Basic Electrical Circuits
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Lecture - 69
Substitution Theorem -Voltage Source

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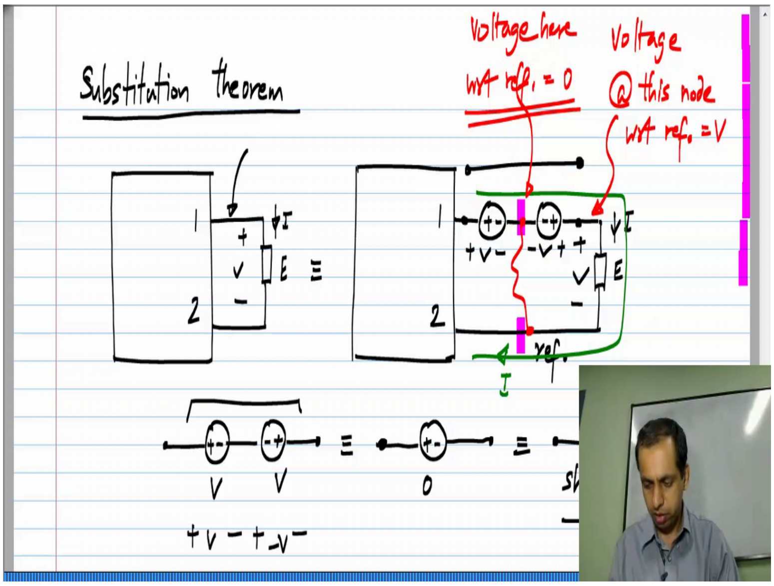

In this lesson, we consider another variant of substitution theorem, where we substitute the element with the voltage sources instead of a current source. Let me again consider a circuit with an element E connected to it. It has a voltage V across it and a current I through it. Now let me make the following construction. First of all, I will consider a series combination of two voltage sources, and connected oppositely; see that if you look at the polarities this has positive sign on the left side, this on the right side, and both have the value of V. Now, this is equivalent to a single voltage source whose value is the sum of the individual values. And if you look at it with the polarity that is why I have V, and the same polarity I have minus v because of this source. So, the whole thing is equivalent to 0 volts voltage source. And zero volts voltage sources nothing but a short circuit or a wire.

I can place this most fancy short circuit in any wire I choose in this circuit without alternate because I am not really changing anything at all. So, it is only that instead of taking of it as wire or a short circuit, I am taking it as the series combination of two voltages of equivalent opposite values. This will be exactly equal to let me replace this wire by fancy short circuit, remember between here and there, it just equivalent to a wire. So, this whole circuit is exactly equivalent to what we had earlier with this element E carrying a current I and having a voltage V across it. Now this itself V and this also V with the other polarity, so this way it is V and that way it is also V.

Now, let us consider the voltages at this node, and that node. Now we can take any reference we want, but just for simplicity, let me take this node itself as the references. I could take anything else I want it; it does not matter at all now. With respect to this reference, the voltage at this node, I will show that in red, the voltage here is V. At this node, with respect to the reference, it is V that is the voltage, because from here to there, you have potential rise of V; from there to there, you have potential fall of v. So, the voltage here with respect to reference node equals rise of V minus V due to the fall equals 0. So, these two nodes highlighted with pink have 0, the references by definition as zero voltage and this as the same voltage as this references which is also zero. Now what does this mean, this means that I mentioned this earlier and used it earlier also, if I have two nodes in the circuit with exactly the same voltage, I can connect the two together without altering anything else in the circuit. So, I can do this, so I connect those two together.

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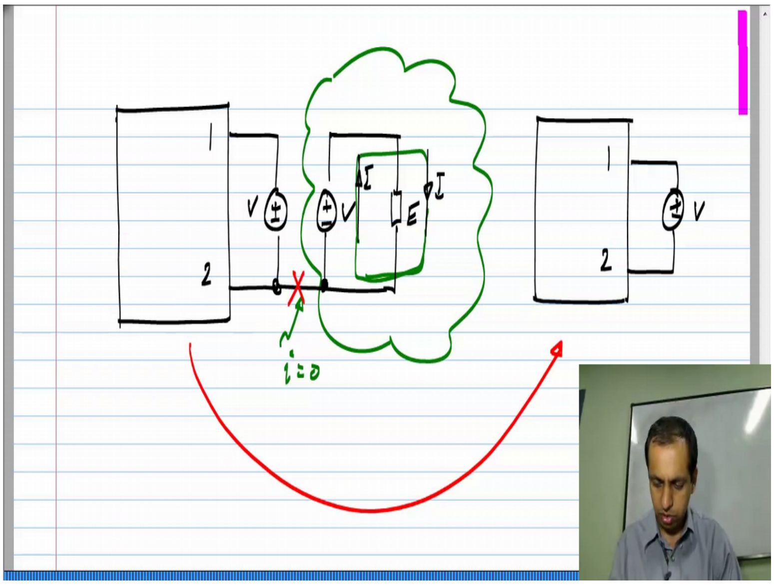

Now let me redraw this new configuration, I have the rest of the circuit, I have the first voltage source which I will choose to draw this way, because I have short circuited it. If I number these as terminal 1 and 2; I short circuited this node to node number 2, this terminal two of the circuit. So, I have this 1 and 2; and then from this point on I have also a voltage source of value V and the element E. Now it must be pretty clear that the current through this is zero that is because I also know that originally I had a current I flowing through this element in this direction and also in that direction through the voltage source V. Now, this is not something new I found, this is exactly the same as what was in here. I had a current I flowing in that direction; with the redrawn circuit, this voltage source is drawn with the negative terminal being at the bottom, and this element is drawn as it is. So, I have a current flowing that way.

Now, if you complete this, this current I flow that way. And if you find that current in this particular wire that I will be zero, because this I goes into that, and nothing comes into that wire. Now in generally, if you have this two isolated circuits, these are connected only via single wire, by Kirchhoff law the current has to be zero. Another way to think about it is, apply Kirchhoff current law into this whole big green circuits, there are no other wires going into this circuit and the sum of all current going in has to be zero. So, the current in this wire which is the only wire going into the circuit has to be zero. Now because the current in this is zero, I can also cut it off and remove that from my circuit. So, I will be left with remember I started off with the element E connected to the circuit like this, and that is the same as this, because the series combination are voltage sources is the short circuit and that is the same as this one this is simply redrawn version of that circuit, and this is the same as that. So, the statement of this idea is another variant of the substitution theorem.

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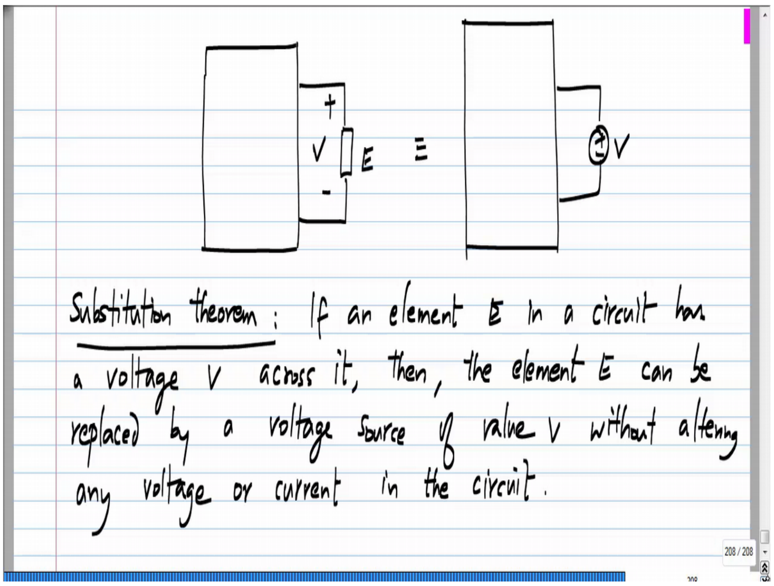

If I have a circuit with an element E, which has high voltage V across it; the element E can be substituted by a voltage source of value V. And if you make this change no branch voltage or current in the circuit will change; in other words the circuit will not be changed at all. If an element E in a circuit has a voltage V across it then the element E can be replaced by a voltage source of value V. And of course, this is without altering any voltage or current in the circuit. So, this is another variant of substitution theorem, where you substitute the element with the voltage source instead of a current source.

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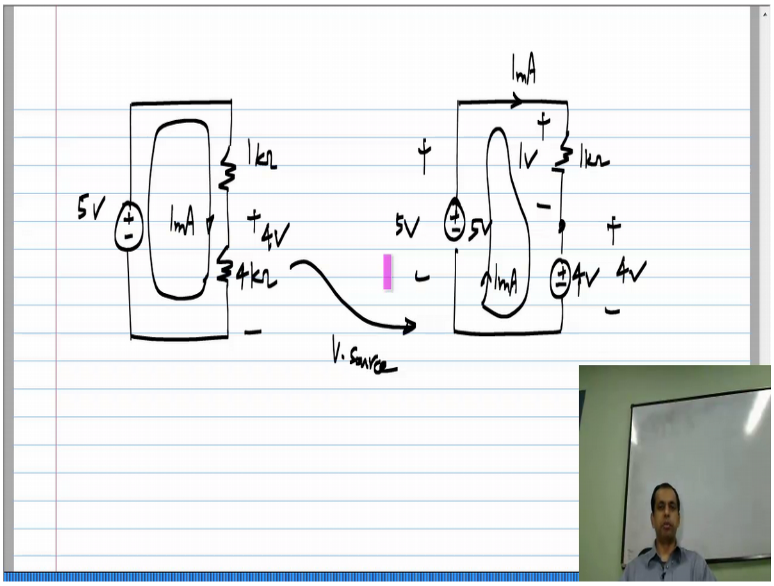

Now, let me show another quick illustration, I will take the same circuit. I have taken with the earlier illustration 1 kilo ohm and 4 kilo ohm across a 5 volts source. And we know that a current of 1 milli amp flows this way. Now let me choose to substitute this with a voltage source. Now, the voltage across the 4 kilo ohm resistor is 4 volts. So, what I will do is, take the same circuit, keep all the other components intact. This is five volts, but here instead of the 4 kilo ohm resistors, I connect the 4 volts source. Now we have to verify if the currents and voltages in the circuit have change; clearly you see that across the resistor, we have 1 volt drop that is 5 volts minus 4 volts. So, the current through this is 1 milli amp.

So, just like before, 1 milli amp current is flowing in the clock wise direction through this loop. Now a voltage across this is obviously 4 volts and across here it is 5 volts. So, comparing element by element and comparing this voltage source to this resistor, we see that no branch voltage or current has change in the circuit. Like the other variant with the current source, this is useful for proving theorems; and sometimes in actual circuit synthetics under some conditions if the voltage source can be replaced by resistor also.