Electrical Machines - II
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Lecture - 50
Core Loss in Induction Motor Simplified Equivalent Circuit

Welcome. So, we were actually discussing about the; another a comparative study between slip ring induction motor and cage induction motor. Cage induction motor is less costly and the one of the important point is, cage rotor can adjust to any number of stator poles and that is why earlier days, people thought that, I mean not thought, it was used stator windings that started playing, because they could not do much with frequency. Frequency was 50 Hertz in our country.

So, the synchronous speed can only be varied, people thought by varying the number of poles, if your hands are tied that you are not allowed to vary frequency, but still you want to get variable speed out of an induction motor, then no other way, but to control the synchronous speed of the rotating field. That can be done by using separate balance, three phase windings on the stator. Rotor you used a cage rotor, because cage rotor has got this interesting property, it can adjust to any number of poles.

Therefore, use either multiple winding on the stator or also single three phase winding, but reconnections above it's various phases could also produce different number of poles, but with the advent of power electronics converters, that is inverter in this case, it is no not now, a I mean your hands are not bound by the fact that supply frequency is 50 Hertz. You can change the supply frequency to any value you like. Therefore, it looks like the synchronous speed of the machine 2 f by p.

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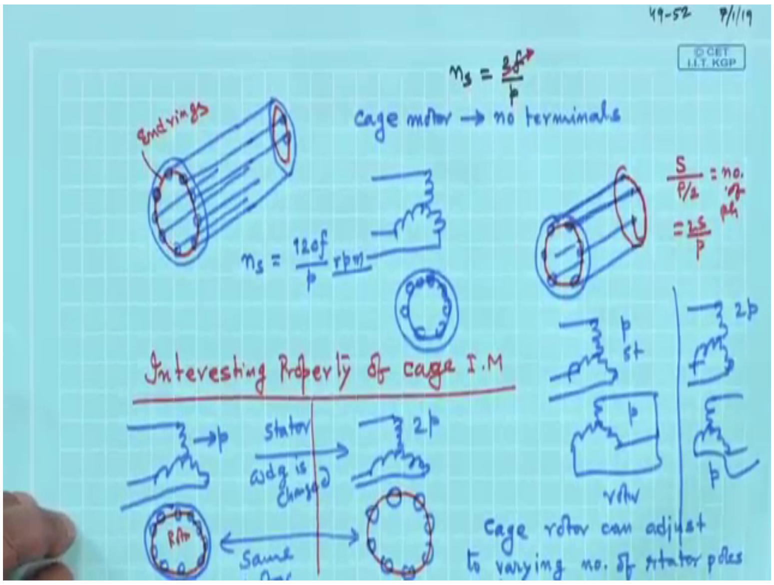

In nowadays, the thing is that do not touch p. I mean, what is the point of having another winding synchronous speed of the induction motor then can be changed 2 f by p. So, supply frequency I will vary p, I will not touch cage induction motor or slip ring induction motor I do not care, p I will not touch, supply frequency I will vary. We will discuss about these things a little later, but this is the things I wanted to tell about the cage induction motor.

Now, the question is if this is the cage induction motor, stator so far a stator is concerned it does not, it looks like it does not know. It is a poly phase winding not a three phase rotor bars are, because after all it is interested to know whether same number of poles have been produced by the rotor, based on that it reacts and draws additional current from the supply just like transformer.

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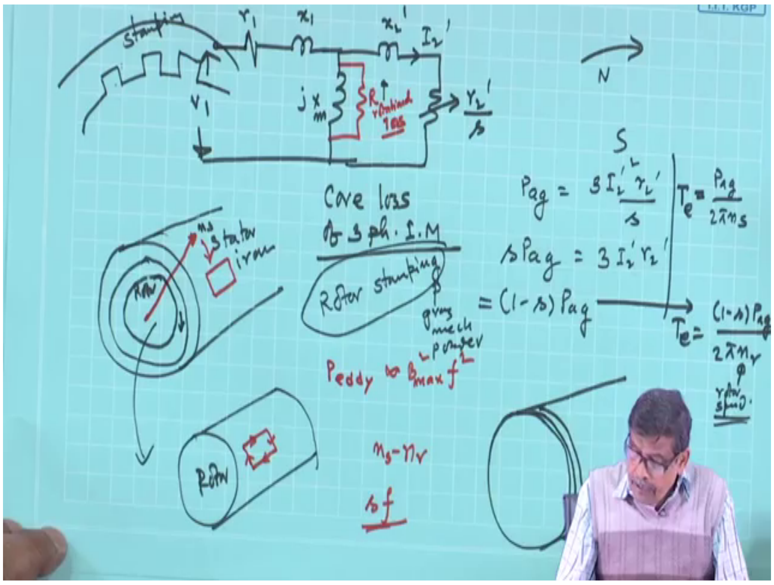

Now, therefore, when I draw the equivalent circuit of a three phase induction motor, whether same equivalent circuit will be valid, I will say yes, it will be. This is r 1 x 1 and this is your x m and this is your x 2 dashed and r 2 dashed. That is how I was drawing at least for a slip ring induction motor. This is my supply voltage, is not, I was drawing at any slip. Now, the question is if it is a cage type induction motor whether can I draw this type of equivalent circuit?

Oh yes, you can. Why? Because I told you stator reacts, on the basis of number of poles it has created or I will, I can also say that if your rotor is sketch type, is not and it can produce adjust to any number of stator poles. Therefore, the ones the number of poles are same I can always think those number of poles have been created by an equivalent three phase winding on the rotor, whose per phase resistance is r 2 dashed and x 2 dashed ok. I can always find out, if there is a rotating field suppose, N S. There is a rotating field I do not know who has created it.

I can always think oh, it has, it has been perhaps created by a three phase balance to winding. Why not and therefore, I can proceed as usual, because after all these parameters which will be the equivalent three phase of the rotor winding per phase parameters and this parameter values can be and these are all referred to stator and this parameter values can be determined by doing some simple experiments. So, my thought process let it be ok, some equivalent three phase winding is present and r 2 dashed and x

2 dashed are respectively that equivalent per phase rotor resistance and stand still leakage reactance of the rotor question comes ok, but your actual machine was this how this r 2 dashed, which your we have already assumed; it is a three phase type and there are resistance per phase, which is bar resistance here ok.

They can be related, I do not bother that can be done in your design course. You will learn, but so far as the discussion on three phase induction motor goes and I know it is a cage induction motor, I should not be, do not it, because of the fact that some equivalent three phase winding I will always think and by some doing some experiments so called no load test and blocked rotor test, whatever this parameters I will find out that will correspond to equivalent three phase winding of the rotor per phase values that is the thing.

So, everything goes all right, whatever we have done, the talk expression this that only thing if you say is this is the r 2 dashed where is r 2 dashed in the bar that I will not be able to tell that is also not necessary. I will be always drawing the equivalent circuit referred to the stator, that should be understood [FL] after. So, this is what? So, cage induction motor can be all those expressions obtained earlier can be applied to get the values.

I will discuss about no load and block rotor test and show you that how to estimate these values later. No matter for slip ring or cage, it does not matter. Now, before that I want to tell you one thing about the in this equivalent circuit if you see this is per phase equivalent circuit, there is some real power input and out of that real power a power will be lost in the resistance r 1 on the stator.

On the stator there is only reactances here, no power loss here, rest of the power I called air gap power which enters into the rotor at that power is here and if you can estimate air gap power that is this current square into r 2 dashed by s. Your torque is already calculated that is torque in synchronous what and divide it by 2 pi n s. You will get the actual torque you need not go to the level of mechanical power developed although that can be done, because Pag is 3 I 2 dashed square r 2 dashed by s.

This is I 2 dashed and rotor copper loss is sPag that is 3 I 2 dashed square r 2 dashed, then mechanical gross mechanical power developed is P s gross mechanical power that is all and if you want to calculate torque developed by the machine, it will be this Pag by 2 pi ns that is all or from this expression, if you calculate same Te will be 1 minus s into Pag by 2 pi nr, you have to write, where nr is the actual rotor speed in nrps rotor speed.

So, it is a good practice calculate Pag do not go up to that level gross torque can be calculated developed by the electromagnetic torque developed by the machine, because machine is running that steady state with some particular value of slip. Now, the question is do the three phase induction motor has got core loss? The answer is yes. Why? Because you see if you see this stator, stator iron core loss I am commenting on core loss on of three phase induction motor.

So, there is a rotating, this is suppose stator iron I will, I am not drawing this slots, conductors are here, stator iron and here is a rotating magnetic field, it moves. Therefore, if you consider any conceivable closed path on the stator irons surface or inside here. On the stator iron, if you consider any conceivable closed path with time this loop will see a rate of change of flux linkage and therefore, there will be also current in this loop and these are called eddy currents and they will consider, they will cause power loss on the stator and this power loss will be proportional to just like transformer.

The frequency at which this flux is cut in this loop; that is f square and the maximum value of the flux density square. So, so Peddy current loss as you as you know in a transformer it is proportional to B max squared f squared like that per unit volume. So, Peddy current loss will take place in the stator iron [FL]. Before I go further, let us see what happens to the rotor body. This is rotor, rotor will rotate, as we know in the same direction of the resultant field or stator field which is moving with ns and this rotor field will also with respect to a stationary observer will rotate at the same speed.

Now, on the rotor body, it is suppose rotor body I am drawing separately, rotor iron, this is rotor. Also you consider a loop on the rotor iron, we find that there is field passing around this loop, but at what speed? You are sitting on the rotor now, you will say that the field is moving pass this loop, at a speed ns minus nr. Therefore, induced voltage in the rotor is decided by ns minus nr or in fact, we have seen it will be sf supply frequency is f, why not ns. So, sf is the frequency of the of the Peddy currents here, in the in any loop closed loop.

But slip is very small we have seen slip will be 0.05 like that, if your supply frequency is 50 hertz. If full load slip is 5 percent 0.05, your rotor current frequency and also rotor

Peddy current frequency will be of the order of 2.5 hertz, very less. Therefore, what people do? People do not bother about the Peddy current loss of the rotor, that can be neglected compared to the Peddy current loss on the stator, is that clear. Therefore, that must be understood.

So, that is there therefore, how to take this Peddy current loss into account. Peddy current loss depends upon the flux, that is the magnetizing current. So, if you want to further improve upon this equivalent circuit, you can write here one resistance, which is called rotational loss. The power loss here is rotational loss, which will be, because of Peddy current loss and of course, it has got another component called frictional loss.

I will come to this, but anyway the to take into account of Peddy current loss, we have to connected resistance there. So, the complete equivalent circuit will be then exact sort of equivalent circuit is r 1 x 1 j x m like transformer only. This is the in transformer, we are writing core loss is represented by this resistance x 2 dashed and r 2 dashed, no matter whether it is cage or slip ring, it is per phase, equivalent three phase, rotor and rotor resistance and rotor leakage reactance reflected on the stator side and you can find out the parameter values.

Now, after telling this of course, you have to see that this rotational loss is small. So, to reduce this rotational loss, what you can do it; this rotor instead of using a solid block of iron, you use circular plates ok. For example, if you have a rotor say stator block like this stator iron. These are called stampings, thin plates, few millimetre thickness flat plates like this here, anything cardboard I have not brought. So, thin plates of circular plates slotted circular plates you take, which are insulated from each other by a varnish coating and stack one above the other to get the length of the machine. So, stator is to be definitely laminated ok, thin plates to reduce this or to make this high.

So, you take care of that, try to reduce the rotational loss as far as practicable by using stampings, while constructing the stator iron. It is not a solid of block of iron, if you use solid block of iron will become too heated up, because of Peddy current losses ok. So, always remember circular, thin, short slotted plates are; next class I will show you a stamping, rotor stamping ok. Rotor stamping, as we used just to point out a number of rotor stamping insulated from each other electrically. If you do not insulate it from each other then Peddy current path will remain, they will short circuit penetrate.

So, that is the thing ok, we will use that. Only thing is people generally, this rotational loss resistance if you also show your that r thevenins and x thevenins this values are much larger than r 1 x 1 no doubt, but those r thevenins x thevenins will get changed. It will become slightly more, I mean involved in calculations because we have to r thevenins we have to calculate, which will be this resistance this x m and this r 1 j x 1 in parallel; so, calculations will be slightly higher.

But if it is neglected, because what happens, magnetizing current is much higher than the core loss component of current. Now, I will right now tell today another one thing, that is called the approximate equivalent circuit. So, this is somewhat exact equivalent circuit ok. So, one of the approximate equivalent circuit, which is very popular and you will find MG says book also emphasize that point.

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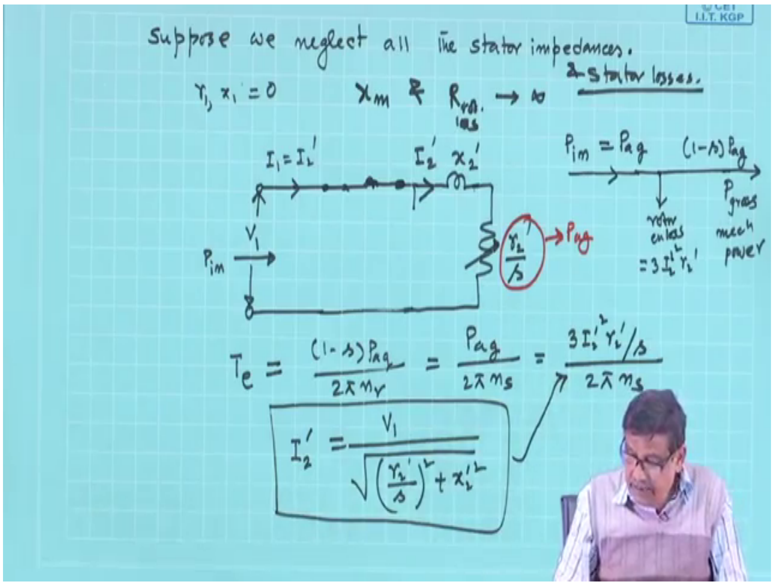

Suppose, we say that suppose we neglect all the stator impedances, what do I mean by this? That r 1 x 1 is 0, it is stator you neglect them x m and this rotational resistance, this is neglected means what? These are pretty high I mean you must understand.

So, these are shorted then. So, r 1 x 1 0 means short no, nothing is there and about this parallel branch open it. When I say all neglect the stator impedances so do not do not short it, they should be opened. X m and R rotational loss register that is this resistance is very large like infinity then the equivalent circuit will simply look like your per phase applied voltage V 1 r 1 is not there, 0 shorted x 1 is not there.

So, r 1 0 x 1 0 and this parallel branch open circuited, nothing is there and then you have only rotor parameters present that will be the simply the equivalent circuit. Now, under this particular assumption, which people prefer sometimes, to have quickly the performance idea of the induction motor ok, r 1 x 1 smaller 1 x 1 will be small. You see that they are small at the design level.

Similarly, try to make X m and R rotational high, in order to reduce the magnetizing current as well as the core loss and frictional loss try to make it as small as possible. Means this parallel branch is also high and with these try to find out, what is the, how much torque is produced at what slip machine produces that torque etcetera, torque slip characteristics very quickly I can do that.

So, for some computational advantage people often resort to this simplest equivalent circuit ok, to get quickly about the idea of how much is the t backs I will not calculate that big expression r thevenins x thevenins, this that. It will give you a very good estimate, not the exact value, that is also true, but it will give you a fair idea, what is the order of the maximum value of theta or or the value of the slip, at each at which it is produced and to the, to do this it is very simple.

For example, one way I can do it, I have already found out r thevenins b thevenins in terms of that the expression of the torque etcetera. I will once again bring out those expressions, there I will put r 1 x 1 0 X m. If it is there in that expression I mean that is infinitely large and I can get the expression for this so called equivalent circuit, whose all losses I have neglected, stator losses. Stator impedance and stator losses I have neglected, but I will not do like that later, because it takes only two steps to arrive at those expressions.

So, I will straightaway use this equivalent circuit to get those things, it will be also a good practice. What we are doing? Suppose, this current is I 2 dashed and this will be equal to your I 1 is equal to I 2 dashed in this approximate case [FL]. Now, what is the input power P input is here, P input and after this P input.

There is no losses on the stator, this power must be equal to your air gap power in this particular case that is what I am assuming and from these you have to subtract the rotor copper loss. What it's value is; 3 I 2 dash squared r 2 dashed. This is the total rotor copper loss and this is 1 minus s into P a g, is the gross mechanical power that is all.

Therefore, torque developed by the machine will be same thing 1 minus s into P a g, if you write, you divide by 2 pi n r suppose, the machine is running with a slip s. So, this comes out to be Pag by 2 pi ns and what is air gap power? It is represented by the power here, this is Pag. So, this will be 3 I 2 dash square r 2 dashed by s by 2 pi ns.

I could write straight away, for any machines equivalent circuit air gap. I mean torque developed is the power here divided by 2 pi n s ok. Now, in this particular case I 2 dashed is nothing, but V 1 r m s value of that will be divided by r 2 dashed by s whole square plus x 2 dash squared and I will put it here and get the expression of the electromagnetic torque, in the next class. You can, in the meantime try on your own ok.

Thank you.