Electrical Machines - II
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Lecture – 66
Development of Equivalent Circuit

Welcome and we were discussing about the single-phase induction motor.

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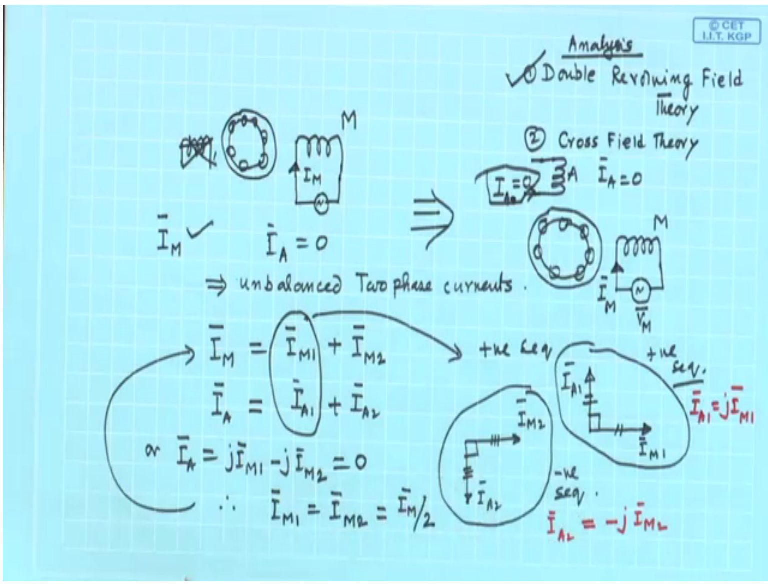

And a in single-phase induction motor will be truly a single-phase induction motor when the motor will run on a single winding that is important ok. It has got no starting torque we have seen. And we have convincingly seen that, it cannot have any starting torque ok. For to incorporate starting torque we have to do something. But the point is, when the machine will be running it will run on a single winding and that winding we call it I am sometimes drawing here let me follow some rule.

This winding is main winding is there and here is the main winding current I M and it is excited from a single-phase source. That is all it should be like that. Now to understand why this machine is having no running torque, but it still will have a why it is not having a starting torque, but it will still have running torque there are generally two ways to analyze the machine. One is called double revolving field theory analysis can be done in two ways analysis. Double revolving field theory this is by one method. Another is called cross field theory.

By these two methods it can be analyzed of which in this class we will consider double revolving field theory. Because if you adopt this method of analyzing, you can invoke all the things you have learned in three-phase induction motor analysis simple. Now in my last class I was telling it is there. Now this situation, nothing will change. If I imagine that, this is the rotor shorted, there is a main winding M and there is another winding in quadrature magnetic axis in quadrature that is called A, but I will not excide this winding at all, only main winding I will excide. So, these and these situations are same inactive, although its magnetic axis is different.

Now therefore, you if you connect here an AC source, this winding which will carry a current of I M V M is the supply voltage. And this winding since I have not connected anything; that means, I A is 0. No source is connected. So, I A is made forcefully 0 and therefore, these two systems are one and the same system. I will try to understand in this machine as if I will say it is a balanced two-phase motor. These two coils are there, one coil is carrying a current I M another coil is carrying a current of I A which happens to be 0. So, the thing is, I M is present and I A is equal to 0. Therefore, these two currents or these are the 2 sets are unbalanced I can treat it as the unbalanced two-phase current.

And then, I will say this unbalanced two-phase current can be broken up into a positive sequence current and a negative sequence current. So I M, the main winding current can be written as a sum of I M 1 plus I M 2 and the auxiliary current why it is called auxiliary I have just arbitrarily now calling, we will see later why they are so named it. I A will have its positive sequence current plus negative sequence current. This I M 1 and I A 1 is the positive sequence and it is a balanced two-phase current. And the relationship between them will be suppose, this is I A 1 and this will be I M 1 and this is 90 degree these two lengths are same.

So, this I M one and I A 1 form a balanced two-phase system. Similarly I M 2 and the I A 2 will form another balanced two-phase system. But the phase sequence in this case is A M in that case it will be m and a mandate. That is; auxiliary winding current we will be lagging main winding current now. So, maybe it will be like this I M 2 and I A 2 and these two are same and this are not same this may not be same to this. So, this is the negative sequence and this is the positive sequence of current M.

Obviously, you can see that I A 1 here if I write I A 1 will be equal to j into I M 1 90 degree. Similarly I A 2 will be equal to minus j I bar M 2. So, I put it here. So, or I A auxiliary winding current if you rewrite I will translate everything in M main winding current. So, I A 1 is j I M 1, I A 2 is minus j I bar M 2, but the case I have considered I A is equal to 0. I am not connected anything to the auxiliary winding only main winding is carrying current that is I inherited the this circuit my thought process I am doing it is there only main winding, I will assume another winding is there because two-phase winding machine analysis will be in the same line as that of balanced three-phase induction motor.

So, that was the reason you bring another winding identical same as M, but carrying no current. So, these are one and the same thing. So, now, these two currents are and this I A is 0 which means that I M 1 will be equal to I M 2. Magnitude of positive sequence and negative sequence will be same. And not only that if you put it here in the first equation this if you put it here you can say this is I M bar by 2. This will be the thing. Is not?

Therefore, what I A 1 I M 1 these two currents forms a balanced two-phase current. I M 2 I A 2 also a balanced two-phase current. And, and so what we can do now, we will consider one sequence at a time and try to see what is the thing that is the idea. For example, this I A 1 and I M 1 if you considered to be present alone, positive sequence first then I will say these coils that is what I am telling consider only positive sequence.

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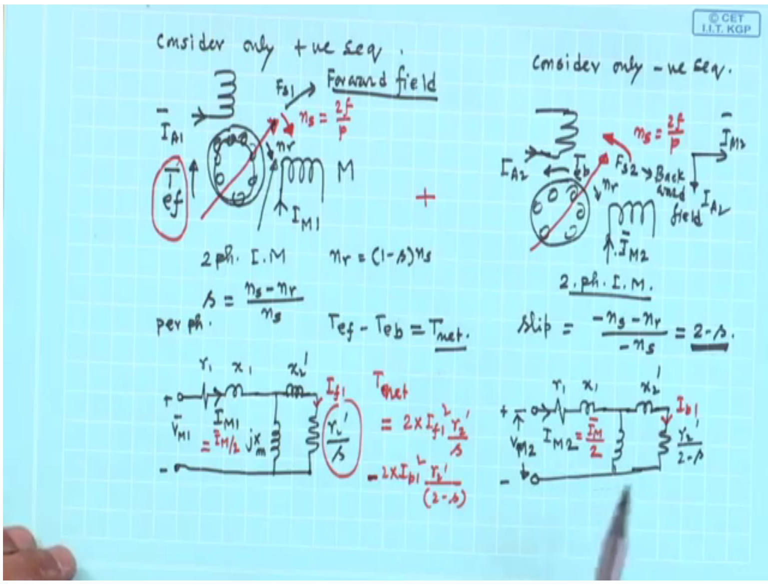

Then I will say, oh this is the rotor this is main winding this is auxiliary winding say that it is carrying a current of I M 1 and it is carrying a current of I A 1. Therefore, it will and these 2 currents are balanced two-phase currents 90 degree apart. So, it will produce a rotating field moving from the leading to the lagging phase I A and I M ok. And the value of this field synchronous field will be 2 f by p like this. Now consider, consider only negative sequence. It is carrying a current I M 2, but phase sequence reverse now and it is carrying a current of I A 2 separately I am considering.

And here, it is like this that I M 2 these two currents are equal magnitude, but this is the phase sequence. So, leading current is M 2. Therefore, this there will be a rotating field here produced in the opposite direction leading to the lagging phase and once again it will have a field n s equal to 2 f by p. But this rotating field will move in the opposite direction as that of this one. Is that clear? Now see the interesting thing. And this plus this will give me this situation main winding alone, no auxiliary winding that is the idea [FL].

Now suppose I say that if that be the case, let us also tell that rotor is rotated. Rotated by say some external agency I want to analyze the machine. Let the rotor is rotating like this. Whether the machine itself has created a torque or rotating I am not commenting on that. Let us imagine somebody is rotating in the clockwise direction with speed n r. At that time, what is going to happen?

Now for the positive sequence, I have assumed it. I have assumed rotor is rotating in the same direction as that of the stator field f s 1 positive sequence, here it is stator field negative sequence. Now this positive sequence field f s 1 is moving in the clockwise direction and this is also rotor is moving also in the same direction. So, we say instead of calling it because of positive sequence and negative sequence, we say that this field will give an M forward field, forward field. Which field is forward?

The field the direction of rotation of that field is same as the direction of rotation of rotor that I have assumed. I am still not sure n r will have some finite value or not. Let us suppose by hand by some external agencies given it a spin, n r it is running and this is this equation. Then, then n r is the speed. Therefore, the speed of f s 1 and speed of rotor rotation, their directions they are same and that field I am giving a name forward field.

And this field f s 2 which is moving in the opposite direction of the rotor rotation, let me call it a backward field. These I can always do give some name.

And mind you, this is a balanced two-phase induction motor. This is also a balanced two-phase induction motor. What is the slip at which this motor is running? s equal to n s minus n r by n s. What is the slip in this case? Slip in this case? It will be minus n s minus n r by minus n s and this will be nothing, but because n r is we have used so many times n s. If you put it, it will become 2 minus s. Looks like it this motor is in somewhat breaking zone or whatever it is.

Obviously from physical consideration, this torque acting on this machine will be in the same direction as the direction of the motor and this torque I call electromagnetic torque due to forward field. And for this rotor, stator field is moving in this way. Therefore, this torque will be there. And then I will say that the net torque acting on the motor will be T e f minus T e b because they will be acting in a opposite direction and. So, this is the net torque T net.

So, you know that there is a forward field there is a backward field from another configuration also I will bring that forward field and backward field concept mathematically it can be brought. But what I have done so far is that; once again let me go rather slowly. This is the main thing. Only a main winding is there, but this is it can be thought of as a balanced two-phase winding on the stator, but this winding is not getting any current and this is the rotor.

Then this I A is equal to 0 and I M, they can be broken up into a balanced positive sequence component this one plus this one. And they can be related with main winding current I M because here is the only supply, these are real things I have applied voltage V M and I M is flowing. And in terms of that I M I have been able to find out what is I M 1 and I M 2 hence, I A 1 and I A 2.

Then I have come to this one and then I am telling there are this is the rotor this is I M 1 I A 1, they are now carrying current. And I A 1 is leading I M 1. So, the stator field will be moving from leading to lagging this is. Similarly the backward balanced two-phase current this currents are balanced 90 degree it will move this way. Then I am arguing that, the electromagnetic torque developed by this motor it is a balanced look like a rotating field is there so, electromagnetic torque in the same direction as the stator field.

And this field and I have also assumed some rotation of the rotor arbitrarily ok. Let, let us assume it is moving at some speed n r in the in the clockwise direction. The field which is also in the clockwise direction, I have given it a name called forward field and electromagnetic torque will be in the direction of the forward field. Similarly this two will produce a rotating field, but the main winding current leads auxiliary current. So, from it will move in the opposite direction and it is called a backward field.

Now then the net torque will be difference of these two. Is that clear? Now after getting this, I will be now telling, what is the equivalent circuit of this machine equivalent circuit of this machine? Equivalent circuit of this machine will be per phase will be r 1 x 1 x m x 2 dashed and r 2 dash by s what else; per phase equivalent circuit, per phase.

And per phase current is I M 1 that is all. Similarly for this machine, stator impedance per phase r 1 x 1 j x 1 x 1 and then there is magnetizing branch referred to stator. This current will be I M 2 and this will be x 2 dashed and then this will be what slip it is running 2 minus s. So, r 2 dashed by 2 minus s that is all. Is not? Because r 1 x 1 r 2 dashed x 2 dashed this 2 motors are otherwise identical. Only thing you have phase sequence is reversed.

What will be this voltage? Whatever will be the drop here it is V M 1, positive sequence voltage. What will be this voltage V M 2? Negative sequence voltage plus minus. What will be this current I M 1? And the I M 1, I have seen it is equal to I M by 2. Similarly, what is I M 2? It is I M by 2 like that [FL]. What will be the value of this T e f? Electromagnetic torque developed by this forward field or forward motor sometimes it is called. It will be this power.

That is; this current is known. So, I will find out parallel combination find out this current, this current square into r 2 dashed by s. What will be the torque developed here? This current square into r 2 dashed by 2 minus s into 2. Two-phase it is a balanced two-phase motor. So, suppose I say that this current is I f 1 and this current is I b 1. How do I know these currents? Because I know these currents: I M 1 and I M 2, parallel combination.

So, torque will be net torque will be 2 into air gap power of this machine I f 1 square into r 2 dashed by s. Then another term I b 1 square into 2 into r 2 dashed by 2 minus s. And that will be the torque produced. But, see this is the thing it has come to like that. And why I have put minus sign here? Because from physical consideration, I know these two torques act in opposite direction. So, negative sign this is also important like that. That is this way I can calculate the torque.

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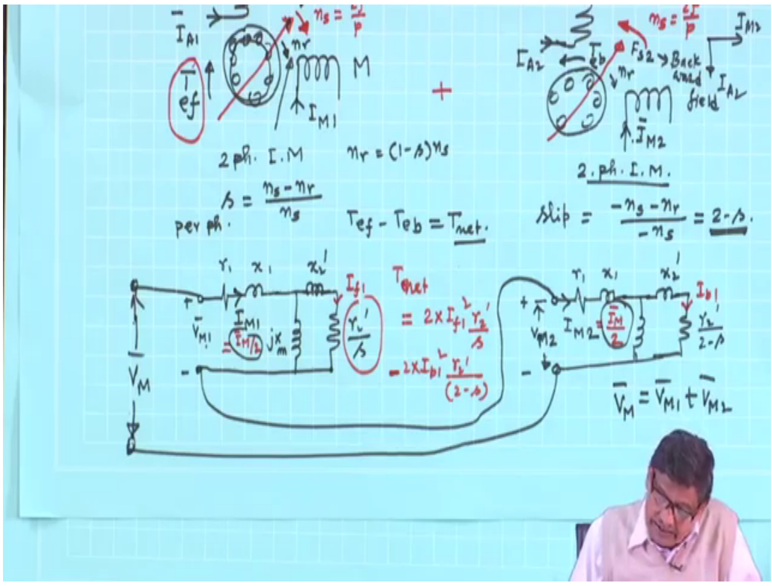

But I will go a step ahead which is so tempting you know. Because you see this is I M 1 which is I M bar by 2. This is I M 2, which is also I M bar by 2. Then it looks like there is no harm if you connect these two in series. Let me do it here. Nothing will change. I will connect it in series, I M 1, I M 2.

And not only that, then you see if you connect them in series this voltage is V M 1 plus V M 2; that means, V M. See as I told you that, I have applied a that unbalanced two-phase system I A 0, I M. I have broken up the currents into balanced two-phase current then I got this ok. Then I have because it is a balanced two-phase machine, therefore; equivalent circuit must be like this. It is also a balanced two-phase machine its equivalent circuit will be like this.

And therefore, this is I M 1, this is I M 2 per phase equivalent circuit. And then I know [FL] I M 1 is equal to I M 2 and this voltage here will be the positive sequence voltage of M 1, this is the negative sequence voltage of M. Therefore, why not connect them in series? And it will be like this. Now this, this is this voltage is V M 1 and V M 2 [FL]. I will do another important thing at this point. That, this is a positive sequence per phase voltage applied. So, V M the this actual applied voltage will also have a positive V M 1 plus V M 2.

And that I am telling it will be the voltage drop here and it will be the voltage drop there. Now in this network, it is all nice ok. You can leave with this equivalent circuit. See after all, you have applied to the actual machine that is this machine what is at your disposure V M and I M. So, in this equivalent circuit everything is fine provided you know what is what, but only disturbing thing is you have applied V M this equivalent circuit is taking a current of I M by 2 that may create something. I mean is it possible to modify it slightly? So that, this current will become I M that you getting yes it is possible.

What you do is this; your voltage here is V M. All the impedances this plus this when you divide with V M you get this I M by 2. Now suppose, I say I will keep this V M same because V M is the applied voltage and divide all the impedances by 2, then the current drawn must be I M. That is now divide all the impedances by 2, then you will see that ok.

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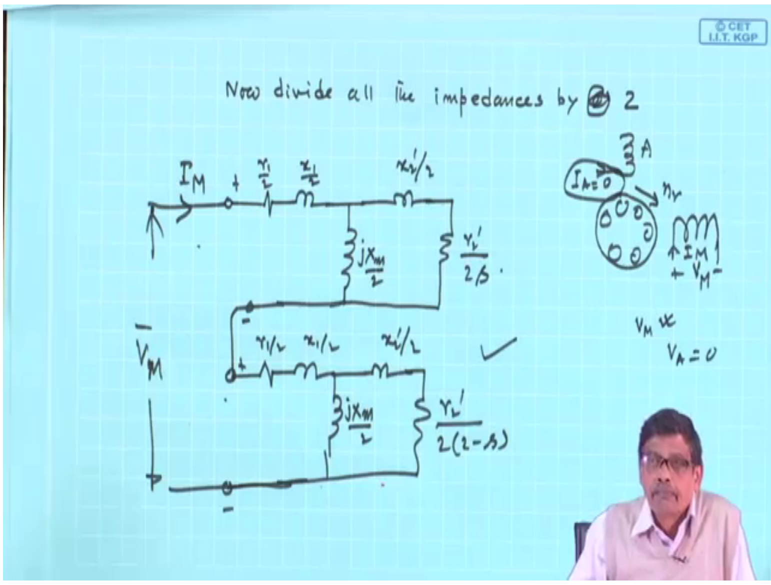

This is r 1 by 2, this is x 1 by 2, this is j x m by 2, this is x 2 dashed by 2, and this is r 2 dashed by 2 s. And this one I am drawing below that the V M 2, this fellow. I am just drawing below. So, this will be r 1 by 2 x 1 by 2. This is j x m by 2, this one is x 2 dashed by 2 and this one is r 2 dashed by 2 into 2 minus s. Then what I am telling and these two are already connected in series plus minus, plus minus. And here is your V M and then I will say this current must be doubled, that is what I am telling. This is the thing.

So, this where our machine was like this, operating on single winding mind you main; you have applied a voltage V M plus minus. This current is I M and it was I have assumed it is rotating in this direction rotor. Then this is the equivalent circuit of the whole motor and there is no even if there is no winding this is valid. Because after all that, auxiliary winding what I talked about I assumed it is not getting any current. So, whether it is present or not is in no way going to dictate what should be the torques in the machine.

So, the whole idea is this current you assume 0, then we analyze this circuit I A and I M unbalanced two-phase current, because I am sure I A is 0. One may question, why not you broke up V M and applied voltage 0 here? No. Never do that. You do not know the voltage here maybe there, there will be because of this rotating fields are there.

But I am certain about this fact I A is 0 if you have not connected. So, that is another important thing it is not that. Should I assume this is V M is there? V A is 0. Applied voltage is 0, but the terminal voltage between these two points may exist. When the things will be running you have excited this. There are rotating fields is no? Therefore, you start with this I A 0 and finite I M here. Break it up, and do the things ok. We will continue with this go up to this.

Thank you.