Electrical Machines - II
Prof. Tapas Kumar Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 63
Electrical Braking of Phase Induction Motor

Welcome to this lecture. And now we were discussing about the Braking of three-Phase Induction Motors.

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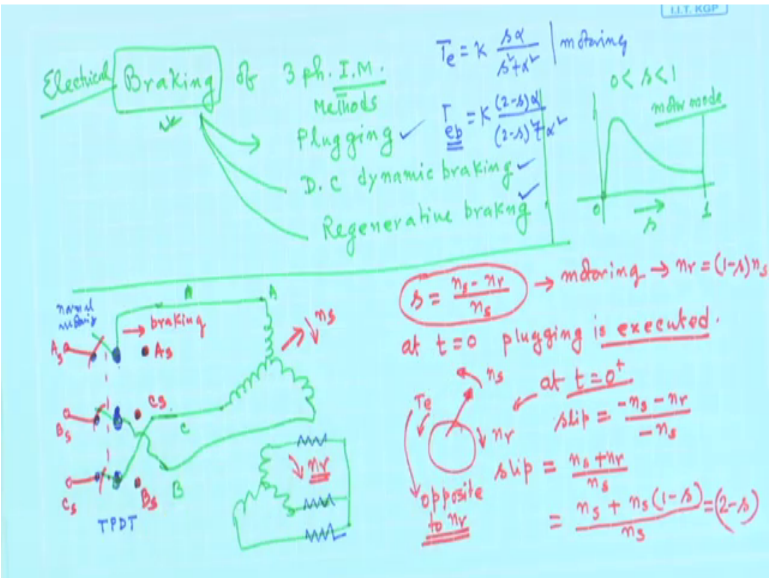

And there are 3 methods as in the previous class I told plugging, DC dynamic braking and regenerative braking of which plugging we were discussing. The whole idea is of braking is therefore, if you want to come make the machine come to a stop quickly physically we understand that that energy kinetic energy to be dissipated fast. Friction alone will absorb that energy, but it will take longer time, so that machine will come to a stop after a long time.

Sometimes it is necessary to induction motor to stop quickly in some repetitive work and once again restart it things like that where you have to apply electrical braking. And so, the opposing torque in which direction the rotor is already rotating must be developed in the machine. So, I was telling that if you have an induction motor with which is supplied with phase sequence A s B s C s supply phases and these are machine terminals A B C phase. Then you have to and it will run normal motor and this way it is normal motor run; normal motor run motoring operation.

Now, what I will do is this is a triple pole double throw switch. So, it will have either this way it should be connected or here it should be connected. Now here from the supply only you bring it like this is s; this s say this s are same and this you tell C s and this you tell B s. So, when you want to brake the machine what I am telling. So, this is braking when this switch will be. It was running nicely at steady speed n r with slip n s suddenly I move this switch which is gang switch together it will move, bring it to this side. Then you can see this supply phase sequence to the stator is reversed and therefore, rotating field will start rotating in the opposite direction.

At t equal to 0; at t equal to 0 plugging is executed; plugging is executed what this executed means it means you have put the switch from here to there very quickly. In that case, what will happen? The rotating field will start electrical time constant is much smaller than mechanical. So, the in the rotating field now will move with same speed, but in the opposite direction and rotor is still moving with the same speed n r here at t equal to 0 plug plugging is executed and at t equal to 0 plus this is the situation.

Rotor is still moving in that direction. Now as you know, the electromagnetic torque developed by the machine will now act along the direction of the field rotation. Therefore, electromagnetic torque the machine will develop will act in this direction.

Now the question is at t equal to 0 plus what is the slip? Earlier motoring operation this was the slip n s minus n r by n s. At equal to 0 plus slip of the motor will be only n s has reversed. So, put minus that is there minus n s minus n r energy remains same n minus n s, this is the thing. But from this you know n r we know when it was motoring it was like this 1 minus s into n s, I am sorry.

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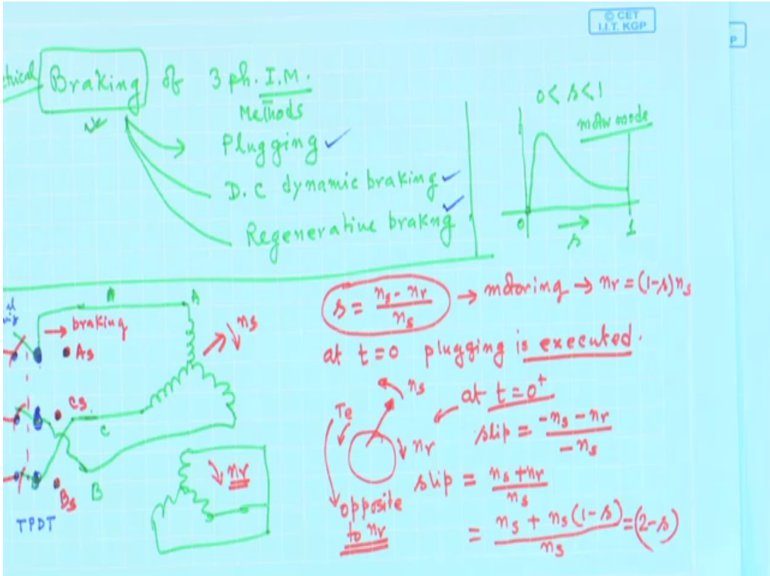

This was the thing n r equal to 1 minus s into n s. Therefore, at t equal to 0 plus after immediately after plugging is executed slip of the motor will become you know if you put this it will be n s plus n r by n s same as here. And it is n s plus rotor speed was n s 1 minus s. What is this slip? At the motoring mode whatever was the slip divided by n s.

So, if you simplify it will become 2 minus s. Therefore, the moment plugging is executed earlier slip was 0.5 slip will immediately become almost 1.95 2 minus s and how much torque is developed by the machine? Direction of the torque must be opposite. This T e must be opposite to n r; opposite to n r. And what will be its magnitude? How to calculate? Everything remaining same formula can be used. Only thing, you calculate the torque replacing s by 2 minus s. For example, the simple formula I will write where ah

it is equal to some k s alpha by s square plus alpha square.

During motoring mode; motoring mode; motoring mode. Now suppose we have done this. So, at T equal to 0 plus this is called braking torque T b will K 2 minus s into alpha by 2 minus s whole square plus alpha square. What else? Because slip has only changed.

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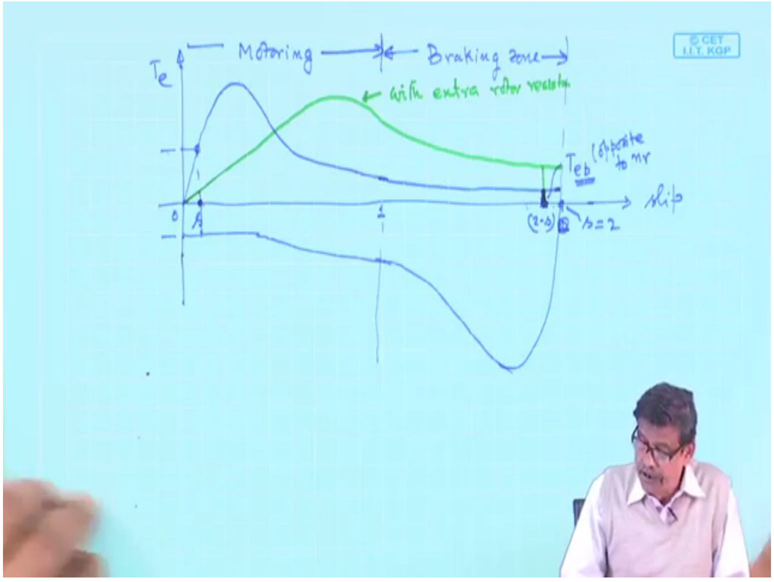

Therefore braking torque can be calculated like this. Graphically it means that it is like this. That suppose, this is the torque slip characteristics of the machine and we are stopping here at slip equal to 1. This is slip equal to 0, this is torque and it was motoring. And machine was operating at this point say at this slip s as a motor.

Now suddenly what I have done? I have changed the supply phase sequence. And I say slip has become 2 minus s suppose this is s equal to 1, so, this point is s equal to 2. So, 2 minus s means here at this point. Whatever is the torque developed that should be the braking torque or in other words what I am telling, the torque slip characteristics while sketching I will not stop at s equal to 1. I will draw it for all s up to 2 using the same formula. Here how did I get the torque slip characteristics by putting different values of slip and stopped at 1 because I know motoring mode one and we are considering motoring mode.

Now, I am in a different situation if somebody does like this change the supply phase sequence applied to the motor keeping the voltage frequency same. Then there is a need to compute the electromagnetic torque if I want to know what is the electromagnetic torque developed by the machine now. I have to read that value from this is 2 minus s this much torque will be produced and this also it is showing positive torque.

But I know physically what has happened it is actually acting in the opposite direction this is the T e b electromagnetic torque, but it is opposite to n r, like this. Therefore, this is called the braking zone. Therefore, often this is the whole range of speed torque characteristics in motoring mode. It can be as a motoring it is like this. If you have done plugging, it will go up to this point. This is the, this point is s equal to 2 and this must be, if it is s 2 minus s will be here. So, much little braking torque will be produced and it is expected machine will come to a stop. If it is a slip ring and this is done.

Now, to read the value of electromagnetic torque straight away what people sometimes do, they draw this characteristics also ready I mean if you are doing plugging you know before. Then the same torque slip characteristics it is not mirror image, the mirror image and then flip around the vertical axis. If you draw like this it has nothing to do with machine operation. What I am telling, if it is operating at slip is you will say electromagnetic braking torque is this much, you have to come here. Now I will say, if you draw it that is you fold it around this x axis slip axis and then take the mirror image, then you will get this curve and this s, this is the initial operating point. Load torque it was supplying.

Load torque was always in opposite direction to the rotation of the motor n r. If you do plugging, I will say electromagnetic torque at that time will be this one. That is all, same thing I am telling in a slightly better way so that you can read the values very quickly. And your if there is an active load there, then I will say total braking torque maybe this plus this at that time acting ok. So, you execute plugging, same torque expression I am using assuming steady state thing, formulas, which may not be very exact thing I am telling you, there will be transients.

But anyway it gives you fair idea what is going to happen. Steady state only equation same equations as if I am pretending holds good there, people do it you get the idea of that. But after so, machine will start slowing down at a much faster rate, it looks like. Now suppose you have made this switch from left to right side and kept the switch there, what is going to happen? Eventually, machine will come to stop no doubt, but then start running in the opposite directions.

Therefore, if you want to really stop the motor then you must have some sort of speed sensor which will sense 5 percent speed it has come, then you disconnect it from the supply. That is this mechanical switch I have put on this or by what you should look at the rotor speed, you have put it that side when speed has come close to 0 switch it off in the neutral position, then it will come. But some arrangement is to be made if you want to make it a automatic process, electrical braking by plugging.

The magnitude of this braking torque can be increased, if it is a slip ring induction motor very easily it can be done. What you do? When you from motoring mode you want to go to braking mode, you put it here and at the same time you insert some resistance in the rotor circuit. Suppose, I do this switching and then automatically some equal values of resistance are put in the rotor circuit. In that case, how to calculate braking torque? Braking torque will be see this is T e. This is with normal rotor resistance, this and this.

But after you have executed plugging, this characteristics will look like this. Something like this with extra rotor resistance and your braking torque will be then this much. Therefore, you can increase the braking torque by perhaps connecting a resistance in the rotor and this curve also can be drawn reversed and flipped.

So, that the reading of this braking torque can be easily estimated; I am not drawing that, you have understood the idea. If it is a cage induction motor of course, there is no scope for increasing the braking torque, but during that plugging operation there may be certain inrush of current due to transience. So, to limit that current people connect some reactance or resistance in series with the stator thereby further decreasing this braking torque available, I mean these are the things; so, it is called plugging. Plugging means you reverse the supply voltage polarity.

Only thing is when the machine come to a stop you should be alert you have to disconnect the motor from the supply. Otherwise it will start accelerating in the opposite direction. And also we came to know that it is 0 to 1 is the motoring mode, then if slip is between 1 to 2 it means it is in the braking zone. If at all a motor if I say it is operating at a slip greater than 1, but less than 2 it must be in the braking zone. That is fine. Another interesting way of braking the electrical motor is called DC dynamic braking; DC dynamic braking.

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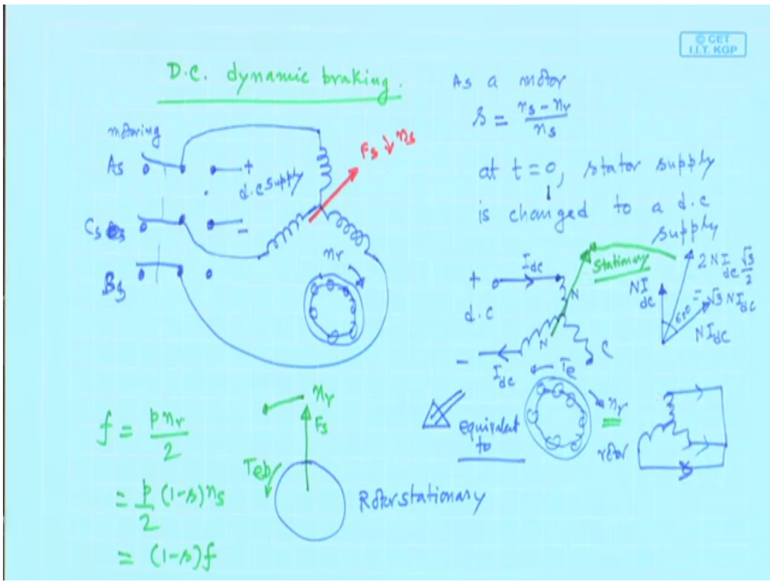

See the ideas are very simple and interesting. Go through this idea, so that it will further enrich your knowledge of induction motors. This is done like this. See suppose, this is the stator of a induction motor. I will tell first verbally what is done and this is suppose your induction motor rotor. And I am sometimes drawing slip rings, sometimes cage. This is the rotor, this is the stator ok.

Now what you do once again you have a switch ok, where you bring the machine terminals in the middle of that double throw switch ok. And here you connect your AC supply here A s supply A, supply B s, supply C s whatever it is ok, supply C s and supply B s you connect. So, it will be motoring mode, switch is a motoring mode. And on this side of the switch what you do? You keep a DC source ready, DC supply battery say DC supply. Therefore, when it is running as a motor this is the situation is B s C s and machine was suppose running at the speed n r as a motor. As a motor; as a motor it was running with a slip n s minus n r by n s.

And there was rotating field here, which was running with n s 2 f by p. Now what I will be doing? First let us talk in language. What we will be doing? Suppose this switch is brought it here, this side and the third one nothing is connected. If AC supply, that is instead of AC supply I know exide the stator which was already running, the machine was running with speed n r with a slip this much. Now suddenly what I will do? I will disconnect the AC supply from the stator winding and inject some DC current onto the stator.

Therefore, suppose at t equal to 0, stator supply is changed to changed to a DC supply that is the switch that is this switch that connected this side. If you do like that, then what is the connection? This is the connection. There is plus minus DC that is all, this side nothing is connected suppose and here is your rotor. Can rotor speed change instantaneously? No. It was still running with this speed at t equal to 0 plus this is the situation. If you connect it like this, first of all you see that DC current will flow. What kind of field the stator winding is going to produce? A stationary field, not moving field is not. Suppose the number of turns of the stator windings are N a and some I dc is passed.

Therefore the m m f or field will be suppose current enters through the start of this phase is NI dc that divided by reluctance etcetera will give you h hence p, so, NI dc. But for this fellow it will be like this, also same strength, but not away because it is leaving the start of that phase. Therefore, resultant field will be like this. And this angle being 60 degree the resultant field will be 2 NI dc into cos 30 degree and that is equal to root 3 NI dc. So, the strength of the field will be fixed in space this time this field will be created, but stationary in space, stationary.

This stator field with what will be created it will not be moving. It is not excited by AC current anymore; therefore, its strength will remain phase ok. Let it remain there, but here is a rotor which is already in running condition. Therefore, this conductors or wound rotor thing whatever it is there will be induced voltage in the conductors and the rotor circuit is closed. Therefore, current will be flowing through the conductors or the if it is it will be easier to understood if suppose this is the rotor either this or this is shorted.

Therefore, there will be balanced three-phase voltages, there will be balanced three-phase current here. But it looks like, it is acting as a generator. Is not? Because it was already running at that speed n r, you have a field here that is induced voltage and there will be power dissipated as heat in the rotor circuit. That is what I am telling, if you want to, so the kinetic energy stored will be dissipated at a faster rate compared to the situation when you simply disconnect the stator from the supply.

Disconnect the stator from the supply and quickly switch it on to a DC supply and then I am arguing, there is a field moving at a speed n r and there is a rotor which can be thought of as equivalent some star winding. We discussed cage rotor whatever it is, there is balanced three phase current flowing and power is dissipated here. So, in which direction electromagnetic torque will be produced now. In case of generator mode, if it is moving it like this. The electromagnetic torque developed will be like that; is it not? Therefore, electromagnetic torque developed by the machine will be trying to oppose the direction of rotation and thereby its kinetic energy will be going on reducing.

Of course, mind you this speed n r with which we started at t equal to 0 plus is gradually decreasing, but at any instant of time the picture is this ok. Whatever is the n r that decides this one. Strength of the field will it change? No. It is 2 NI dc by root 3 by 2. Therefore, I have now a situation like this. Now to cast this problem, in terms of induction motor, theories what we have learnt, I can see this as equivalent to this situation can be analysed as equivalent to this one. I will assume rotor stationery; rotor stationery and this field; this field this, this stationary field which was this field created by this DC current is moving in the opposite direction with a speed n r, that is the situation. Let n r vary with time, but any instant of time this is the situation.

So, then I will argue that there is a rotating field whose speed is n r not n s and here is an induction motor. So, electromagnetic torque developed by this so called equivalent motor electromagnetic torque must be this. And that is the braking torque it is creating, I can always think. See these are the nice things ok. That rotating field concept I can still apply I will only argue that this field is moving in the opposite direction now, earlier I assumed n r in this direction.

So, that speed I give to this stator field and presume that rotor is stationery. So, it looks like for this induction motor I have to find out this starting torque or block rotor condition torque. Is not? That is what if I can find out then I will be able to calculate the braking torque.

Just to give you an idea what I am going to do in the next class, that first of all this stator field which is now stationary F s here also it is F s, it is moving with a speed n r. Therefore, I can always attribute to this that my balanced three-phase winding is carrying a balanced three-phase current of frequency pn r by 2. That is now say, I am now switching over ok.

I want to see that if you have drawn this then I will argue, this three-phase winding is connected to a how this n r speed of a rotating field can be obtained. By energising the same stator winding with some AC source whose frequency is pn r by 2 that is this so called synchronous speed of this imagined motor situation now with the hope that I will be able to calculate then the braking torque for this motor; so, this is the thing.

But now what is n r? N r is as a motor n r is nothing, but 1 minus s into n s, because when it was running motor at t equal to 0 plus I am considering. So, whatever I want to find out the braking torque right at t equal to 0 plus say, then this is the situation n r equal to 1 minus s. Then I will put it like this 1 minus s into n s. And then I will say this is nothing, but 1 minus s pn s by 2 is when it was connected to frequency f stator AC supply, with that supply in terms of that. That is an induction motor which is now supplied with this frequency and its rotor is stationary.

I want to calculate what is the torque produced by it? And that will give me an estimate of braking torque. Therefore, I will invoke the equivalent circuit in the next class and how to calculate it. Easy, but the see the whole idea is why I am telling this way braking is also not done these days. This is apply inject it, but only good point about it is machine will eventually come to stop. No question of rotating in the backward direction, what will happen? When this speed will become 0, no induced voltage, no current in the rotor. Anyway, I will continue with this in the next class.

Thank you.