Basic Electrical Circuits
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Lecture - 12
Mutual Inductor

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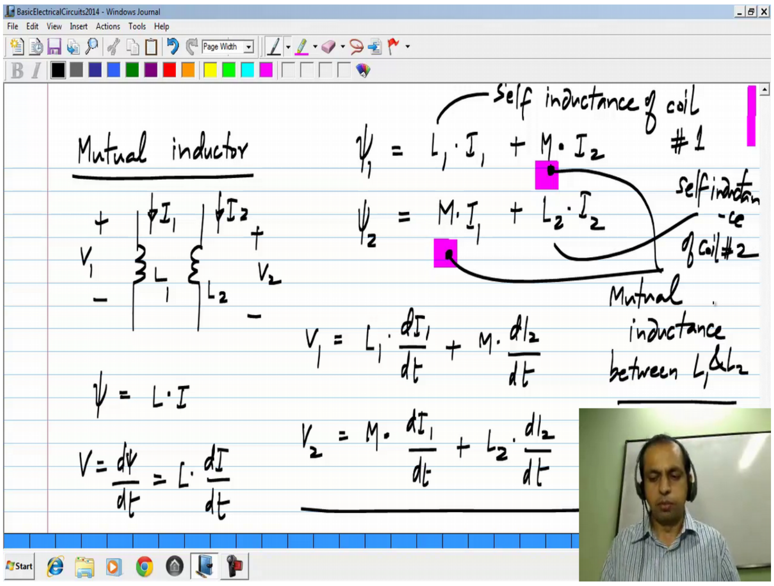

So, another basic element, which we can consider now, is what is known as a mutual inductor. This is related to the inductor we know that if you have a voltage V across an inductor L and current I through the inductor L the flux linkage is given by L times I, and the voltage is given by the time derivative of the flux linkage which is L times and the time derivative of the current. Now because the magnetic field of an inductor extends outside the inductor it turns out that you can place another inductor, and to distinguish between these two, I will call this as L 1, I 1 and V 1, and I will call this L 2, I 2 and V 2. they can be arrange to be closed enough to each other such that when you pass the current I 1 to L 1, it induces of magnetic filed in L 2 and causes some flux linkage there as well. So, the flux linkage in inductor L 1 is related to I 1 as well as I 2, and similarly the flux linkage in L 2 is related to both I 1 and I 2. So, this is possible because the magnetic field in an inductor can spread outside the physical extend of the inductor.

So, in such a case, what happens is that the flux linkage in L first inductor is some L 1 times I 1 which is what we expect knowing what we know about inductors, but it also related to some other constant M times the current in the second inductor. And similarly the flux linkage M 2 is related to L 2 I 2, which is what you expect given the second inductor plus the same mutual inductor times the current in the first inductor. So, the same coefficient appears here and here we would not discuss why that is the case, but that is the fundamental property that is the proportionality constant between I 2 and psi 1 is the same as between I 1 and psi 2. And this constant is known as the mutual inductance between L 1 and l 2.

So, because of this again we can get the current voltage relationships which are that V 1 is L 1 dI 1 by dt plus M dI 2 by dt and V 2 is M dI 1 by dt plus L 2 dI 2 by dt. So, this the mutual inductor and the voltage depends on the rate change of both coils. This L 1 is called the self inductance of coil number one; and L 2 is called self inductance of coil number two; and the M is called the mutual inductor between these coils. The self inductance of coil one is the inductance, it would have which gives the relationship between voltage and current; if the coil two was not even present. Similarly for the self inductance of the second coil is mutual inductance appears only one you bring these two coils together, so that the magnetic field from one inductor and influences the other inductor, and these are the current, voltage relationships. Clearly this is not a two terminal element; there are four terminals, two for each inductor.

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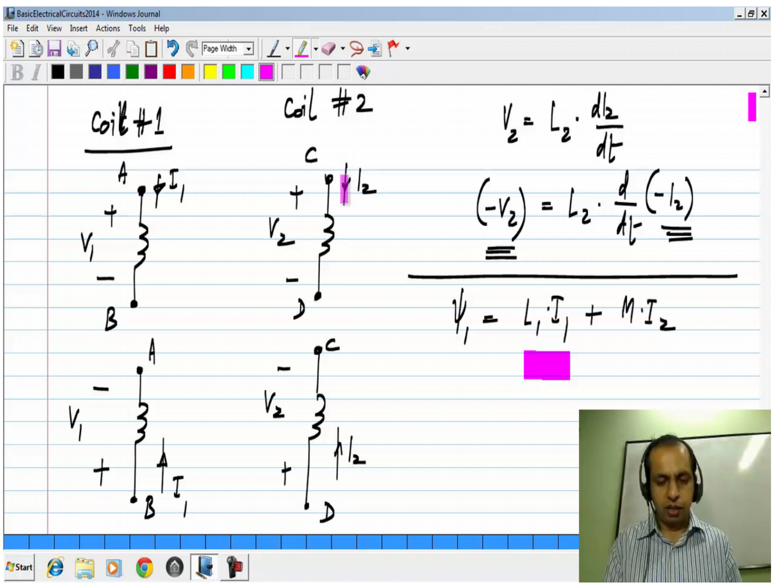

Now if you have been careful you would have notice some ambiguity that is let me take the two coils again. If I take the first coil by itself, I will define V 1 and I 1 according to the passive sign convention and to remove any ambiguity, let me call these terminals A and B. And I could equally well have defined this A and B mark the physical terminals, I could equally well have defined V 1 in the opposite direction, and to be consistent with passive sign convention, I have to consider I 1 in this direction. Now when I have coil number 2, again I have the same two possibilities, I have C and D. And I can take V 2 this way, and I 2 this way; or V 2 in this direction, and I 2 in that direction that is I can consider C to be the positive terminal for the defining the voltage or D to be positive terminal for this defining the voltage.

This makes no difference to the self inductance definition because direction I 2 also reversed, because if I wrote V 2 is L 2 dI 2 dt, I could also write minus V 2 as L 2 time derivative of minus I 2, which corresponds to the direction chosen in the bottom picture. If I define this voltage something else, it is simply the negative of that voltage and this current is the negative of that current, but when you have a mutual inductor, there is a problem. Now I could define coil 1 to be like this and coil 2 to be like this or like that; that makes difference for the mutual inductance because this current is opposite of that current. If I took the flux linkage to be L 1 times I 1 plus M times I 2. So, there is no ambiguity for the self inductance part for this itself, but for the second part if I take coil 2 I 2 in this direction, I get something and if I take it in the opposite direction, I get the negative quantity.

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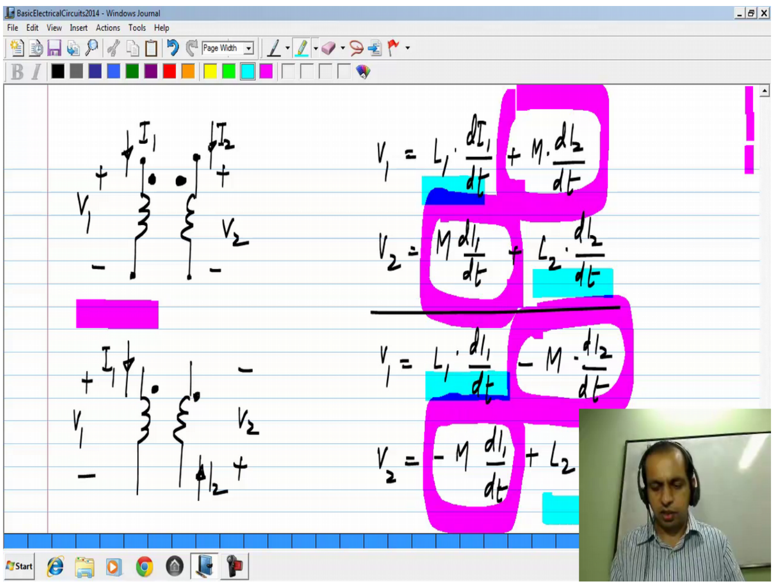

So, to remove this ambiguity, when you have a mutual inductor, let say we have V 1 and I 1. You place dots next to that coils, and you have V 2 and I 2. These dots are there so that the sign ambiguity in the mutual coupling is removed. So, once you have given the dots, what you do is let say you choose V 1 and I 1 like this, let me remove this one. Let say you choose V 1 this way for the definition of V 1 the terminal with dot is positive and I 1 flows in to the dot then you take V 2 also with the terminal with dot being positive, and I 2 flowing into the dot. With this, V 1 will be given by L 1 dI 1 by dt plus M dI 2 and dt, and V 2 will be M time derivative of I 1 plus L 2 time derivative of I 2. So, this removes the sign ambiguity that is you take both currents going into the dots and voltages according to the passive sign convention then you get the plus sign here.

If for whatever reason you choose to consider I 1 flowing into the dot I 2 flowing into the terminal without the dot then of course, you have to choose voltages consistent with passive sign convention; that means that the positive terminal of V 1 is wherever I 1 is flowing into and the positive terminal of V 2 is wherever I 2 is flowing into, in this particular case, V 1 will be L 1 dI 1 by dt minus M dI 2 by dt; and similarly V 2 will be minus M the time derivative of I 1 plus L 2 time derivative of I 2. So, as you can see, the sign of the induced voltage from the other coil that is the mutual induced voltage is what changes. The self-inductance part which given by this, this, this and that do not change. So, when you specify mutual inductance you also specify the dots, so that there is no ambiguity in the sign of currents and voltages.