Electrical Machines - II
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Lecture – 46
Change in Torque – Slip Characteristics as Supply Voltage & Rotor Resistance are Varied

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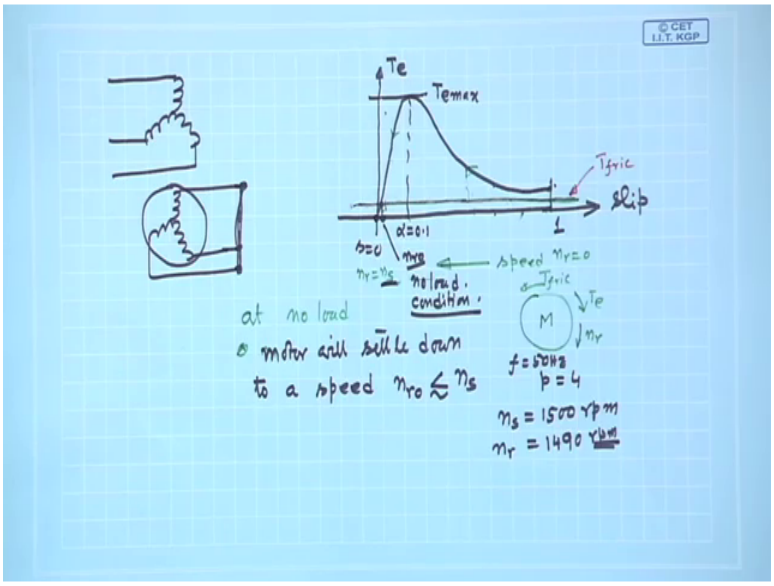

Welcome and so we were discussing about the Torque Slip Characteristics of a 3 phase induction motor. And which is very important, it gives us an opportunity to understand how the machine settles down to a particular operating point. And under no load condition I told you it will be like this.

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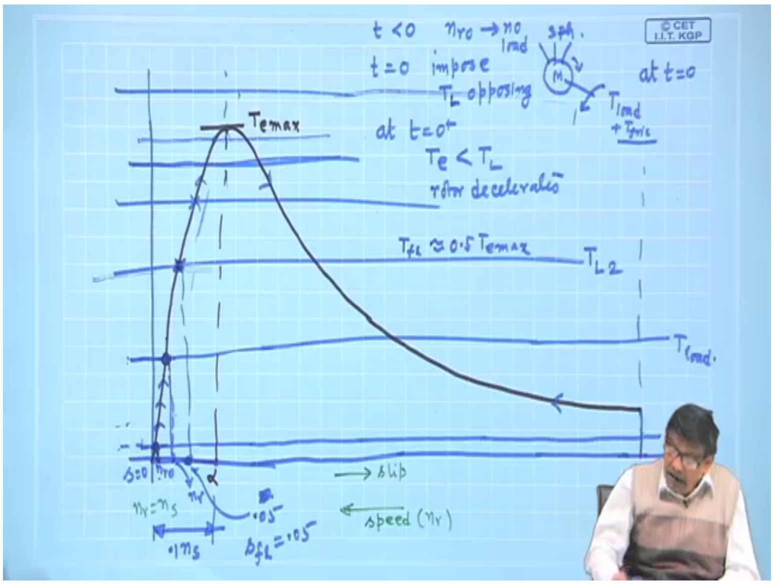

Now I will further examine what it is going to do if there is a real load torque present on the machine. So let us imagine, and I will draw in a very large scale; so that. So, these always draw the torque slip characteristics correctly.

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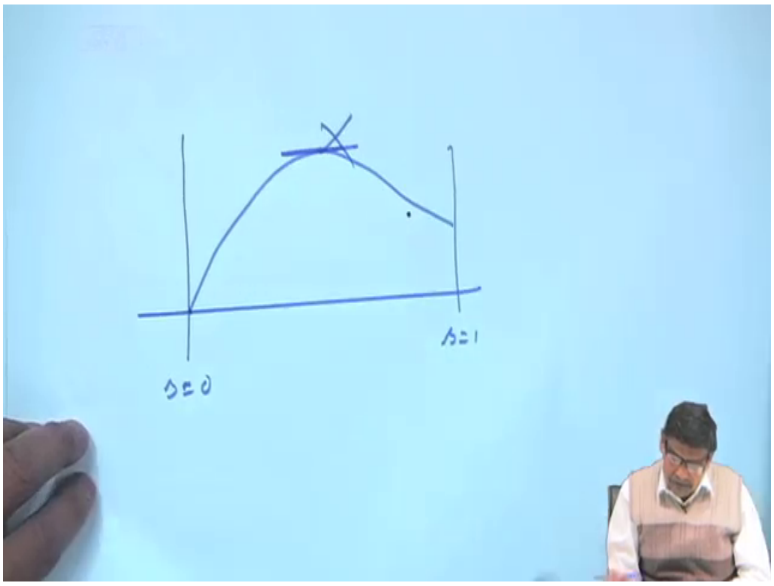

Correctly means do not draw a torque slip characteristics of a well designed induction motor; something like this s equal to 1 s equal to 0, students are often found that they draw it like this; and no never draw. Because the T e max for a well designed motor will be closed by s equal to 0 a typical value I told it is s equal to 0.1.

So, just do not draw like this; so this is the thing. And this is suppose s equal to 1, this point; and this is s equal to 0. And I told you also it is a good practice; so this is this side is slip and this way also you draw this is 1 this way you draw speed which is n r and the n r value is just opposite n r equal to 0 and this is n r equal to n s like this.

And then the torque slip characteristics will be somewhat like this, initially it is very steep; and then it goes like this. And this is t s and this is T e max T e max expression of which we know. And this is the slip at which maximum torque occurs is called alpha. and I told you that if the opposing torque is friction which is very little suppose this is the level of T friction present on the shaft of the machine this is T friction you switch on the supply, this is your starting torque.

And machine will accelerate, it will go like this all the way, and then it will finally settle down here; which is very close to synchronous speed. And machine is running like that, and then the machine is set to be running at a under no load condition. Of course you have not purchased a motor to run it and then no load condition, you want that your motor serve some mechanical load.

For example, the motor will raise water to a tank at a certain height, then really opposing torque will come and there the mechanical torque will be developed and the motor is going to do some mechanical work; or suppose the motor is doing some rolling operation in a steel plant then opposing torque really comes. Now I will formulate so this is the no load speed energy rho which is very close to n s now let us imagine.

So here is your motor, and I will just show it like this. It was earlier running under no load condition here is supply you have given just 3 phase supply; and it is running at n r 0 speed. Now let us imagine on the shaft of the motor I have suddenly put some mechanical load I ask the motor do some mechanical work for me, that is connect the external mechanical load on the shaft no resistance nothing like that it is mechanical load and therefore, let us imagine that at t equal to so machine is either to running at n r 0 speed; so t less than 0, the speed of the motor is n r 0 on load.

Now at t equal to 0 what I do? I increase the load torque on the shaft of the machine that is the opposing torque a step jump I give suddenly on the shaft of the motor. So, machine was nicely running here; suddenly I put this opposing load torque. So, it is like this, come from T friction the net opposing torque is T load. So, this is T load plus T friction whatever is there that is there.

So, this will be suddenly motor will see at t equal to 0 impose, T L opposing which is generally denoted by T L load torque ok. Suddenly I have put. So, machine was running like this and I have put an opposing torque. Now what the motor is going to do/ I told you, motor is nothing but an inertia.

It will accelerate, provided the electromagnetic torque is greater than the opposing torque or it will run steadily at some RPM when this 2 are equal or it will decelerate if electromagnetic torque developed by the machine is less than the opposing load torque these are the 3 things we know from Newton's laws of motion.

Therefore, at t equal to 0 plus at t equal to 0 plus after you have impose these opposing load torque on the shaft; can speed change instantaneously no speed cannot have a step jump speed will be at t equal to 0 plus immediately after you have impose these opposing torque has to be a n r 0 itself or the slip cannot change instantaneously.

Therefore, what will be the electromagnetic torque developed by the motor at t equal to 0 plus it will still remain this value. Because at the speed machine is still running at t equal to 0 minus it was running at n r 0 at t equal to 0 plus 2 it will rain at this speed; therefore electromagnetic torque developed by the motor is only this much at t equal to 0 plus, but the opposing torque is this much. Because this I have suddenly imposed at there is no scope for showing time in this diagram you must understand that.

Time is in my mind. So, at t equal to 0 plus n r 0 will remain n r 0 rotor speed, but you have imposed a opposing load torque that I can show nicely here; and then I say at t equal to 0 plus electromagnetic torque developed by the machine is less than T L. That is the conclusion; because at the speed opposing torque is this much and electromagnetic torque is only this much.

Therefore, what motor is going to do motor to decelerate rotor decelerates. Now rotor decelerates means speed decreases therefore operating point starts moving; speed will now decrease. This way it will move a time will come when it will come here of course, because of inertia suddenly machine cannot stop you must understand also this point I will tell now in this diagram because it was decelerating and suddenly is that deceleration stocked will not happen because of once again inertia.

So what happens motor may cross this way, it may cross this point where t load is equal to electromagnetic torque developed by the machine; operating point may shift there, but the moment it crosses this point I find T e is greater than T load therefore, it will accelerate. Therefore, maybe after few oscillations here it will go this way then it will come it will do few oscillations here of course finally, it will settle down there because the moment it comes speed try to decrease.

So, operating point machine always try to seek this point as its final settled point; so after maybe few oscillations it will come here. So, once again you see the this is the black 1 is the characteristics of the motor. And load torque is the characteristics of the lord; which demands constant load torque at all the speeds 2 things are entirely different, but if you superpose 1 above the other then the point of intersections are important.

That is this is the point of intersection and machine will now run therefore, at this r p m n r which will be further less than the no load speed, but none the less close by to n s imagine you have increased the load further T load 1 T load 2 once again you have it was running here with supplying T load you increase the opposing load torque further then I know.

I will going like this once again machine will try to come and settle down here, is not increase it further opposing load torque operating point will come here. And you know it will go on running at final speed which is now less than synchronous and it is visible now I mean no load speed was very close to synchronous, but as you go on increasing the load; it will be running at lesser and lesser speed steadily.

Now, in this way the opposing load torque can be increased of course, variation of the speed from no load to full load; full load of course the term I should not use I am not told what full load is, but as you go on increasing the load torque speed drops. But speed will not drop by a very large amount; because of the fact the this is only this is this value of n r this is only 10 percent of n s I mean some typical value is not only by ten percent the speed may change as you proceed like this, in case it will come run here, but this variation of speed or variation of slip is only very little.

Therefore induction motors earlier days people used to say that it is a almost a constant speed motor like a DC shunt motors if you do not touch field winding of a DC shunt motor variation of speed from no load to full load is very little almost like a constant speed motor; because variation of speed if it is a 4 pole 50 years machine it is 1500 RPM 10 percent of that point 1 only the speed may change by 150 RPM or so as you go to of that side. Now coming to the full load torque what is full load torque and the how it should be I mean decided upon ok.

Let us go ahead further. You go on increasing the load torque operating point moves to the right it comes here like that. Suppose you increase the load torque beyond the torque which the motor is capable of doing maximum torque motor is capable of doing that is T e max. Suppose somebody says it is working here fine, but I will increase the load torque opposing torque beyond T e max what is going to happen ok.

If you are starting from this point, load torque greater than electromagnetic torque machine decelerates it comes here load torque is still greater than T e max even speed will further decrease and as you can see operating point moves like this; and as the load torque opposing torque you have made greater than T e max and at node point in this range 0 to 1.

This trend is going to be reverse that is T L is always greater than T e developed whatever point you take. So, what will happen machine will finally, come down to stand still. Therefore, you see this way if you go on increasing load torque, when the load torque demand is greater than T e max then the final steady state operating point running at some RPM is not available that operating point itself is not there and machine will eventually come to a stop.

So, the question is when you increase the load torque on the shaft of the machine you should be a bit careful it looks like the this 1 is 0.1, and an another point. Suppose somebody has increased machine is capable of doing producing this much torque let us let me put this torque; it will run and let this be called full load torque and mechanism is designed to run at this full load torque then it will run at this speed, but this is not advisable why because this point is crucial.

This operating point as you move closer to T e max and you do not know then may come some disturbance you are close to the vulnerable point your load torque is close to T e max still less than T e max motor is capable of producing that torque. But as you close closer to T e max you are running the risk because motor is running doing some mechanical work, but disturbance you cannot avoid.

It may so happen that load torque has suddenly increased by a small percentage on this side then you are gone if by chance load torque increases by 10 percent or 20 percent then this value, it crosses that graded point that where you know machine will not be able to recover and give you a final operating point running steadily at some rpm. Therefore, it is quite advisable your load torque full load torque you designed such that it is not very near to T e max.

Although theoretically it is possible 1 may design when machine is capable of developing T e max, but is it prudent to do that no because disturbances will be always there; load torque may suddenly increased this way that way. So, people then say that to avoid such a scenario; you design the full load torque which is in the mid way of this linear motion of the torque slip curve the this portion is closer to a linear relationship.

We will discuss it further, but it is quite steep i in the linear portion and 50 percent of T e max; and let us arbitrarily say that my full load torque I will never exceed it will be close to 50 percent of T e max, better you do like that suddenly it cannot be close to T e max or no point in a choosing a T full load here, at this level close to synchronous speed.

Then you are not utilizing the motor, motor is capable of developing T e max this much and somebody says my full load torque is here, may motor is not properly then utilized. So, keeping all this things in mind people suggest that better design your motor full load torque; 0.50 percent of say T e max such that the full load speed it is since this zone is almost linear will be about I mean this slip value will be also about this is 0.1.

So, this will be 0.5 say so induction motors are designed; at a full load slip this slip steady state slip corresponding to full load torque T f l which is here suppose mid way between this 2 is say slip sfl is equal to say 0.5. Then you have n f margin because always remember that any electrical motors can be run overloaded for sometime is not it, is not that you overload the machine and machine will burn, 15 20 percent over loads are possible but for a definite amount of time continuously do not run a motor overloaded.

Then the question of burning of windings this that comes in because to burn a coil, suppose a coil related current is 5 ampere. If I pass 10 ampere do you think the coil will burn? It depends. If you pass 10 ampere which is capable of carrying current 5 ampere if you pass 10 ampere for long time, it goes, but 10 ampere for may be for 2 seconds you can allow it does not matter 5 seconds you can allow.

Because you know to burn a thing, you not only require the power, but power into time how much joules you are trying to dissipate time is a factor amount of heat generated is not only decided by i square r also into time how much heat and that heat resist the temperature breaks the conductor burns it this that. Therefore, overloading is a good engineering practice provided one knows how much to overload and for how long time that is most important. That is why keeping all this things in mind full load torque of a induction motor is a operating point is decided somewhere midway between these two.

It can be this way that way bit; a 4 percent full load slip is also possible you will see in motors. But it will be of that order 4 percent, 5 percent, 6 percent that is the full load slip typical value of full load slip of a 3 phase induction motor.

So, this zone mind you is very steep; then and this occupies only one-tenth of the scale about roughly; and then this is the rest of the things. [FL] After we have done, now see the interesting point. For example, I told you this point I will draw it separately so that you understand it better a way. So, always draw torque slip characteristics properly that is one thing.

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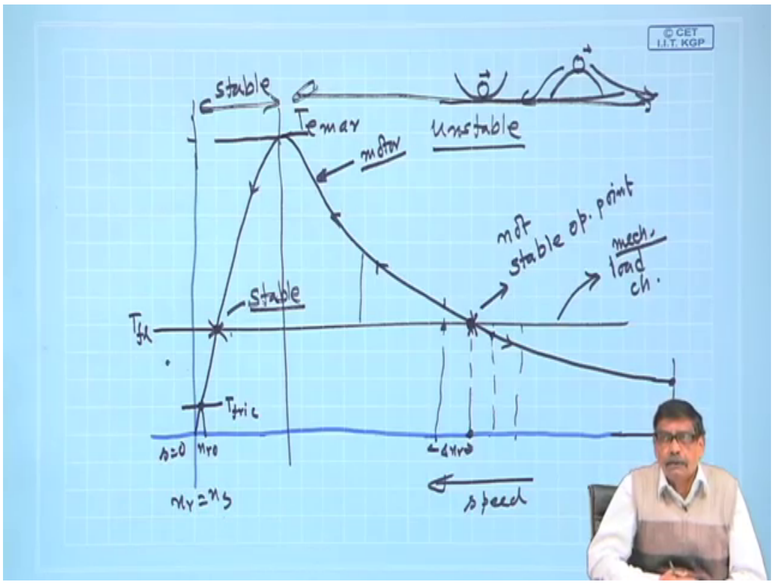

So, it is suppose the torque slip characteristics make practice drawing yourself. So suppose this is the, a typical well designed 3 phase induction motor the torque slip characteristics is like this. This is once again s equal to 1 this is s equal to 0 this is T e max. Although here also I have not drawn properly this should be one-tenth of this approximately I mean this is T e max. [FL].

I told you at no load it was operating here, T friction suppose and T starting was greater than T friction. Now when I told that T friction is suddenly raised to this level; say full load torque level, suddenly a step jump at t equal to 0, I have done this; earlier it was running at no load speed n r 0. Now suddenly it is increased and we know the final operating point will be here. But we must now observe this 2 torque slip characteristics very carefully. One is because of the motor this is motor characteristics, how much torque it will generate and this is the load characteristics, mechanical load characteristics.

It demands that no matter at what speed it is running it requires a constant load torque it means that. Now you observe carefully there are 2 operating point it looks like because at this 2 operating points T the electromagnetic torque generated by the motor will be equal to the opposing full load torque present mechanical load torque present. Therefore, it looks like that I have told till now, here also you see this is the full load torque ok.

There are it looks like there are 2 operating points, why not it will operate here. I while explaining I told it moves here; it did not reach there before that it reaches those things are fine. But what happens at this point let us try to explain that. So, suppose this is the full load torque, and let us for argument sake assume that motor is somehow settled down at this point; then if it is settle down to this point where it is absolutely fine electromagnetic torque and opposing full load torque are equal and machine will perhaps run at this RPM whatever it is, and it is at very low RPM as you can see compared to this side. But this operating point is not stable operating point not stable operating point. Why, what how do you test stability? Suppose we say that a ball kept in a bowel this is the floor you have another bowel which is kept inverted keep these 2 balls; this one is stable this was this ball is not stable critically stable.

Because a slight disturbance comes wind flow blows this fellow will roll down and it will never come back on its own to the original position it cannot. But here it is if suppose slight disturbance you did, and release your hand it will oscillate a bit. But once again come back here; so this operating point is of this kind. These 2 are equal it is critically stable but a slight disturbance come because you do not know. Suppose this speed has slightly dropped what is the speed? Speed is this way, you do not know a speed may change a bit n r equal to n s this is n r equal to 0.

Suppose speed drops a bit by some external factors its speed comes here, and the operating point then should be like this. If there is a slight disturbance in speed in this direction delta n r then you see full load opposing torque is greater than electromagnetic torque; it will further decelerate operating point will move like there.

And there is no point where electromagnetic torque can match this full load torque present and machine will come down here. Similarly if there is a disturbance this side delta n r, delta n r you immediately conclude electromagnetic torque is this and opposite load torque is this motor will accelerate. And it will accelerate means it will go here it will come here still it is greater than accelerate and finally, this is the stable operating point this will settle down here think about this interesting behavior of the machine.

So, for a constant load torque we then conclude we may conclude that this zone is this stable zone and this zone of this unstable zone. We will discuss further about this. So, hope you have understand about the operating points, and about the stable operating point and how the full load torque should be decided upon mid way between 0 and T e max approximately.

That way it is designed; so that you do not go close to a place where at the boundary stable and unstable zone meets; because that will be somewhat disturbing a slight disturbing comes motor will not operate it will come to stop. So, think about this points and carefully go through this. We will continue from this point next class.

Thank you.