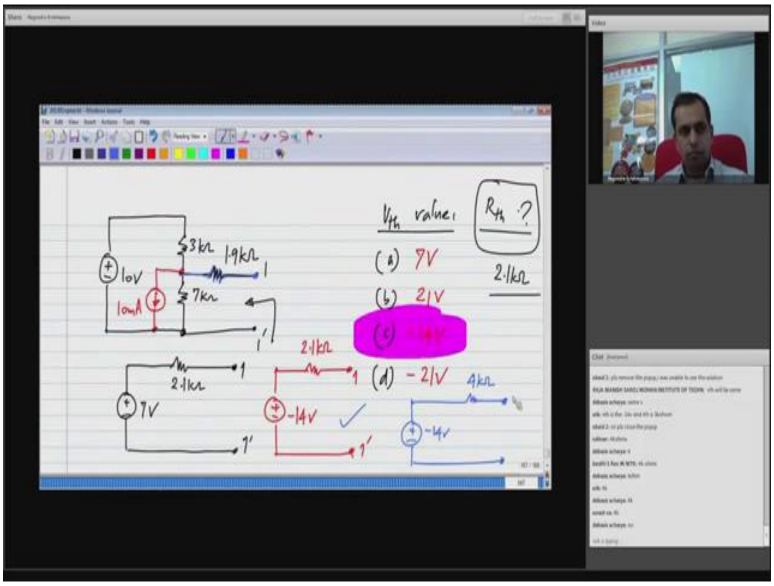

So, the equivalent circuit for this including that would be minus 14 volts and 4 kilo ohms. So, this is just to illustrate the point that we can make the circuit more complicated, but the representation can be made exactly the same and you can find the representation. Now, this circuit is still too simple, even if you had a 100 resistors and then controlled sources and so on. You can still find the Thevenin equivalent circuit. So, any questions so far on any of these calculations or proof of Thevenins theorem.

So, that seems pretty clear.

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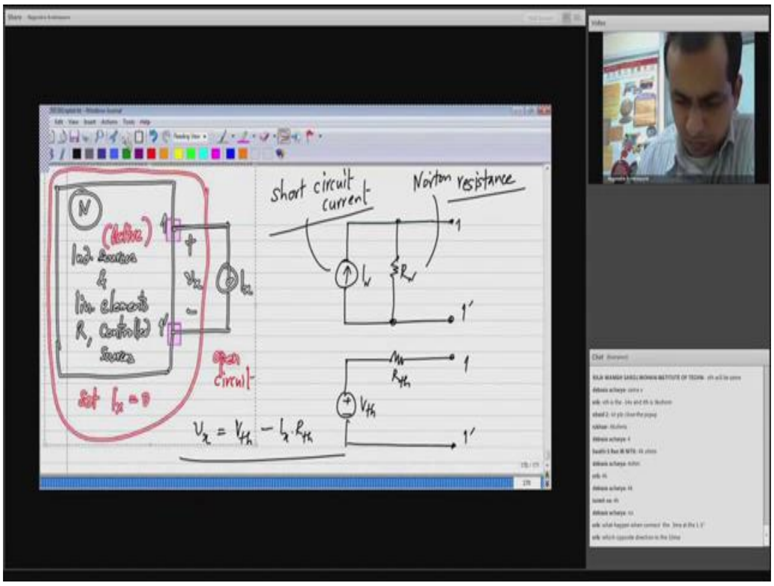

Now, there is another theorem which I will not prove, you can try to prove it yourself by following available methods and if you get stuck somewhere you can ask me later. So, instead of using a voltage source and resistance in series, any network of the same type any network with linear elements and independent sources can be represented by a current source I n and a resistance R n in parallel. So, instead of voltage source V th and a resistance R th in series, we can represent the same by a current source I n and the resistance R n in parallel.

So, now it turns out that this I n is now what is known as the short circuit current and R n is what is known as the Norton resistance. So, we have the short circuit current and a Norton resistance. Now, what is the short circuit current? The short circuit current is, you take this terminals 1, 1 prime, short circuit it and measure the current.

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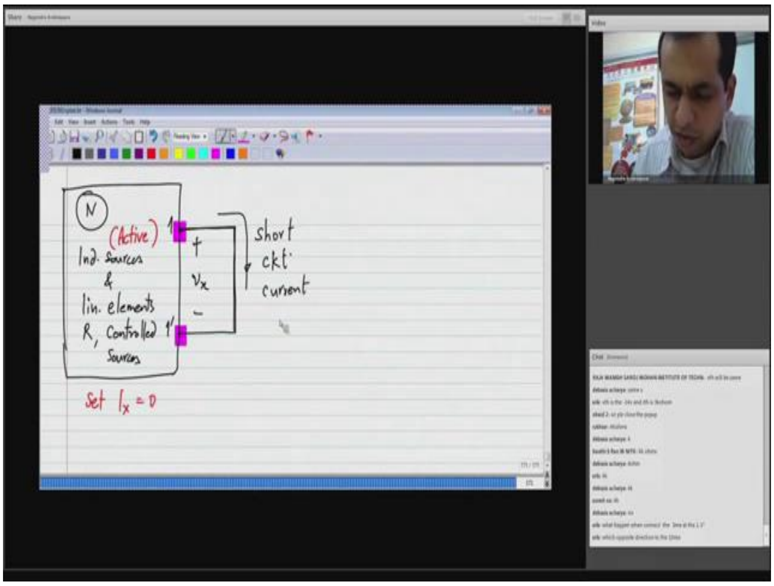

So, short circuit this 1 and measure the current flowing from 1 to 1 prime that is the short circuit current I n.

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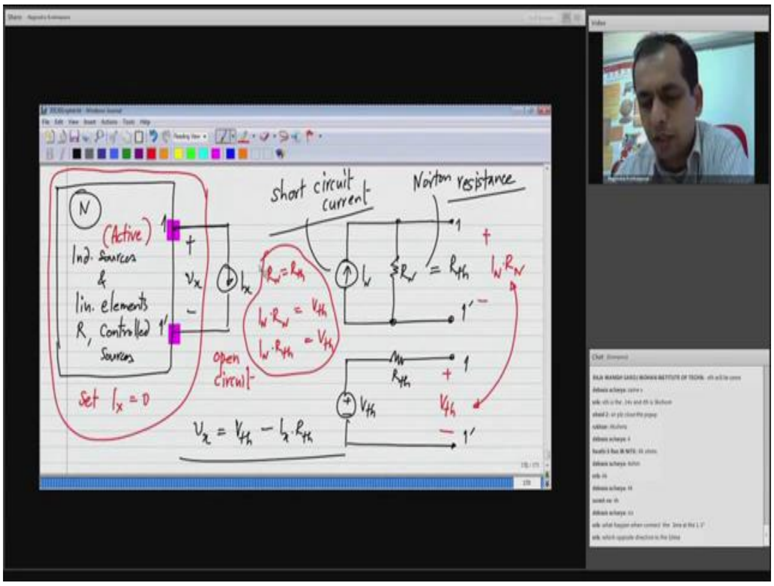

And R n is the same as the resistance looking into this circuit with all the independent sources nulled which will be the same as R th. So, the Norton equivalent the resistance and the Norton equivalent circuit and the Thevenin equivalent circuit will be exactly the same because they have nothing but the resistance looking into the circuit N with all the independent sources set to 0. And this I n is the short circuit current that is when you short circuit 1, 1 prime. You will have a current I n and this V th is the open circuit voltage that is if you have an open circuit 1, 1 then the voltage that appears at 1, 1 is V th.

Now, this I n is of course related to V th in a very simple way and a very easy way to see that is first of all this is the Norton equivalent circuit of this and this is Thevenin equivalent circuit of the same circuit. So, clearly these two also have to be equivalent to each other and if you look at the open circuit voltage between 1, 1 prime what we have is V th itself because by definition there is a open circuit voltage and here also you see that no current flows through R th.

Now, in this case if you open circuit 1, 1 prime, all of these I n will flow into R n and the voltage that appears is I n times R n. And these two have to be equal to each other. So, I n times R n equals V th or I n times R th equals V th and R n and R th are the same thing. So, I hope this is clear as well. So, instead of using a voltage source and resistance in series, you can also use a current source and resistance in parallel as an equivalent to any 2 terminal circuit which has independent sources and linear elements. And this idea of using a current source and resistance in parallel is known as Nortons theorem.

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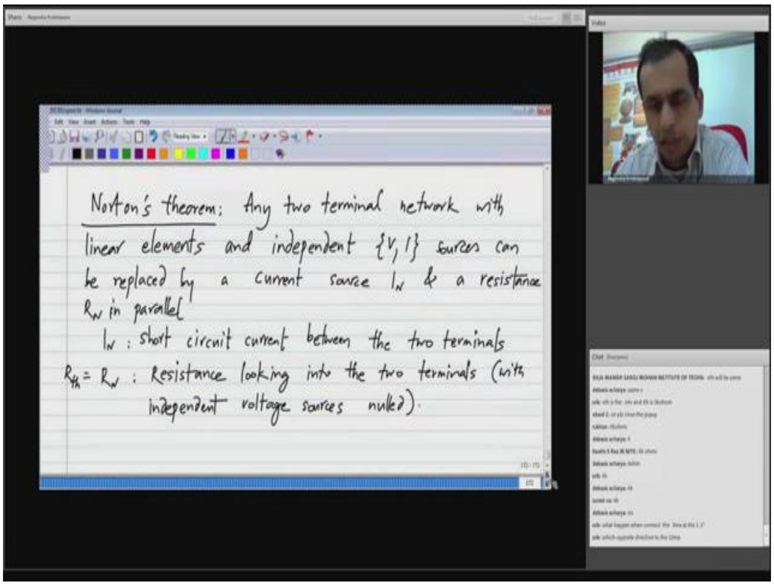

Just for completeness, let me write out the statement, R th and R n are the same and I n is short circuit current between the 2 terminals when you short circuit it that is the current that flows there. So, again I hope this is clear.

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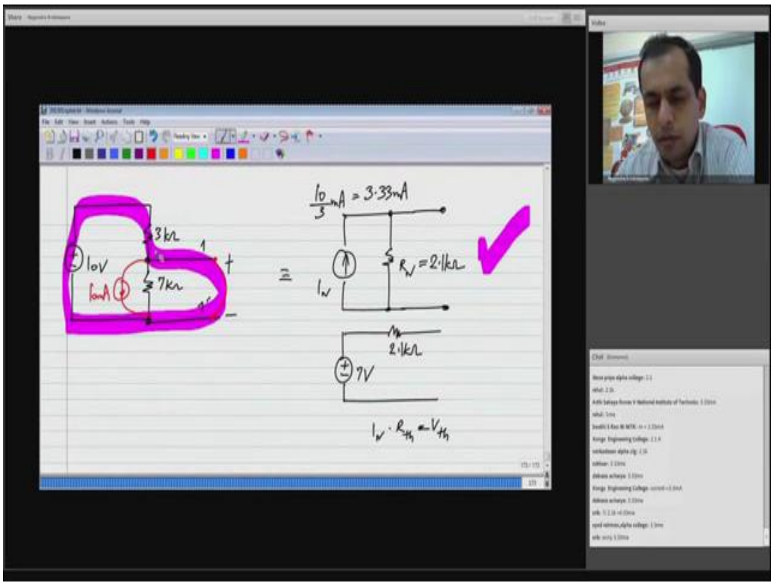

So, very quickly we will evaluate this. What would be the Norton equivalent? This has to be represented by a current source I n and a resistance R n in parallel. What will be value of R n in this case? What is the value of R n? So, clearly it is the same as R th we calculated so this is 2.1 kilo ohms and what is the value of I n?

Then again all of you are able to recognize that it is 10 by 3 milliamps or 3.33 milliamps. You can either get it from the previously calculated Thevenin equivalent circuit that is we had 7 volts and 2.1 kilo ohms and we know that I n times R th equals V th. From this, you can calculate or even in this case looking into circuit. If you short circuit this what happens is that you have this 10 volts and 3 kilo ohms and a circuit like this no current flows through 7 kilo ohms because it has 0 volts across it. And the current that flows this way is 10 volts divided by 3 kilo ohms or 3.33 milli amperes. So now, you can also try it with all the other things added when I added 10 milliamp etcetera. You can figure out what happens. So, that is the story with Nortons theorem.

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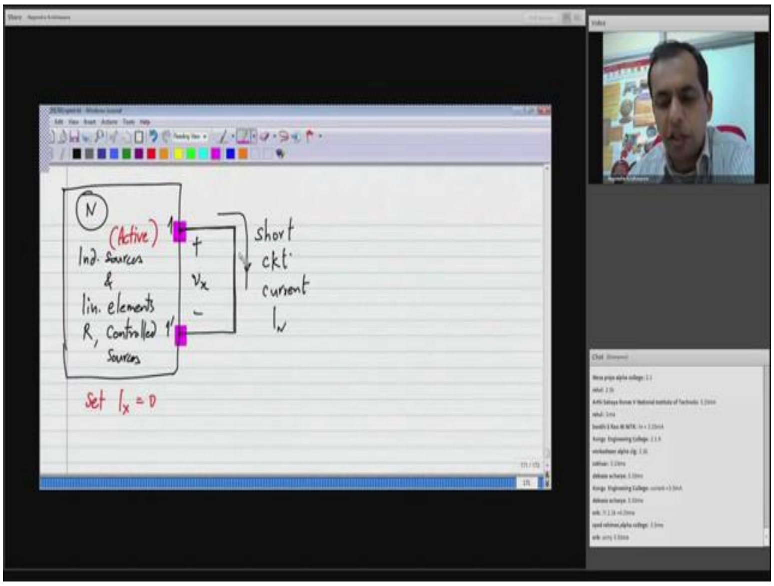

And you can prove it in exactly the same way that we proved the Thevenins theorem. To prove Thevenins theorem, what we did was we used a current source here and then used superposition in somewhere. Now, instead of a current source you can use a voltage source like any load can be substituted either by a voltage or a current source. So, let say you substituted with a voltage source here and then you apply superposition and then you can try proving Nortons theorem.

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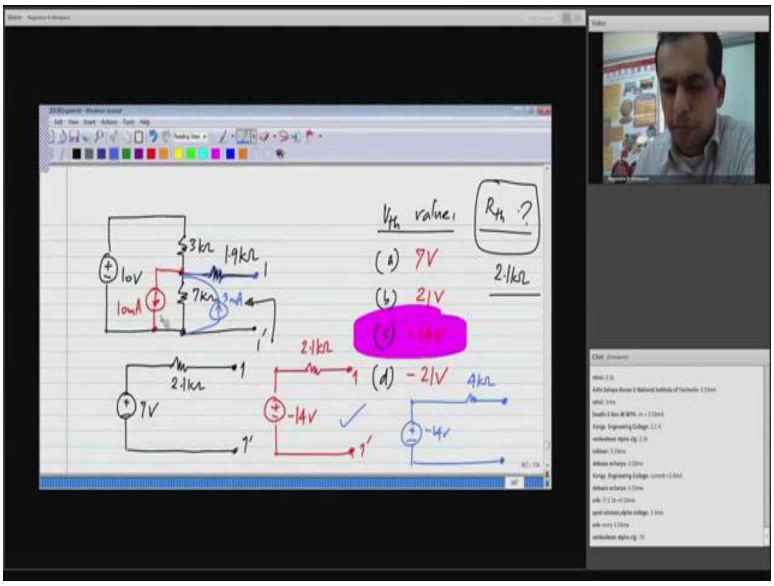

Now, earlier there was a question which think was regarding this circuits and if there is other current source here, 3 milliamp what happens? Now, this is quite simple this 3 milliamp and 10 milliamp are in parallel. It is like having just a 7 milliamp current pointing downwards. So, instead of 10 milliamps you have a 7 milliamps.

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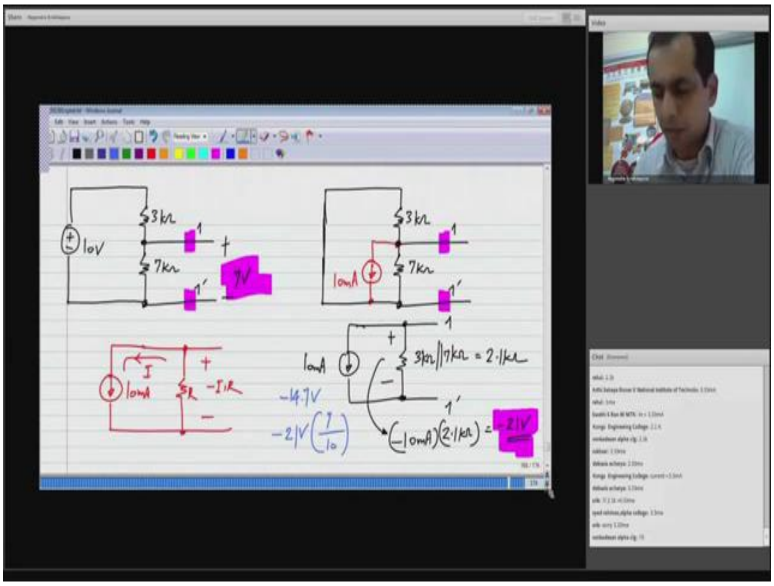

Now, the contribution of the current source, so this was minus 21 volts so instead of that it will be in proportion minus 21 volts times 7 by 10 that is the meaning of linearity right. So, you can calculate how much this is. This will be minus 14.7 volts I believe. So, instead of adding minus 21 to 7 you have to add minus 14.7 to 7, so the net voltage will be minus 7.7 volts. This is fine, any questions?

So now, we have discussed the Thevenins and Nortons theorems. They are very very useful and they are used very frequently for representing circuits of 2 terminals. And this happens all the time you design some circuits it is very complicated, then it has two terminals available to the outside world. And what you want to do is to give an equivalent picture to the user, and this will do exactly that you will get with the Thevenin and Norton equivalent circuit, which is very simple you will get the equivalence of the circuit at those two terminals.

You will not get an internal picture of what is happening, but at those 2 terminals the behavior of voltage and current will be equivalent to that of the original circuit. There is a question of where to use Norton’s theorem. I guess the question probably is which 1 to use Thevenin or Norton and is entirely based on convenience. Sometimes, we use Thevenins theorem, sometimes we use Nortons theorem. In fact, there is an interesting thing here that we can discuss briefly. Now, like I said any circuit so there is also another question what is the proper condition for Thevenin and Norton.

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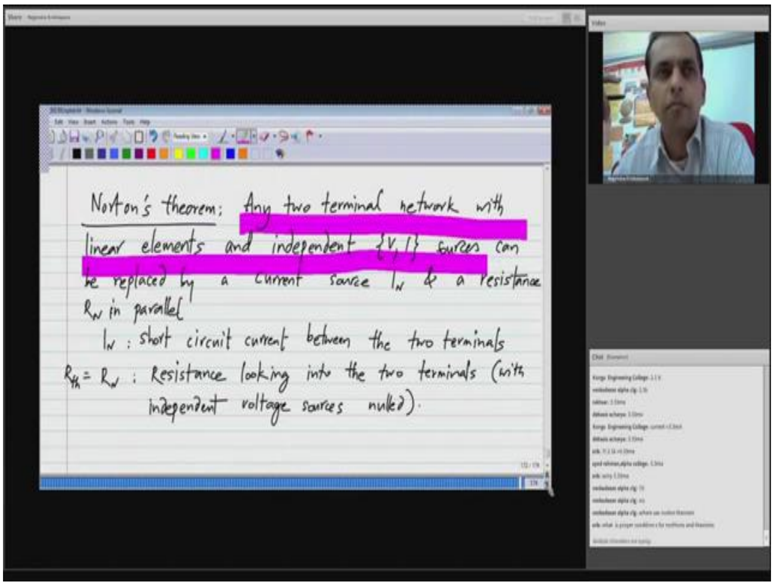

I guess what is meant is what kind a circuits can be represented by Thevenin and Norton and that I wrote out here. So, this is exactly the condition any 2 terminal network with linear elements and independent voltage and current sources. If you have a circuit that is like this then it can be represented with either Thevenin or Norton equivalent circuit.

So, if you have non-linear elements you cannot do this and also 1 thing which I mentioned last week as well that if you do have dependent sources in this that is okay, but it should be dependent only on quantities inside N. You cannot have a maximally value controlled.

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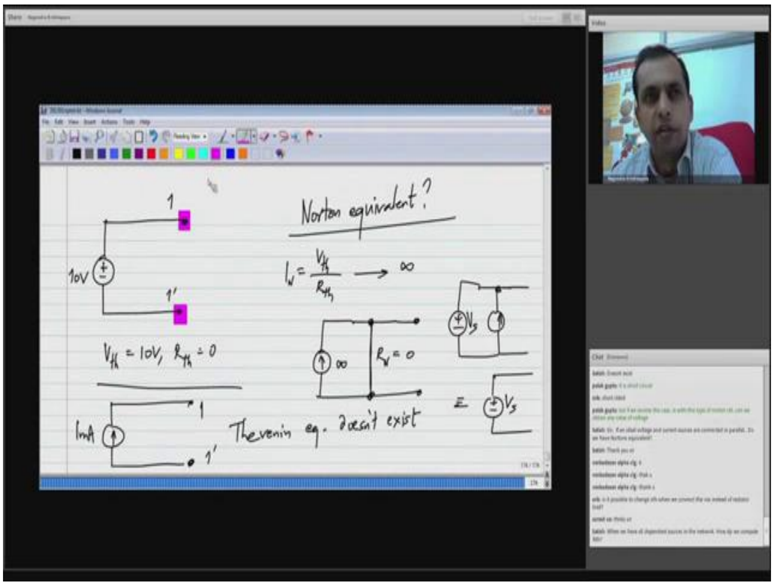

Now, like I said any 2 terminal any circuit with only 2 terminals available can be equivalently represented at the 2 terminals, using either Thevenin or Norton equivalent circuit. So, now let me say this is my circuit. This is now an extremely simple circuit I have a voltage source. Now, what is the Thevenin equivalent of this and what is the Norton equivalent of this? I have only a voltage source please try to reason out and answer this question this is not so much of calculation, but reasoning out. I have only a voltage source connected to terminals 1 and 1 prime.

So, what is the Thevenin equivalent of this and what is the Norton equivalent of this? I think that answer for Thevenin equivalent is very clear. It is the same as this circuit with R th equal to 0, V th will be 10 volts and R th will be 0. But what is the Norton equivalent of this circuit?

Yeah again I have got some answers saying either the current will be infinite or it does not exist. All these are correct. First of all, there is also a question why the R th of this is 0 and that is quite simple. So, in this you have a single independent source and that you set to 0. So, you make a 0 volt which is a short circuit and then you look into 1, 1 prime so what you see is 0 ohm resistance. So, R th equal to 0 for this that is pretty clear.

Now, the Norton equivalent does not exist because I n is V th by R th and if R th is exactly 0 if it is non-zero then you can find it. If R th is very small, you can find this I n which will become very large, but if R th is 0 this will tend to infinity.

That is you have an infinite current and across it you will have 0 resistance because R n which is R th is 0. Now, and this infinite current through this 0 resistance can give you some voltage in this case 10 volts, but this is really a useless representation. When you have infinities in the circuit you cannot calculate anything, but I am just making the equivalence here otherwise to imagine it. You imagine some resistance in series with this voltage source and take the limit as it goes to 0.

So, my point here is that while in general any circuit can be represented by either Thevenin or Norton it is possible that 1 of them does not exist. So, 1 or the other will surely exist, but if you have a pure voltage source between terminals 1 and 1 prime the Norton equivalent does not exists because you cannot short circuit and find the current or in other words if you short circuit, if you short circuited, an infinite current will flow.

Similarly, if you have a pure current source between the terminals 1 milliamp 1 and 1 prime. This again, the Thevenin equivalent does not exist and the Norton equivalent is the same as this. It is just a current source. Now, we have a couple of questions. First of all, if we reverse the case we can get any voltage that is exactly the point here it is indeterminate.

So, when you have infinities here, it is indeterminate. Now, the other question is if you have a voltage source and a current source do you have a Norton's equivalent? If we have a voltage source and a current source then in parallel the result is just a voltage source. This mentioned a few times before if you have a voltage source in parallel with anything whether it is a current source or whatever else it is same as the voltage source itself. Whether you have a current source or not, it does not matter. The only thing that it will change is the current through the voltage source otherwise nothing will change.

So, clearly if this is a voltage source and there is no legitimate Norton equivalent circuit for this one. So, I hope that part is clear as well. So, there can be degenerate cases where 1 or the other equivalent circuit does not exist, but at least 1 of them will surely exist. And again somebody asked about the application of this theorem as I said it is widely applicable the basic point is to abstract all the details of a very complicated circuit. You have a very complicated circuit with lots of components instead of using all of that in every circuit analysis. If you are interested in the behavior only at two terminals, you can use either the Thevenin or Norton equivalent circuit.

Any other questions? So, again there is some confusion regarding the load. This equivalence is independent of the load whatever you load, load you connected the behavior at 1 and 1 prime will remain the same as in the original circuit. So, if you want to find the effect of the load on the original circuit, you instead connect the load across the Thevenin equivalent circuit and you will find exactly the same behavior. So now that, we have discussed the Thevenin and Norton theorem, let us move on to another very powerful theorem which is, which is also used widely its mainly used to get more theorems of circuit behavior.

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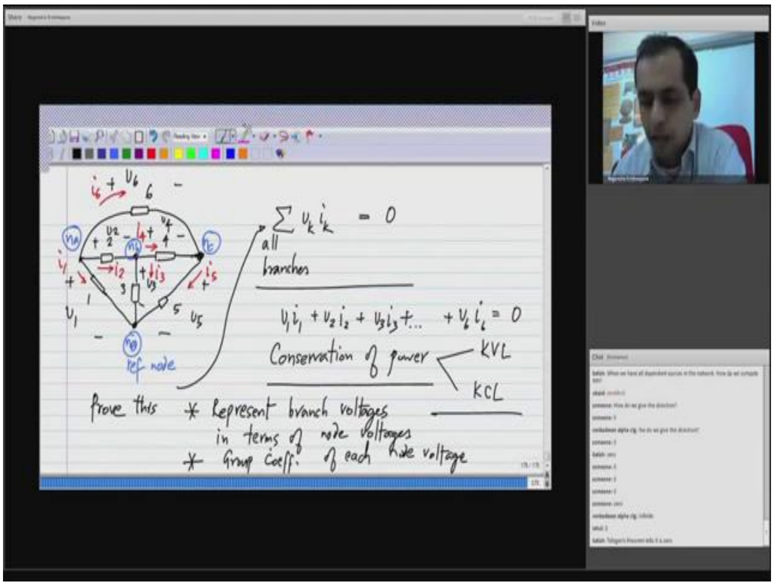

Now, let say we have some circuit we will show arbitrary branches. I do not really care what the branches are. They can be any elements and I will number the branches, let say 1, 2, 3, 4, 5, 6 and I will label the voltage of every branch V 6 and then I will also label the currents consistent with the passive sign convention i 1, i 2, i 3, i 4, i 5 and i 6. So now basically I have a circuit with I mean this I have shown with 6 branches, but any number of branches is okay, right. Now, let say we compute. The sum of power in all the elements that is sum of V k i k over all branches. What do you think this is going to be? And please give me a guess I see many people are still asking questions I will deal with them soon after I deal with this particular thing. That is in this particular case I sum the power in all the branches, V 1 i 1 plus V 2 i 2 plus V 3 i 3 upto V 6 i 6. What is it going to be?

Now, it turns out that this number will be 0 and this is known as conservation of power. Now, this conservation of power what it means is that if you have a circuit and if some sources are dissipating power and some others will be generating power. Whatever power is dissipated has to be generated in some part of the circuit. So, there is no other external source of power, right. So, you have only electrical variables here and electrical connections between elements.

So, whatever power is generated in some elements will be dissipated in other elements or whatever power is dissipated in certain elements has to be generated in some other elements of the same circuit. So, that is what this statement means that power is conserved in a circuit. Now, this also can be proved and this can be proved basically using only Kirchhoff's voltage law and Kirchhoff's current law. Now, this is completely unrelated what kind of elements we have. It could be linear, non-linear or whatever, but as long as our elements obey KVL and KCL which is basically fundamental property of the circuit. This conservation of power holds good.

So, in fact I would strongly encourage you to try and progress using only KVL and KCL. And I will give you a hint. So, let me not name them n 1 2. I will label these nodes in n 0 which is the reference node. You can consider this to be the reference node. It does not matter which 1 it is and node n a, node n b and node n c. So, we can try to prove this by making these products V k i k that is V 1 i 1, V 2 i 2 etcetera and these V 1 i 1, V 1 V 2 and so on are the branch voltages.

Now, you try to represent these branch voltages in terms of the node voltages that is V a, V b, V c with respect to the reference node. And then you group all the terms containing V a and V b and V c together and then you use Kirchhoff's current law, you will be able to prove this. So, please take it as an exercise and do that hopefully you will be able to do it, otherwise we will discuss it later.

So, for this we have to represent branch voltages in terms of node voltages and group the coefficients of each node voltage and then you will be able to pretty much in any case see the answer. So, let us stop with this discussion here. I will continue with this in the next lecture, but there were few questions regarding Thevenin equivalent circuit. The first 1 is, what we do when we have dependant sources? Now, dependant sources you find it in exactly same way as we did with resistors. Now, with resistors what we did was to use the resistor formula to calculate the resistance.

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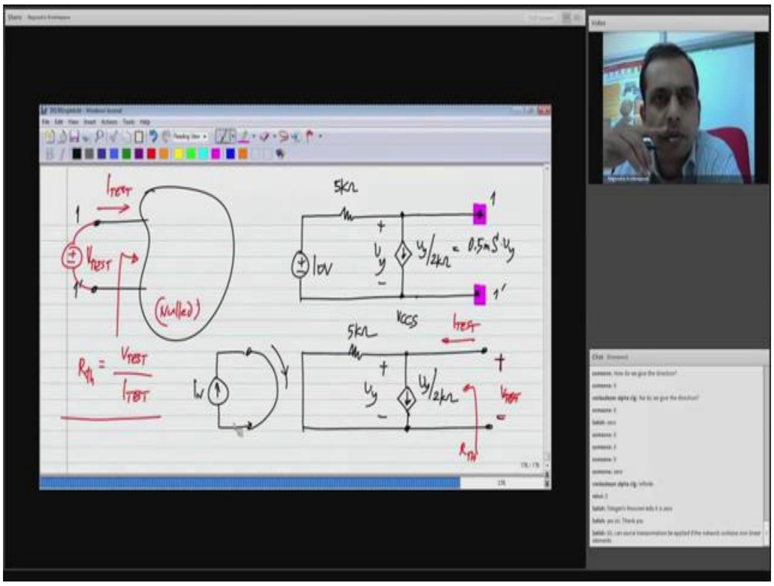

But in general if you have any network with 2 terminals let say 1 and 1 prime. The way to find the resistance looking into 1 and 1 prime is to apply a test voltage V test and analyze the circuit. In case of Thevenin's theorem, whatever is inside will be nulled, all the independent sources will be nulled. And you find i test. Now, because you have a single independent source V test this i test will be proportional to V test. So, the Thevenin equivalent circuit will be Thevenin resistance sorry will be V test by i test. Now, this is true whether you have dependent sources or not. Now, when you have resistors only sometimes you may be able to use the formula for series or parallel combination of resistors, but in general even with resistors this is the method to use .

So, let me take a very simple example again. This is a voltage controlled current source whose value is let me call this V y and value of this is V y divided by 2 kilo ohms or 0.5 milli ((Refer Time: 1:23:45)) times V y, let say this is 10 volts. So, how would you go about doing this? You have to find the open circuit voltage which of course, you do by in the normal way 1, 1 prime. You do circuit analysis to find out the voltage across this and you have to also find the Thevenin resistance for that you set the 10 volt to 0 so that it becomes a short circuit.

You have 5 kilo ohms here and you have V y and this all these things will remain exactly the same you do not change anything in the dependent source. Then you apply this V test and find i. The ratio of the two will give you R th looking into this. Now, this is a very simple circuit, but whatever arbitrary connection of dependant sources you have, you can still follow exactly the same procedure. I hope this is clear.

So, procedure is exactly the same you have to find the resistance between 1 and 1 prime. If you are given a black box, let say in the lab and asked to find out the resistance between 1 and 1 prime what will you do? You will apply some voltage across 1 and 1 prime, find the current that flows through it, take the ratio or you force a current from 1 prime to 1 or see the voltage that is developed across it and take the ratio. So, that is how you do it for any circuits. Now, it just happens that if you have only resistors you may be able to take some shortcuts .

Now, the other question was somebody said how do you give the direction? I am not sure what is meant by this. May be what is meant is the direction of the, direction of the current source. So, when you find the Norton equivalent circuit you will short circuit the output from 1 to 1 prime and you measure the current flowing from on to 1 prime. So, that give you the direction, right.

So, if the current is actually flowing from 1 to 1 prime then inside you will have a current source like this. If in the short circuit current is flowing that way then inside I n will be like that and if it is in the opposite direction I n will also be in the opposite direction. So, there is no confusion here. Now, another question is can source transformation be applied if the network contains non-linear elements. Now, like I said before the path that you are transforming has to contain linear elements.

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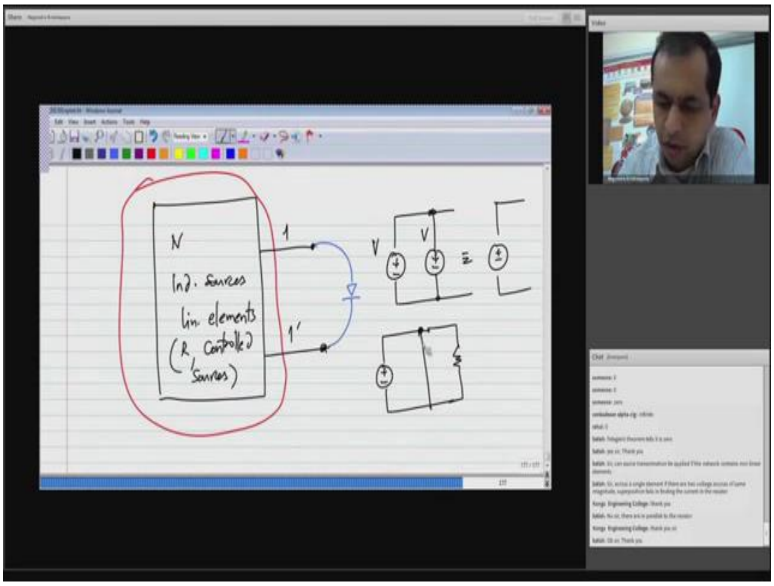

So, what I mean by this is the following. So, I have taken the example of this network N with independent sources and linear elements. And linear elements includes the resistance, I mean resistances and controlled sources. The only condition that the controlled sources have to be controlled by something inside N some branch voltage or branch current.

And you have 1, 1 prime. Now, the part that you are transforming this has to be linear. If you have non-linear elements elsewhere in the circuit something like this then that is okay, this will not, this is not what you are transforming. So, whatever I have shown inside the red box that is linear and that can be represented by this Thevenin or Norton equivalent circuit. And this source transformation means that you either represent I mean you go from voltage to current source representation which means that, that is also applicable to the linear circuit. Any other questions?

So, there are no more questions. Please try to do some of the things that I indicated that is trying to prove the Norton's representation that it is valid for any circuit, that is 1 thing you can do. And you can follow the lines of what we did for the Thevenin representation and you can also try to do the other one, that is try to prove conservation of power for any circuit using KCL and KVL.

There is another question again I am not clear of what this question is. It says across a single element if there are 2 voltage sources of same magnitude, superposition fails in finding the current in the resistor. The question is, Are the volatge sources in series? Is that what is meant here?

Now, see if you have 2 voltage sources of same value in parallel. Now, this is the same as the single voltage source. So, that is one thing. Now, if you insist on using superposition, you will get a degenerate answer because if this is V and this is V and here to set this to 0, then you have to short circuit it. So, you have infinite current here and some voltage across the resistor and so on. So, this is basically a degenerate condition and you cannot represent things like this.