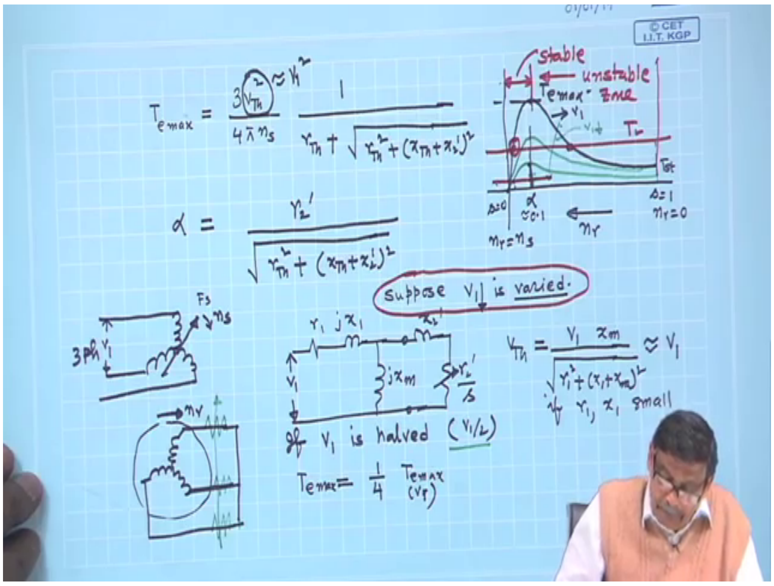
Electrical Machines - II

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

Lecture – 46
Change in Torque – Slip Characteristic as Supply Voltage & Rotor Resistance are Varied

Welcome to this next lecture and from the equivalent circuit we have in my last few lectures. So, we do the torque slip characteristics and highlighted the importance of that, because torque slip characteristics tells you if the machine is run at a particular speed or slip how much electromagnetic torque the motor is capable of developing.

(Refer Slide Time: 01:00)



And in our last lecture, based on the equivalent circuit we got these two very important results; one is T e max, the maximum electromagnetic torque developed by the machine is V Thevenin square by 4 pi n s. Mind you this n s is in r p s mechanical speed and 1 by this is r Thevenin's plus square root of r Thevenin squared plus x Thevenin's plus x 2 dash squared. This was T e max and these slip value at which this T e max occurs; I denote it by alpha and it was a like this r 2 dashed by square root of r Thevenin squared plus x Thevenin's plus x 2 dashed whole square.

So, these were very important results now, and the typical torque slip characteristics we will always draw that will be something like this. Here it is s equal to 1, here it is s equal to 0 and speed is this way which is n r equal to 0, and this is n r equal to n s. And this is T e max, T e max and this is the value of slip at which maximum torque occurs and these are the expression for that. Therefore, if the equivalent circuit parameters are known we will be able to predict what the motor, how much maximum torque the motor is capable of developing and at what slip it does. I told you that for a very well designed motor this alpha should be a typical value, could be 0.1 and this is you know 1, and this is starting torque.

And then I told that if the torque slip characteristics is known machine will operate at the point of intersection. Suppose this is the load torque, point of intersections motor will operate, it gives two speeds out of which one is stable; that is this one is the most important one. Machine cannot settle down at this point, although T e equal to T L, because it is critically stable. A slight disturbance this way or that way we will change the operating point, either to this point or to this point; that is motor will not run and it will never come back to its original position that is why it was called unstable.

So, far as a constant load torque is constant and last time I told; therefore, this zone for a constant load torque like this is stable, stable zone and this one is unstable zone. Unstable zone and motor will operate primarily in this steep portion of the torque slip characteristics. And also we noted that the full load torque, if it is full load torque it will be more or less in between. So, that you keep an up margin from the line of demarcation between stable and unstable zone, and the full load slip could be of the order of 0.05, half of this is 0.05 and so on.

Now today what we will do is, this we will try to see how this torque slip characteristics gets modified if I change certain parameters in the, which are appearing in the equivalent circuit. For example, this is the stator of the induction motor which is energized from 3 phase supply and this is the rotor, I have assumed starts are connected for the time being. And these rotor terminals are shorted and you give 3 supply here ok, and machine, a stator field is produced machine runs, suppose in this direction and obviously, the net field is also moving in this direction with n s; stator field or main field whatever it is.

Now, this r 2 dashed and x 2 dashed are the inherent resistance and leakage reactance of the rotor; r 2 and x 2. These are of course, reflected values, it should be multiplied by s square terms we know that. Now and here this per phase voltage applied is V 1. Now if you change the supply voltage how this torque slip characteristics is going to modify let us first examine, suppose we will vary the supply voltage. Suppose V 1; that is the supply voltage is varied, obvious reason if V 1 is the rated voltage; I am not going to increase the voltage, because it will exceed the rating of the induction motor you know.

I can only reduce the supply voltage; therefore, V 1 if it is suppose reduced, so V 1 is to be reduced only. Not increased because assuming V 1, this is the torque slip characteristics corresponding to rated applied voltage like this. Then you will see that if V 1 is decreased, that becomes meaningful, no question of increasing the supply voltage. It may exceed the rating of the suppose 400 volt 3 phase machine; I should not go beyond 400 volt. Now if V 1 is decreased then the question is, how V Thevenin's, because V Thevenin's has got the term V 1 and recall the equivalent circuit here r 1 x 1 which are small.

And here it is x m and this is x 2 dashed and this is r 2 dashed by s. This is the equivalent circuit. Now here it is V 1. So, I am playing with V 1, I am reducing it. Then we know that V Thevenin's is nothing, but the magnitude of this V Thevenin's is V 1 applied voltage divided by this current; that is r 1 square V Thevenin's open circuit voltage. So, r 1 square, this is also j plus x 1 plus x n whole square. You note this will be this into in to x n that will be the magnitude of the voltage. Generally r 1 x 1 is small, so this is approximately it will be not a bad idea to understand what is going to happen if V 1 is varied to approximately tell ok this is close to V 1.

Because r 1 x if you neglect this will be under root x m x m x m will cancel, it is approximately V 1. So, because if r 1 x 1 small compared to x n. So, if that be the case, so if you reduce the voltage in this expression of T e max, the T e max will also get reduced, because V Thevenin square is approximately V 1 square, as a first approximation we can assume that. Therefore, if V 1 is halved suppose halved; that is V 1 is halved then T e max now will become that is V 1 by 2 you have made. So, it will become one-fourth T e max, will become one-fourth of the T e max when supply voltage was equal to V 1.

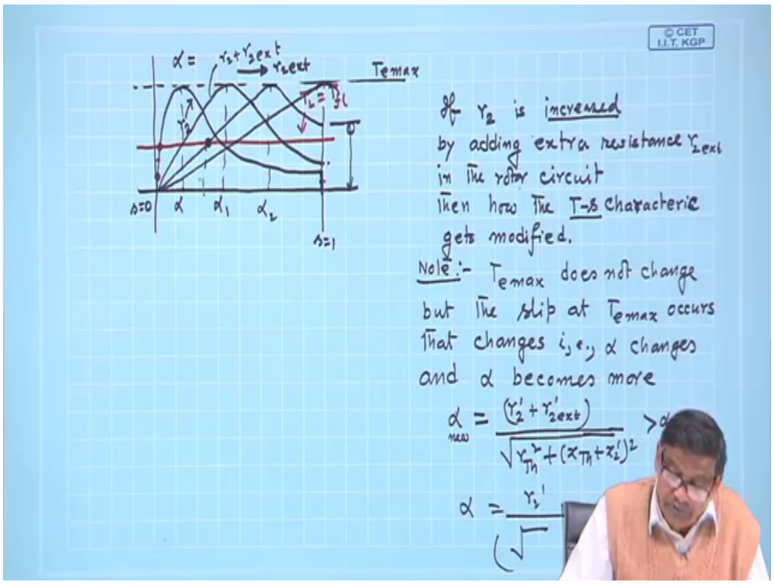
Is not it, it a maximum torque will become one-fourth. If you make it one-third it will become one-ninth, because square of the voltage, supply voltage dictates what should be this T e max. Therefore, if this is the T e max for applied voltage V 1, if you have reduce the voltage by half your torque slip characteristics will become like this. This one will become one-fourth that of this, slip at which maximum torque occurs, that does not change. Therefore, this peak here will remain same, alpha value remains same, but it will become only one-fourth. And therefore, under an applied voltage which is equal to half the rated voltage.

And suppose this is the full load torque of the machine you can easily see, you cannot supply a full load torque, because the machine is not at all capable of developing t l in its range of 0 to 1. So, the effect of variation of supply voltage reduces T e max drastically. If the supply voltage is made half it becomes one fourth and so on. Therefore, this is how the torque slip characteristics will get modified for different different voltage. If you reduce it like this so, this is V 1 decreasing, V 1 decreasing a family of curves you can get.

Keeping frequency constant frequency supply frequency, I am not going to change and I have assumed you do not have any provision to vary the frequency. Therefore, this is the effect of variation of supply voltage on torque slip characteristics. Therefore, with applied voltage less you can supply a load torque which should be below this T e max and half of this. So, the operating slip here will be like this and full load torque maybe, which should be also drastically reduced. You cannot connect a mechanical load which demands a load torque whose value is greater than T e max now that is this one.

So, a machine will looks like, will underperform. We will come to this point later when we talk about speed control of the induction motor. So, this is the effect of variation of supply voltage on the torque slip characteristics. Now there is another parameter which we can vary and see what is going to happen.

(Refer Slide Time: 15:25)



Before that one problem I will try to just mention and this is like this. See this is the torque slip characteristics I told you. This is s equal to 1, s equal to 0, and this is suppose the full load torque, as I told you like this t load is equal to t full load, suppose somewhat midway. Now you can see the, if the motor one way to supply this full load torque is that with the load torque present already on the shaft of the machine and the machine is stationary. If you switch on the supply your starting torque is only this much, machine can develop and opposing torque is this much.

Therefore, motor will fail to start because we have not produced enough starting torque to overcome the opposing full load torque which is already present ok. Therefore this machine cannot be started as it is with full load mechanical torque, connected to the shaft. So, what is the way out? One way out is that do not connect the mechanical load first, then the machine has to start only against the frictional torque which it can do frictional torque, maybe within this limit and then machine will settle down to no load speed. And then you connect the your mechanical load torque, then the operating point will shift here and settle down here which is the stable zone.

But sometimes what is needed is that, the machine has to start this mechanical load will be permanently connected, whether it is running or not and you switch on the supply and machine should be able to supply this full load torque that is the thing required, but then we are facing this problem, that ok. Starting torque is only this much what can we do?

There is a way out what is that, and there is a very nice thing we have seen that these two relations are very important.

What is r 2 dashed? r 2 dashed is the rotor circuit resistance and here I have shorted the rotor. So, this small r 2 is the inherent value of the rotor resistance per phase. Now if we could, the idea is at the time of starting I will connect some resistance in the rotor circuit, because rotor terminals are available. I will connect some resistance in the rotor circuit at the time of starting; therefore, I am essentially trying to understand how the torque slip characteristics will get modified if I vary the rotor resistance.

How I am varying? We made an total resistance this r 2. Now I will connect some r 2 external. So, total rotor resistance will become this r 2 plus r 2 external per phase in the rotor circuit. And this r 2 plus r 2 external dashed then I have to substitute in the expression of the electromagnetic torque as well as in the value of the slip at which maximum torque occurs. So, you see this is the thing. So, this is the torque slip characteristics with inherent resistance r 2.

Now, I will increase the rotor resistance by connecting some external resistance of equal values in each of the phase here is and then I will short. So, if r 2 is increased, if r 2 is increased by adding, by adding extra resistance on the in the rotor circuit, in the rotor circuit, rotor circuit then how the torque slip characteristics gets modified that is the question we are asking our self. Now the value of the slip T e max if you look at the expression, does it depend on r 2. No r Thevenin's has to do something with r 1 and x n.

V Thevenin's is supply voltage constant, there no r 2 dashed. So, T e max value is not going to change. What is going to change is the slip at which maximum torque occurs. Note if you increase r 2 by connecting external resistance, say r 2 external, I will say T e max does not change, T e max does not change, but the slip at which T e max occurs T e max occurs that changes; that is alpha changes and alpha becomes more. Now alpha becomes more compared to the rated condition this alpha.

This is the alpha with inherent total resistance per phase. Therefore, the shape of the curve will not change, because some parameters we have increased a bit resistance. Therefore, what will happen if you add some external resistance. What I am telling this T e max is fixed, it is not going to change, but the value of alpha at which maximum torque it will be, alpha new will be r 2 plus r 2 external dashed ok, r 2 dashed plus r 2 external dashed divided by [FL]. I mean that things square root of r Thevenin square plus x Thevenin's plus x 2 dash squared. This will be the value of alpha new.

So, and this will be greater than alpha which was, what was alpha? Alpha earlier was based on alpha was simply r 2 dashed by the same square root. I mean whatever it is, but only numerator was r 2 dashed. Therefore, this alpha was less and it will then becomes something like this. This one is, this is for r 2 dashed, this is for r 2 plus r 2 external. So, this slip at which maximum torque occurs now will become alpha one.

Now, if you observe carefully by doing these, this starting torque has been increased. Earlier it was this much, but now it is this much, but still it is less than that opposing full load torque. So, therefore, we will be tempted and rightly. So, because of the fact that alpha shifts to the right and then further increase r 2 external then you will get a torque like this.

So, r 2 external increasing this way. I will write it like this to external. If you further increase it will, maximum torque will occur at some value of alpha 2. And you now find that by incorporating an external resistance in the rotor circuit, this starting torque has now become greater than the load torque. And if you now switch on the supply with the opposing torque present then machine will start.

No problem, and machine will start and will settle down at this point, because this is the load torque characteristics with some r 2 external present and machine will run at this speed, because that is the stable zone. Only one point of intersection we are getting. In fact, if you wish you can connect a judicious value of r 2 external. So, as to get this starting torque equal to the maximum torque, the motor can develop because I will then connect, there exist, some value of r 2 external such that this T e max which does not change as you vary r 2.

T e max may occur here at s equal to 1 so that machine will accelerate fast. Therefore, not only that this problem that that with inherent rotor resistance, although the machine is capable of starting where against full load torque. One way out is, do not connect that full load opposing torque at the beginning. Do not do anything with the rotor, keep it shorted right at its terminals. And then after machine settles down to no load speed put that opposing load torque on the shaft and then machine will operate here, but I am now telling another interesting thing if the rotor terminals are available, I will connect some r 2 external in the this green resistance, external resistance equal values.

So, that balanced thing is preserved. So, per phase resistance will be r 2 plus r 2 external and I will switch on the stator supply, but which torque slip characteristics it will follow. If you have added enough rotor resistance such that it is modified here then machine will accelerate fast and operating point will shift, and this is the point of intersection this load torque is present, it will run at this speed. You know now the big question is, whether after getting that starting torque advantage should we keep this resistance intact in the circuit? The answer is obviously, no.

Because of the fact if you kept the resistance in the circuit permanently after exploiting the starting torque, advantage that particular property rotor resistance will be x r 2 plus r 2 external and the power loss in the rotor circuit will be then more while supplying the full load torque, efficiency of the motor will reduce. Therefore it is better you connect some selected value of r 2 external and then as the motor picks up speed, you gradually cut out the resistance. Finally, this rotor circuit should be shorted.

We will discuss it further in the next class.