Electrical Machines - II
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Lecture - 64
Electrical Braking of Phase Induction Motor (Contd.)

Welcome. So, we were discussing about the Electrical Braking of 3-Phase Induction motor. And as you know there are two methods already I have discussed. One is called plugging and plugging we have discussed that is what you do, you interchange the supply two terminals, indicating that a phase sequence applied to a already running motor is suddenly changed. And then we discussed how to obtain the braking torque from torque slip characteristics.

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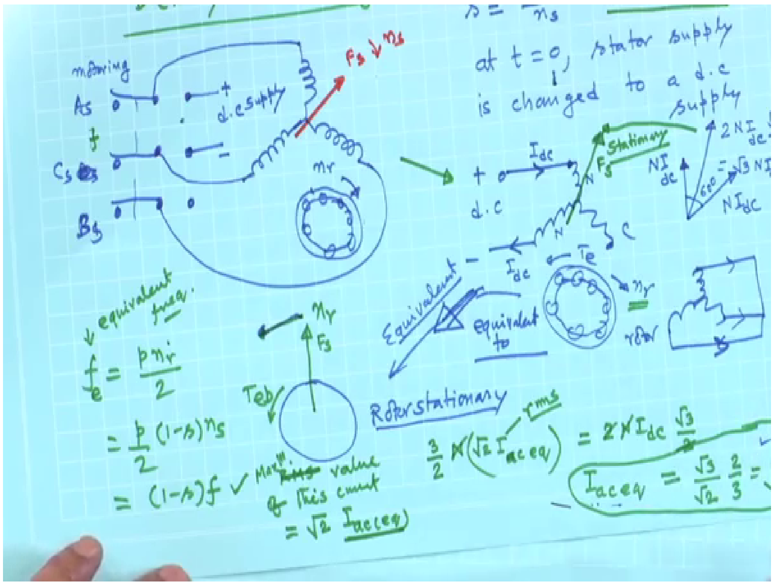

Then we were discussing about DC dynamic braking, and in DC dynamic braking the diagram is here last time. So, we it is like this that the motor stator is a normal operation of motor, you connect it to a 3-phase supply like this. And when you want to brake the machine, you switch the supply to a DC supply such that at that time at t equal to 0 plus the circuit will look like this that is you inject DC current in the stator.

And since it was running as a motor steadily at that speed say at a speed n r n r. Then the machine was running at a slip s equal to n s minus n r by n s, which is which means that n r is n s. And what is n s, n s was 2 f by p n s was 2 f by p as a motor, this was the things prevailing.

When we suddenly disconnect the AC supply, and inject some DC current in the stator winding, speed cannot change instantaneously. Let us try to estimate, what will be the braking torque at t equal to 0 plus. So, so the moment you switch over to DC, the m m f or flux density whatever you call it, it will be produced in this direction NI DC, b will be proportional to this. Similarly, this phase b will be in the opposite direction, because current is coming out from this. And we get the net m m f which will be produced is 2 NI DC into root 3, 2 2 will cancel out. And this field will be stationary, because only DC current is flowing ok.

However, rotor is moving. Now, this thing can be considered to be rotor is stationary this thing, can be considered to be rotor stationary. And that field which I called stationary is moving in the opposite direction with a speed n r. Therefore, it looks like it is like a 3-phase induction motor, which is stationary at s equal to 1 the slip of this machine s equal to 1. And the stator field is moving in the anticlockwise direction with a speed n r.

Now, the question is although this field has been created by DC current I know, but I can always think that this field has been created by some balanced 3-phase currents. The frequency of that current, then must be p n r by 2, and this n r is nothing but 1 minus s into n s, so I put it here. And I find that the same field is produced as if by a balanced 3-phase winding, frequency of which here I should only this frequency equivalent frequency, let me write equivalent frequency f is this original AC supply frequency here.

So, in terms of that it comes out to be this; so equivalent frequency, and it will be moving this. And naturally, the torque will be in this direction, and that is what I need, because machine was rotating in this direction. Now, we have created impose a torque on the shaft, which is opposite to the direction of motion, therefore it will decelerate rather quickly that is the whole idea; so it was like this, and DC current is this.

Therefore, this stationery field first is being thought of as if it is a rotating field, and it is created by the same 3-phase winding which is supplied with currents whose frequency is this that is what I want to tell ok. But, now the question is what is the magnitude of that current equivalent RMS current, strength of the field is known we recall that it is 3 by 2, suppose number of turns of this machine is n per phase 3 by 2 N.

And this is I max if you recall our b resultant and this one, this should be I max of that imagine the 3-phase supply of frequency f, it must be driving a current whose RMS value. Here I write RMS value of this current, value of this current maximum value of this current will be equal to root 2 times I ac equivalent, where ac equivalent is the equivalent rms current. So, it will be root 2 into I ac equivalent; this is your I max 3 by 2 this one.

And this strength I equate to this strength that is equal to 2 NI dc into root 3 by 2, 2, 2 cancels, n, n cancels from where I will get I ac equivalent, which would have produce same strength of the field as the DC current is producing. If the AC current rms value is like this that is root 3 by root 2 root 3 by root 2 into 2 by 3, which is equal to root 2 by 3 into I dc. So, what is the conclusion, conclusion is this DC current is there.

See these are very nice things. It will further strengthen your idea of 3-phase induction machine. Some field is there which stationery, rotor was moving, and this thing is equivalent to field is moving in the opposite direction, rotor is stationary. Now, this field it has been created by dc current no doubt, but I can always think it has been created by a balanced 3-phase winding that is balanced 3-phase winding means this stator.

Now, the question is to create this field, what will be the ac current here that ac current is found out by equating the amplitude of this field. Amplitude of the field in case of 3-phase current is 3 by 2 N into I ac max here that is nothing but root 2 I ac equivalent, this is the RMS value. And this must be equal to this from which I get I ac equivalent to be root 2 by 3 I dc.

In short, you pass a dc current here, I will say this is same as to calculate the torque, whatever it is you consider the rotors to be stationary that is a field here, which is produced by some balanced 3-phase ac current to RMS value is this. And of frequency this that is important equivalent frequency and the machine is stationary.

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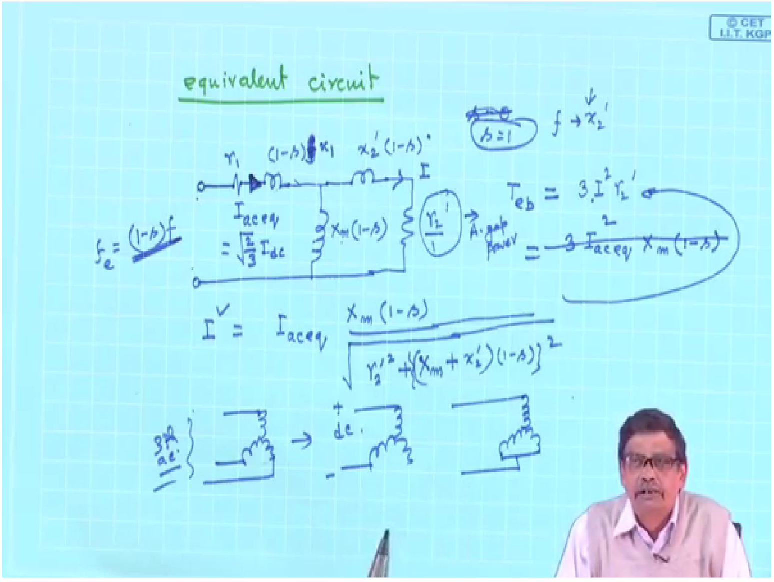

Therefore, I will be able to calculate the torque produced by this machine. Now, therefore what will be the equivalent circuit equivalent circuit, equivalent circuit will be stator impedance r 1, there will be a magnetizing reactance x 1, and there will be what is called x 2 dashed, and there will be an r 2 dashed by slip. [FL] What is the value of slip, we have noted it is equal to 1, because rotor is stationary.

Therefore, it should be this by 1, x 2 dashed is the standstill rotor leakage reactance per phase, when the in this equivalent circuit when the frequency is f is not, standstill standstill rotor leakage reactance that is frequency 50 Hertz that is the supply frequency. But, here the supply frequency is 1 minus s into f that is at frequency f, I know x 2 dashed, so this must be multiplied by 1 minus s.

Now, similarly x 1 is the frequency of the supply frequency f here, but that frequency is now equivalent frequency is 1 minus s f. So, it must be multiplied by 1 minus s into f, similarly x m the magnetizing inductance, it should be multiplied by 1 minus s, this is an important step. And then I am telling this current rms value of the currents, say I do not have any idea about the applied voltage, it is also not necessary. I know this rms current has to be this is I ac equivalent, which I have found out to be root 2 by 3 into I dc.

Now, to calculate the torque, what all I have to calculate is the power here air gap power of this equivalent machine. And what will be the magnitude of this equivalent, I know the rms current here. Therefore, this current square if I call this current is some I, so that braking torque will be this air gap power in synchronous what, it will be 3 I square r 2 dashed that is all.

Now, what is this value of I, this is a rms current which is divided into 2 parallel branches. Therefore, magnitude of the current I, in terms of this will be simply that parallel rule of impedances. So, this current into X m divided by these two impedances, so it will be 3 I ac equivalent square into this reactance X m into 1 minus s. I I first write down this is ok, this is understood.

Now, what I am telling is this, I is equal to let us not make it whole square this that I will be equal to the total current I ac equivalent rms into this reactance X m into 1 minus s divided by some of these two impedances their magnitude, so that will be equal to under root this plus this, this whole thing, it will be equal to r 2 dash squared plus if I make a mistake you point out X m plus x 2 dashed into 1 minus s, this whole square correct. So, this is how I will be able to calculate this I, I will put it here get the torque got the point.

So, braking torque in dc dynamic braking, the stator is disconnected, when it is running as a motor nicely from a 3 phase supply. And you wish to bring the machine to a quick stop, what you do you switch over from ac supply to dc supply with the help of some switching on the stator side rotor side, you do not do anything. Therefore, rotor speed if it is n r, and initial slip at which it was running was governed by this f was this supply frequency.

Now, there is dc no supply frequency no ac, but you know it is a stationary field know the moment dc current flows, and stationery field motor is also running. So, you imagine rotary stationery from this you come here from this diagram, then rotor is stationary now, give this speed to this stator field in the opposite direction. Whatever the rotor ex[perience]- will experience torque is same as this fellow nothing new in that.

Therefore, based on that I have to calculate the torque, but now this rotating field is in reality it is not there. But, we have translated this problem from stationery field moving rotor to a stationary rotor, and a moving field. And any moving field, I can always think of it is developed by a balanced 3-phase current. So, I will assume that this rotating field is developed by the same 3-phase supply of frequency f of frequency f no of frequency, because the speed of the rotating field is known. So, I will say the frequency of that 3-phase supply must be p n r by 2.

If that be the case in terms of original supply frequency a f and slip, this f e becomes 1 minus s into f and then I have to calculate the torque of the machine. Mind you it is its rotary is stationary. This is the equivalent thing of this one. We only wish to calculate the torque how much it will be produced. Now, the question is then how to calculate the torque? You can calculate the torque the strength of this field if you assume it has been developed by a balanced 3 phase ac current of RMS value a ac equivalent, then 3 by 2 into N into the peak value of the ac current that will be this that you equate to this and I ac equivalent current is known.

And once it is known then I will say that the per phase equivalent circuit, above voltage I am not making any comments what kind of voltage is necessary. I will be able to now tell how much is the per phase applied voltage by because I know the currents I know the parameters, I will be able to calculate the voltage drop. Now, here only thing is this r 1 x 1 this into x 1, x 1 is the mind you in the equivalent circuit x 1 is the leakage reactance of this stator at frequency f. What is x 2 dashed, x 2 dashed is the leakage reactance of the rotor at standstill condition that is at frequency f original this thing.

Therefore, now I am telling whatever is this supply its frequency is 1 minus s into f, therefore, this reactances are to be modified by multiplying with this 1 minus s into f or 1 minus s only no f here right, it will be reduced by a factor, no f here please, so 1 minus s into x. And this one, similarly it is x m into 1 minus s. Then I know the equivalent dc rms current. And torque a is absolutely depends on the air gap power at this machine it is stationary that modified value of the slip is 1, and then you calculate this i how to calculate use the series parallel rule, and then put it here to get the torque.

Now, from ac to dc supply connections only it is a comment I will not going into details because these are not. See I have shown it like this. This was this stator connection original, is not it, original this is the stator connection your supply is 3 phase ac. Then I told you switch over to dc, connect it like this plus minus dc. You could also connect a dc source from this to this in several other ways, there are several options. For example, you could join this to get a dc current, are you getting, there are many options are there by which you can create a stationary magnetic field.

If you do differently what thing will change is this ac equivalent circuit because you have to then sketch what is the m m f resultant m m f because of this current and equivalent current will be available. Therefore, you inject some dc current and get the braking torque ok, anyway think about it. These are exercises if you go through I am once again telling it will further make you much more comfortable with rotating magnetic field and things like that, and how intelligently it can be applied in various situations ok. So, this is the thing.

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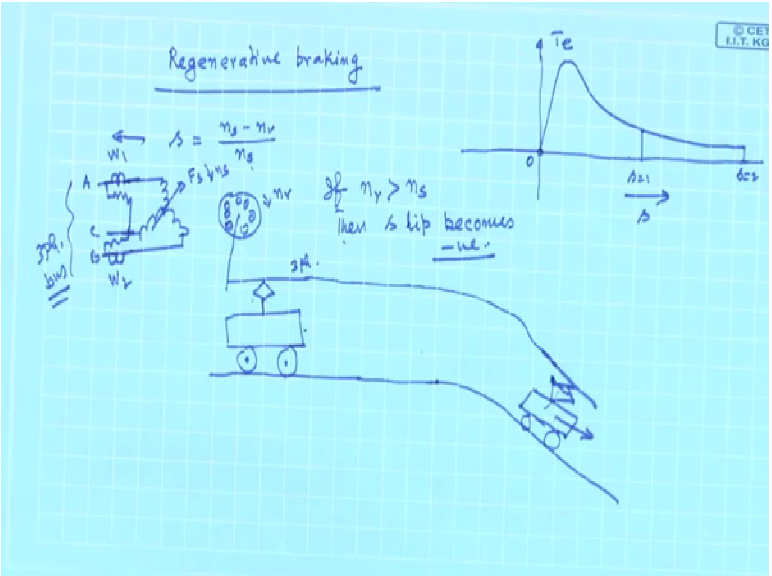

Now, another method is called of braking is called regenerative braking. Here also I will give you the idea regenerative braking. Recall in my last class while doing plugging I told you the torque slip characteristics, this is s equal to 1 is necessary that motor may sometimes go to braking zone plugging slip maybe 2 minus s, and you have to calculate the torque here. But for dc dynamic braking since 1 minus s is coming you should not take this torque and say that is the torque, no, because after all that is not ac supply. In plugging in both the situation it was ac supply, you have only change the phase sequence, but anyway this was the torque slip characteristics over the range s equal to 0 to 2. [FL]

In regenerative braking, what is done is this machine is made to run as a induction generator that is slip becomes negative ok. Now, the question is, is it possible? At least one instance I will ask you to think in this way. See slip was equal to n s minus n r by n s. And I told you in general operation n r at best could be highest value of n r as motor operation motoring, n r is equal to n s that is all. And when n equal to n s there is no rotor induced voltage, no rotor current, no torque is developed that is this point that is n s.

Now, suppose with the help of machine is running under no load condition. So, what I am telling this is this, it is connected to your 3-phase bus supply A, B, C 3 phase supply, and here is your rotor ok. Now, and n r it is running and this is F s, n s, it is going like this. Now, suppose machine is running under no load. And you imagine on the shaft I have also a prime mover ok, maybe a dc motor is connected.

The stator connected to the bus, and this dc machine speed I will go on increasing. And it to may so happen n r will become equal to n s. And then if you further increase the rotor speed n r, n r will become greater than n s, but as a motor it cannot do so, unless there is a external source external prime mover which is making its speed more than the synchronous speed. If you do like that, if you somehow make n r greater than n s, then slip will become negative, slip becomes negative.

Therefore, that air gap resistance becomes minus r 2 by s, the negative resistance indicating that it will not consume power, it will I mean difficult to understand, but anyway if you this same equivalent circuit should prevail, why not there is a relative speed, there is induced voltage in the rotor there is current only thing slip becomes negative. What I am telling is if you connect an wattmeter here, say to demonstrate this connect two wattmeters W 1, W 2 to measure the power, you will find when n r is less than n s normal motoring operation W 1 plus W 2 is positive.

But if you somehow make rotor speed greater than the synchronous speed n s, then you will see the some of the wattmeter readings are becoming negative, indicating that power is now flowing from this machine to the bus, this is bus 3-phase bus power will be flown back to the machine. So, if n r is equal to n s, then we and the machine is connected to the bus, mind you this point is important, it is not a generator in isolation.

You connect it, and then if you want to operate it as a motor, then what you do you have a suppose dc motor prime mover, so that we can easily understand. And then after connecting it if I want to make this induction motor act as a generator and fit power to the bus, there must be a prime mover, a generator without a prime mover cannot sustain.

So, so this prime mover speed if I make greater than n r greater than n s, then electrical power will be pumped into the 3-phase pass where from that power will come from the prime mover dc motor. It will take power from the dc bus make that dc machine run as a motor and power will be fed back to the generator. So, this kind of operation then must be called dc I mean generator operation, it a I am not talked about braking. What I am telling simply that by any chance if n r becomes greater than n s, then motor will become a will go to generator mode. And if it goes to generator mode, electromagnetic torque must oppose the prime mover torque is not that is the idea

Now, you image in this situation. Suppose, you have a vehicle traction, it is moving like this. Suppose, it is supplied from a 3 phase supply in single line I am drawing it is there phase supply pantograph, it goes there, there is an induction motor which is driving this fellow on a flat track. Well-the speed of this machine rotor speed, hence the this speed cannot be greater than synchronous speed, rotor speed cannot be greater than synchronous speed.

Now, suppose this track has got a downhill. So, this fellow comes here vehicle, your this is the 3-phase overhead line it comes like this, it comes a down slope. What is going to happen you know gravity will assessed, it will try to accelerate is it not, and its speed rotor speed of this thing which is ultimately connected to the shaft of this induction motor will make n r greater than n s.

And then the power flow will be from the motor to this supply lines, and this is called regenerative braking. It is very good, because it if it goes there somebody is there to create an opposite force to counter gravity, imagine there is no regenerative braking torque, it would have accelerated, and finally it will meet with an accident perhaps. So, it is inherent.

Anyway, thank you, we will continue with this, you think in this term.