Electrical Machines - II
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Lecture – 42
Equivalent Circuit of 3-phase Induction Motor (Contd.)

Welcome and we were discussing about the Equivalent Circuit of the Induction Motor.

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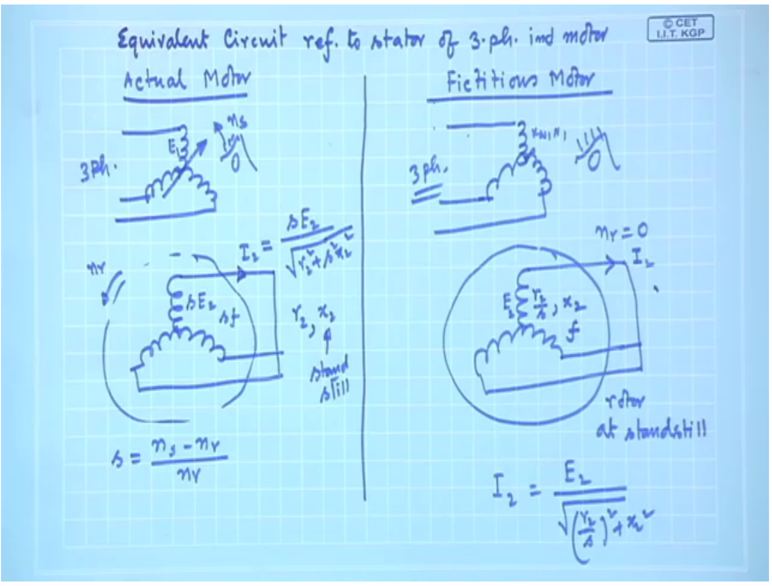

Equivalent circuit refer to stator, refer to stator of 3-phase induction motor. And let me quickly just review because this was slightly looks like involved, but really not so and what I was doing is this, let me draw a vertical line here. This is my actual motor, actual motor, what we did last time it is necessary and read many times look at this video if necessary and this is a fictitious motor or imagined motor fictitious. This motor is not in existence [FL]. What was the thing? This was my primary suppose with this is star connected.

I am not drawing r y b all this things. This is there and here is your rotor and these two are all these are shorted. Here you have energized with 3-phase supply. And here, machine is running with a speed n r and your fields are moving with speed n s ok. And when you when it is running with a speed or some slip s, I know the induced voltage here is s E 2 per phase and here it is E 1 per phase induced voltage and there will be some rotor current. This I 2 will be equal to s E 2 by root over per phase current r 2 square plus s square x 2 square, where x 2 is the standstill leakage reactance fine.

Now when this current flows you are sitting on the stator. What you will observe? It is drawing carrying a current I 2. Therefore, rotor produces a field, rotating field. Where it will be positioned? Last time I told you the position of the rotor field depends on power factor angle of the circuit. Power factor angle depending on that rotor produces a rotating field and that will be also moving in the anticlockwise direction.

And what will be the strength of this field? Strength of this field will be this rms current and mind you no matter whether the rotor is rotating or not, sitting on the stator you will always see rotor field is moving with synchronous speed; many a times we have seen that. Although, rotor is rotating with n r speed, rotor field whatever will be created the amplitude magnitude of that field depends upon the maximum value of this current that is root 2 into I 2 that decides the rotor field and rotor field will be positioned at depends on the power factor angle of the rotor circuit where it is positioned. And anybody is sitting on the stator will see a rotor field is produced and it is moving.

Now, what I am telling you consider another motor and this machine has got its winding resistance per phase r 2 and standstill inductance rotor leakage inductance x 2, that was there. Now, consider a fictitious motor. Here the rotor was moving. What I will do? sSame supply I will connect. Stator is identical with that of the rotor; number of turns are same K w 1 N 1 effective number of turns, same voltage I have applied. And here is your rotor. The point ultimately I am trying to tell is this one and this rotor is also shorted, but n r equal to 0 no I am not allowing it to rotate. And I say, that this machine rotor I have manipulated the parameter values.

How I am manipulated? Its resistance so it is a stationary rotor at standstill. We are imagining. What will happen if the rotor winding resistance per phase is r 2 by s? What is s? s is this is sleep at which this machine is running. It is a number; after all I can always imagine I have a resistance. With respect to actual machine it was r 2. Let us imagine this resistance is r 2 by s. And the standstill leakage reactance is x 2. So, this motor is at standstill. What will be the rms value of the current?

So, what will be the induced voltage? Induced voltage here, it will be E 2 only. What will be the frequency of the current? f only because it is at standstill and what about the frequency of the rotor current here? s f. That was the problem here, I mean obvious problem that there is a primary winding, there is a secondary winding, but I cannot just connect these two by multiplying with a square and etcetera, because the frequencies are different. Now what I am telling, you imagine this fictitious motor, it is non non-existent. It is not there. What is there is this motor.

Now, I am telling imagine its rotor resistance per phase is r 2 by s; s is this sleep of this actual motor and x 2 is same as the x 2 here at standstill condition x 2 and machine is stationary. And you have applied same voltage the same 3-phase voltage we have applied. Now the important point to note is this sitting on the stator you will the how we will see the you have to react what rotor is doing you want to see. You we will see that the observe here can only see the rotor field.

The observer here can also see the rotor field. Rotor field matters how it is seen by this stator. Based on that it will draw additional current, that is what I am telling. Now the question is this rotor rotating magnetic field in this case and in this case will be same. Because the rotor rotating field its amplitude is decided by this I 2 and this I 2 rms value of the current is same as the rms value of this current number wise.

Therefore, its peak value of the current is same as this one. And the position of the rotor field is decided by power factor angle, last time we discussed by drawing the position of b r etcetera. Same power factor, this and this. So, so far as the stator observer is concerned, he does not know whether rotor is doing really spinning at inner with some sleepers or it is stationary with this parameter values of the rotor winding; you cannot distinguish. Therefore, stator will react in the same way in both the cases. That is the mood point and if that be the case, then we will say that that.

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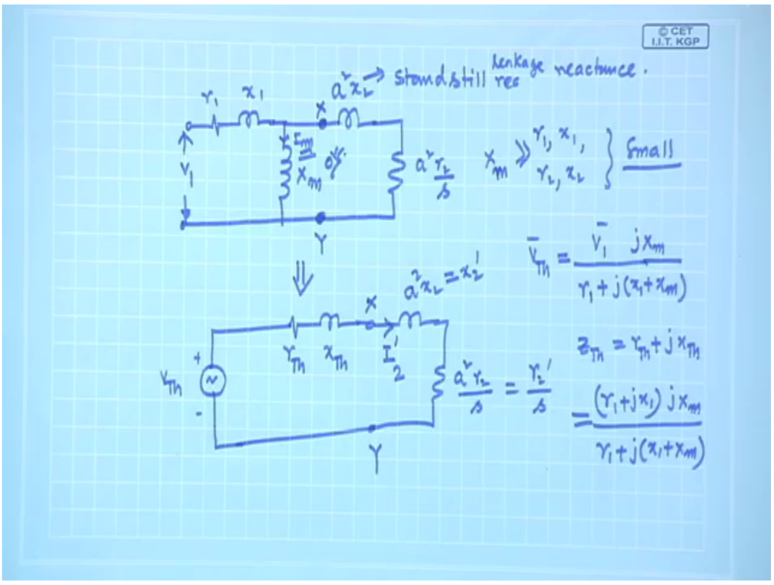

We can then say the equivalent circuit of the transformer can be like this, referred to stator it will be a square x 2 and a square r 2 by s. Why? Because this frequencies are same now in this stator and rotor in this imagined motor these are same, same frequency. Ratio of the voltages are there is no a s term now, e 1 by e 2 still K w 1 n 1 by K w 2 by n 2 everything is in place and this is equivalent circuit. Only thing was that this 2 circuits that is this circuit and this circuit.

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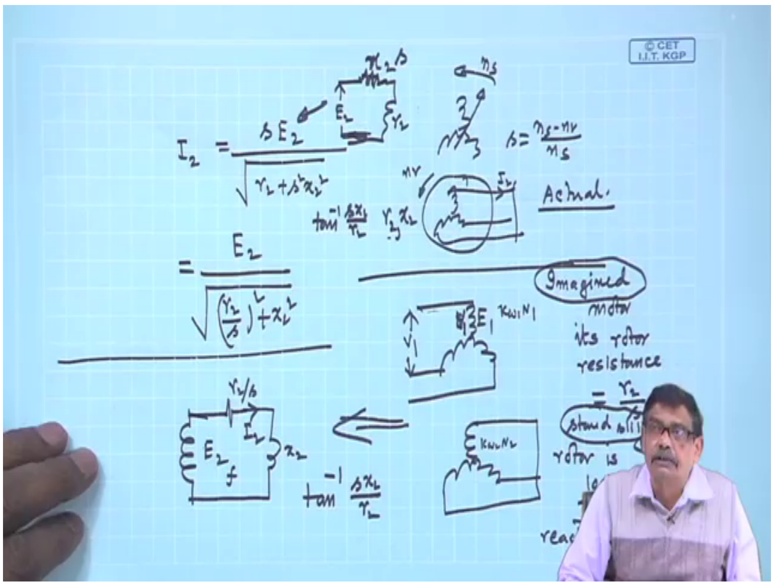

These two are not equivalent circuit, because real power is different in both these cases. And that also he explained because of the fact that in this case there is definitely some mechanical power output because machine is running with some slippage. n s is not equal to n r, it is overcoming that opposing torque and therefore, there is some mechanical power output.

So, whatever current only source of input power is through this port, through this stator there is no other source connected. So, total power that is; the copper loss in the rotor and the mechanical power and if there is stator resistance, stator copper loss, this total real power must come from this. In this case, the same total power it will draw because, stator will react in the same way in both the cases. So, whatever extra current it draws it is decided by rotor current and its power factor angle those things are remaining, same magnitude of the rotor currents, and this that.

Therefore, in this case for this motor standstill condition, I will say rotor copper loss is I 2 square r 2 by s and that is certainly greater than I 2 square r 2. Why this discrepancy? Because for this machine I 2 square r 2 is the rotor copper loss, but there is also mechanical power loss. These two together must be your I 2 square r 2 by s that is what I want to tell. Anyway, think about it. So, once this is done then I am comfortable. Ok, this is your applied voltage V 1 and this is your magnetizing reactance X m, this is a square x 2. What is x 2? Standstill reactance leakage reactance, these are small leakage reactance, a square r 2 by s ok.

So, this is the equivalent circuit. You can draw it also in 1 stroke citing some other reasons which are not so nice to understand. That is why I told this things, but anyway a square r 2 by s a square x 2 and so on. Now once this equivalent circuit is drawn then rest of the things are routine type. I will show you how; that is you can now develop the expression of the torque of the induction motor that is we will now adopt a rater softer method to calculate the torque produced by the motor, current drawn, its power factor, how motor with sleep changes, what thing changes in the circuit and things like that.

So, V 1 is the per phase voltage, all parameters are per phased and this is referred to stator this equivalent circuit here. Therefore, if this parameter values are known that is we are substituting the rotating machine business by some circuit. It is connected across a supply then we feel always comfortable ok, b by z I will do, get the currents in any branch I like and from that I will try to interpret, where is the mechanical power, how to find it out and things like that.

At standstill condition, put s equal to 1. If the motor is running with 4 person sleep put s equal to 0.04, calculate it, so this has got a very useful applications. That is the impedance offer to the supply by the three phase induction motor really depends on sleep. I can find out the performance putting s equal to 1 at standstill condition what the motor is going to do or for that matter when the motor is running at any sleep s that is the thing. Mind you, this r 1 x 1 and r 2 x 2, these are small small quantities compared to your magnetizing reactance ok.

There will be also eddy current losses. I will address that slightly later. Magnetizing current is large, you cannot neglect it. And in most of the cases, you will not be able to bring this forward across the supply as we often do in case of a transformer. Because, magnetizing current of same rating of a transformer and that of an induction motor, I m value is higher. So, x m is not that high as in the case of a transformer. It requires large magnetizing current to establish the flux in the core. So, this is I m. Now, what people do is this the these two points, about this two points, you of course, a X m is larger than this orders that is fine it is large compared to this. But with respect to a transformer of same rating, X m will be small because of the presence of the air gap.

To establish a flux in the air gap, you require large magnetizing current that is the thing. So, this will be the thing. Now mark these two points, say x and y, x and y and look into this circuit. This circuit can be about x and y I can find out a Thevenin's equivalent of the circuit such that your supply voltage will be v Thevenin’s and there is a resistance and inductance which will be x Thevenin’s and then your x y points, and then your reflected rotor circuit a square x 2 and a square r 2 by s.

Sometimes this s square r 2 is written as r 2 dashed by s and this is written as x 2 dashed. As you know, in case of a transformer also we have done it. And this current is actually your rotor reflected current I 2 dashed. Is it not? This is the thing. [FL]

Once I get this, and I assume that the motor is running at any sleep phase, I would like to know what is the torque developed in the machine I want to find out [FL].

Remember here, this V Thevenin's will be how much? It will be V 1 divided by r 1 plus j x 1 plus x m is not? This will be V Thevenin's, where this side is not there. So, equivalent these two are in parallel, is it?

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And multiplied by j X m right? Correct. This will be V Thevenin's and what should be the Z Thevenin's? Z Thevenin's is the r Thevenin's plus j x Thevenin's and it will be the parallel combination with this shortage. So, r 1 jx 1 into jx m divided by r 1 plus jx 1 plus x m. This will be r Thevenin's, a real part is r Thevenin's, imaginary part is x Thevenin's. But mind you as I told you r 1 x 1 is smaller compared to x m.

So, whenever you connect a low impedance in parallel with a higher impedance the equivalent impedance will be of the order of the low impedance only. That is; this r Thevenin's x Thevenin's still remains low. Because any low impedance in parallel with a high impedance, equivalent impedance will be of the order of lower impedance.

In some cases people forget about x m x m is not there then it will be simply r 1 x 1, I think you got the point. So, this is how this equivalent circuit is drawn. Then, I want to find out this machine what will be this current drawn? I 2 dash suppose I say, and after calculating the current, we will calculate power and we will try to calculate the torque developed by the machine.

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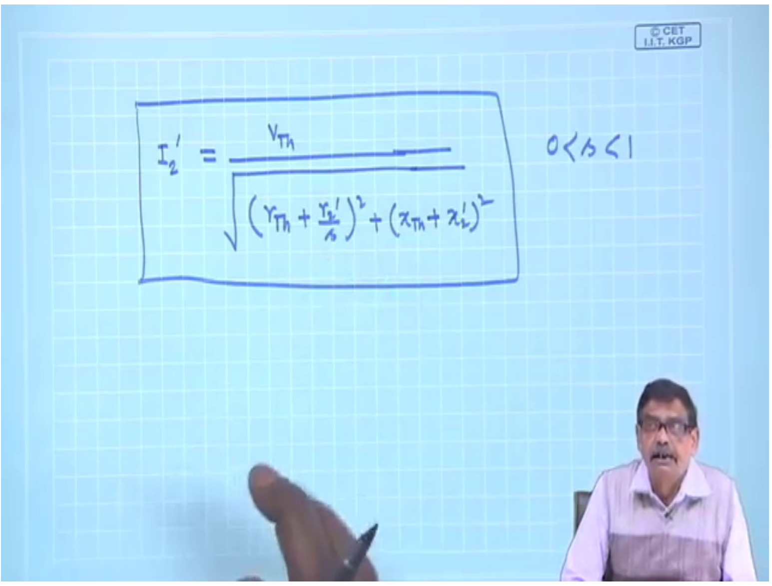

For example, I 2 dashed the magnitude of the current drawn will be V Thevenin's divided by square root of this is all circuit these are very routine, r Thevenin's plus r 2 dash by s whole square that is; this. This is the resistance part r 2 dash s plus r Thevenin's and then plus x Thevenin's, plus x 2 dash whole square this will be the current.

At standstill, what is the current drawn? Put s equal to 1. And mind you, s is a number less than 1, so the current drawn when the machine is running at certain sleep s will be smaller than when it draws some current at standstill condition, that is s equal to 1. This impedance r 2 dashed by s s is below. Anyway, this is the thing [FL]. What happens to this? In this machine, if you look at the real power; that is V Thevenin's I 2 dashed into cosine of the power factor angle if this circuit gives you the power consumed in r Thevenin's and r 2 dashed by s. Is not? Power is given to the machine.

So, I can write like this. This is called power flow diagram with respect to this circuit if i draw it.

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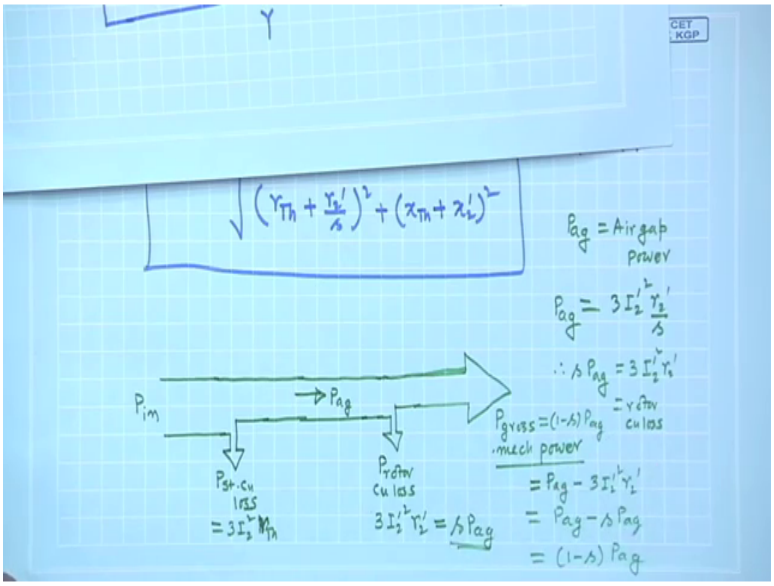

You can see that. Suppose I say, this is p in, electrical power input, these it will supply some power loss in this r Thevenin's. So, stator copper power loss. Mind you, these two are Thevenin's equivalent. This current square into r 1 you will see that it will be same as this current square into r Thevenin's, because in this circuit only resistance was r 1 it has to be so, this is p stator copper loss if you subtract this power loss.

There is no cold loss, I have not shown any cold loss here. So, this power as if it is crossing the air gap and this is called p air gap. People think like that stator I have given supply, then that power as if it has cross the air gap remaining power, real power, and entered into the rotor. Now, after it has entered into the rotor, then what will happen is this. In the rotor circuit, it starts from here that is here it is P a g it is called air gap power. P a g a very important term air gap power

And after that what it will do? it has to supply the power loss in the winding resistance and this air gap power must be equal to, as you can see this power in this circuit must be equal to the power in r 2 dash by s, that is it will be nothing but 3 I 2 dash squared into r 2 dash by s. It has to be, because in this circuit real power kilowatt only resistance in this circuit is r 2 dashed by s. So, this current square I 2 dash square into r 2 dashed by s is the air gap power. So, P a g is this, but I know the winding is having some resistance physical resistance r 2 dashed and there will be power loss.

So, from this if you subtract the rotor copper loss, P rotor copper loss. And what will be that value? For examples here, this value was 3 I 2 dashed square r Thevenin's I was just telling. So, it should be 3 I 2 dash squared into r 2 dashed, this you must understand. It is not r 2 dashed by s, because your actual machine is having a resistance of r 2 dashed and it is carrying a current of I 2 dashed.

So, copper loss, rotor copper loss has to be 3 I two dash squared r 2 dashed that is all. And then, the remaining power I can say is the gross mechanical power developed, gross mechanical power. Now look P a g is this, so s into P a g is 3 I 2 dash squared r 2 dashed is the rotor copper loss in all the 3 phases that is why that 3 rotor copper loss which will be same as 3 I 2 square r 2 in the secondary terms, but we will always draw equivalent circuit refer to the stator, so this one.

So this thing three I 2 dash square r 2 dashed, this is P a g it is nothing, but s into P a g, rotor copper loss. And gross mechanical power this one then must be P a g minus 3 I 2 dash squared r 2 dashed which is equal to P a g minus s into P a g is equal to 1 minus s into P a g. So, gross mechanical power is nothing but P a g s P a g is the rotor copper loss, this minus this will be 1 minus s into P a g

So, this is the result I am telling it this is an important result.

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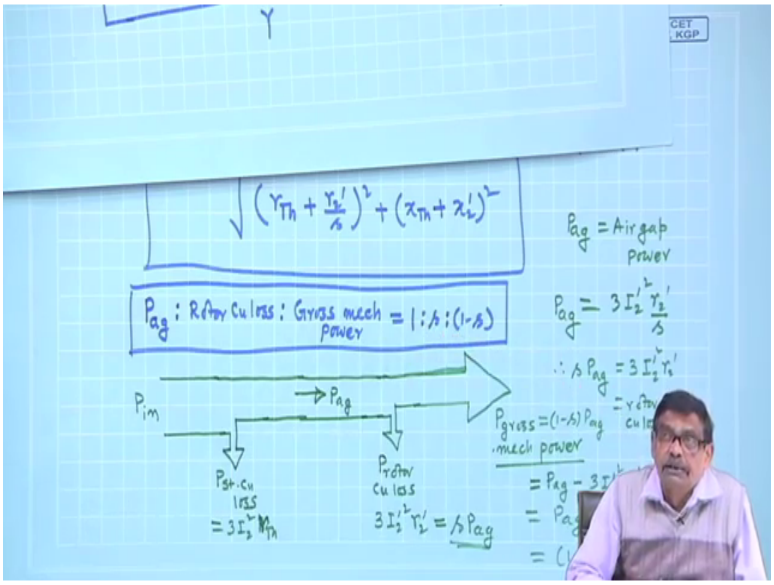

In a 3-phase induction motor, P a g isto rotor copper loss isto gross mechanical power developed will be 1 isto s isto 1 minus s. This is an important result. If s equal to 1 standstill condition no man mechanical power output over 0, but the moment it starts rotating this ratio air gap power is to rotor copper loss is to gross mechanical power will be divided in the ratio of 1 isto s isto 1 minus s, where s is the sleep at which machine is operating. What is sleep? That is motor is operating at a speed n r n s minus n r by n s.

So, please go through this up to this derivation and next time we will continue with this and find out the expression of electromagnetic term then torque sleep characteristics etcetera.

Thank you.