Electrical Machines – II
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Lecture – 69
Introduction to Starting of 1 Phase Induction Motor

Welcome and we will be we are discussing in fact, about the equivalent circuit and torque slip characteristics of a single phase induction motor running on single winding, ok. And, then the torque slip characteristics must pass through a at s equal to 1, it is 0; unlike three-phase induction motor there was a definite starting torque, but in case of single phase induction motor starting torque will not be there and then at any slip of course, if it operates there will be torque developed.

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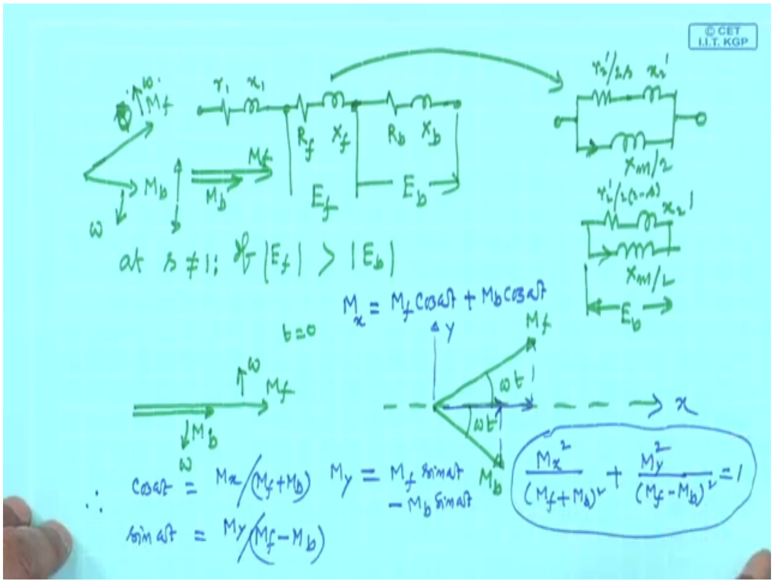

And, the equivalent circuit from this the net torque at any slip can be calculated as r 1 x 1 and then that parallel branch equivalent impedance I denote it by X f here, and then the backward field R b and X b. This R f X f is nothing, but this one r 2 dashed by 2 s at any slip and this is x 2 dashed and this is X m by 2; this is R f X f is this one. Similarly, r b x b is r 2 dash by 2 into 2 minus s, and this is x 2 dashed and this is X m by 2, this is also X m by 2. So, this can be brought in this one.

Now, what I am telling the current in this magnetizing inductance decides the strength of the field. So, current in this magnetizing branch will be decided by the voltage coming here. Let this voltage be E f and this voltage be E b. Then, E b by E f by X m by 2 will be this magnetizing current here that will decides the strength of the forward motor field. Similarly, E b this voltage that is E b by X m by 2 will decides the magnetizing current here and as you can see the value of E f and E b will be same when s equal to 1, but when it is not then this voltages will be different.

For forward motoring mode that is if E f is greater than E b then this strength of the forward field will be more and strength of the backward field will be less and both of them of course, will run at synchronous speed in the opposite direction, that is what I was trying to convey. Now, let us see what happens at any slip at s not equal to 1, this is the situation. So, at any slip s for forward motor slip; s f I am not writing it is understood it is forward motor slip I am talking about.

So, if this is the case then the strength of forward field if it is like this M b will be strength of the backward field will be less, this length will be less and it is moving in the forward direction suppose the forward direction is this way omega, this is the backward direction. So, motor will run along the direction of the forward field and the field which a moves along the same direction as that of the rotor rotation I have called that to be your forward field any case.

So, two lengths M f and M b are moving in the opposite direction. So, what will be the locus of the resultant field it is interesting to examine that. So, at some time they will be as they are moving they will be together like this; M f, M b. There will be instance and at some time they will be away and then in the negative direction.

So, let us assume that let us start counting time from this instant, that is, this is M f and this is M b they are along the same space line and then I am saying t is equal to 0 here and each one of them is moving with a speed omega, forward and backward field. Therefore, at any arbitrary time forward field will be here M f and backward field will be there M b and this is your that initial point they were together. So, this will be omega t and this will be also omega t.

Now, to find out the locus of the resultant field what we will do is this we will find out the x-component of the resultant field M x will be nothing, but M f cos omega t that is this projection and plus M b cos omega t. Similarly, this is the suppose the x axis you arbitrarily tell this is y axis then M y component will be M f sin omega t minus M b sin omega t, is not? Therefore, if you eliminate that is therefore, that is the x coordinate and y coordinate therefore, I can say that cos omega t cos omega t is equal to that x x coordinate of M resultant M by M f plus M b and sin omega t is M x M y by M f minus M b. So, eliminate time, square and add.

Therefore, I will get M x square by M f plus M b whole squared plus M y by M f minus M b whole square this must be equal to 1, cos square omega t plus sin square omega t you do and then this is the equation of an ellipse, ok. Therefore, the x coordinate of the resultant field is M x, y coordinate of the resultant field is M y at any time t. Therefore, if you eliminate time you get this.

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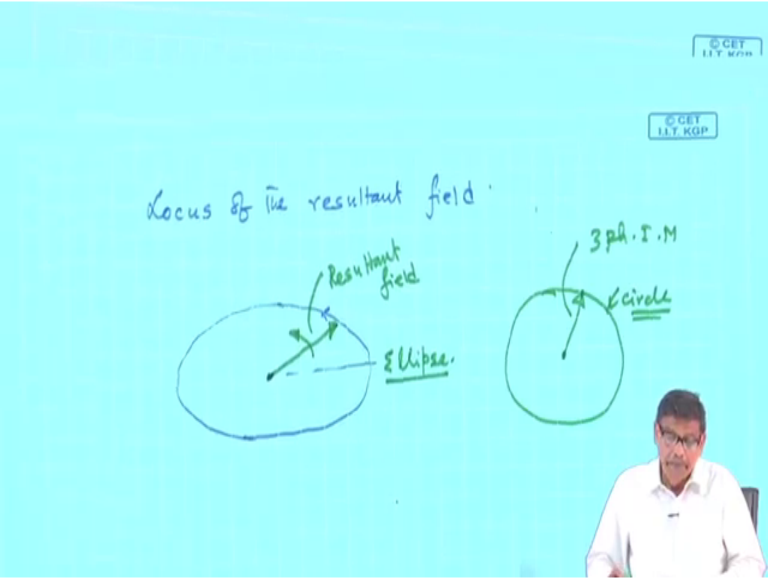

Therefore, it will be the locus of the resultant field locus of the resultant field field will be the will be an ellipse here and it will be somewhat like this. This is the semi major axis M f plus M b and M f minus M b. So, that is a essentially what I am telling the resultant field will move with a speed omega and it is like this. In case of three-phase induction motor, the resultant field was lying on a circle of constant amplitude 3 by 2 some M max, is not? Three-phase induction motor it was a circle, three-phase induction motor strength of the field rotating field was constant at all time.

So, we see that there will be a resultant field the locus of that will be lying on a ellipse indicating that the it is some rotating field, but not of equal strength, ok. [FL] We will come to this little later, but that is the idea that that at any slip s when it is moving it is doing like that,.

Now, let us come to this; so, locus of the resultant field will be an ellipse in this case ellipse, ok. So, please make habit to draw the torque slip characteristics correctly for three-phase induction motor as well as for single phase induction motor.

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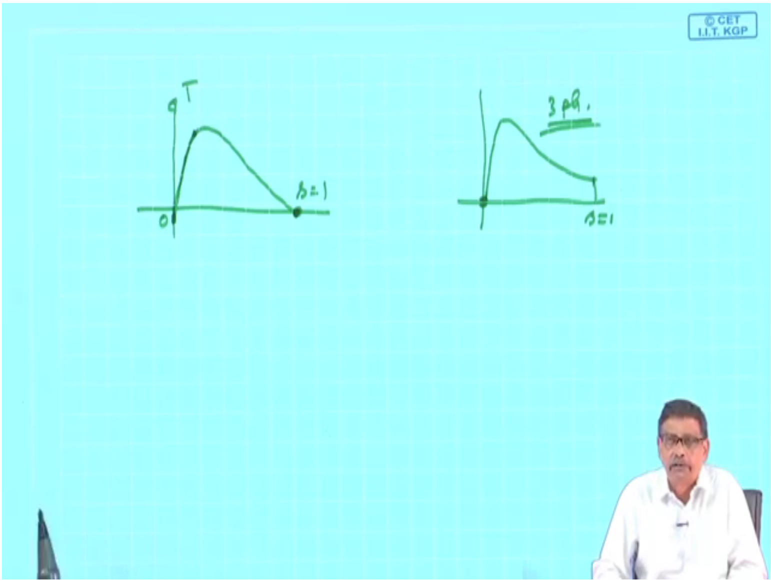

In single phase induction motor, the torque slip characteristics essentially will be like this; not a it will start a little below from this then this is s equal to 1, zero torque, 0 to 1. Three-phase induction motor, it will be staring from here it will go at s equal to 1, definite starting torque will be there three-phase [FL]. Now, the question remains that you cannot of course, leave it at this stage without solving the problem of starting a three-phase induction motor. You must do something so that the machine to the machine you incorporate some starting torque, ok.

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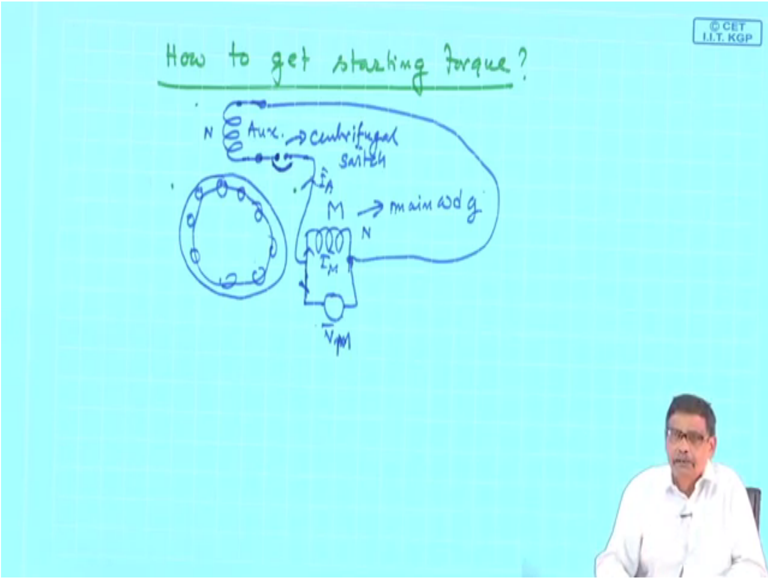

This can be done, but, how to get starting torque? So, to do this what you have to do is this, this is the rotor; cage rotor. Here you have to bring another winding that main winding is the main thing you have to bring now physically the other winding. It is now nothing like a dream or thought nothing is there, but auxiliary winding. It is physically the machine must be wind like a two-phase induction motor with main winding having some transcend; this is also having some transcend. And, these two will be the winding and these two windings I will connect parallel and connect across a supply here, so that both the windings will now carry current.

And, by doing something I will incorporate this starting torque and after the machines starts then this auxiliary winding; this is called auxiliary winding and this is the main winding, I will disconnect this auxiliary winding. What is done is this, there is a centrifugal switch, and these two windings are connected in parallel and then a supply I am telling the last thing first this is how it will look like. So, this winding is now physically present in the machine. There is no this way, that way; auxiliary winding is there with some what is called centrifugal switch, centrifugal switch and at this centrifugal switch is such that when the speed is very low or zero this is closed.

So, you switch on this supply here there will be current in the auxiliary winding there will be current in the main winding and you will find machine is having some starting torque. It may have starting torque because now two windings in quadrature is present.

Hopefully, there will be some sort of like two-phase induction motor, perhaps it will develop a torque that is why it is running, like that I will conclude at this stage. And, it will pick up speed and after pick it picks up speed suppose speed becomes 70 – 80 percent of the nominal speed of the induction motor, then the centrifugal switch will automatically get open circuited. And, since the machine has already attends speed it will continue to run on a single winding.

So, primarily if it is really a single phase induction motor, ultimately it has to run on a single winding and auxiliary winding is brought in to assist the motor, so that it can develop some starting torque. After it has developed starting torque in presence of both main and auxiliary winding machine will accelerate, after it reaches some speed this switch which is speed dependent it is operation is it will open circuit it is normally closed switch otherwise. So, that is the idea.

Now, the question is this auxiliary winding and main winding what should I do? That is this currents should be then manipulated. So, that apparently it looks like I will try to make it operate at a two-phase motor. See if these two windings are identical and if you have balanced two-phase supply available which is however, not the case. Suppose a two-phase induction motor with a main and auxiliary winding is there. You connect it to one source to a two-phase source such that the currents in both of them will be at 90 degree apart then the problem would have been solved, but unfortunately it is supply voltage is three-phase or single phase.

However, the simplicity of single phase induction motor is that we are going to make a simple motor like induction motor which will run on single phase supply that is the whole idea, ok. So, what to do?

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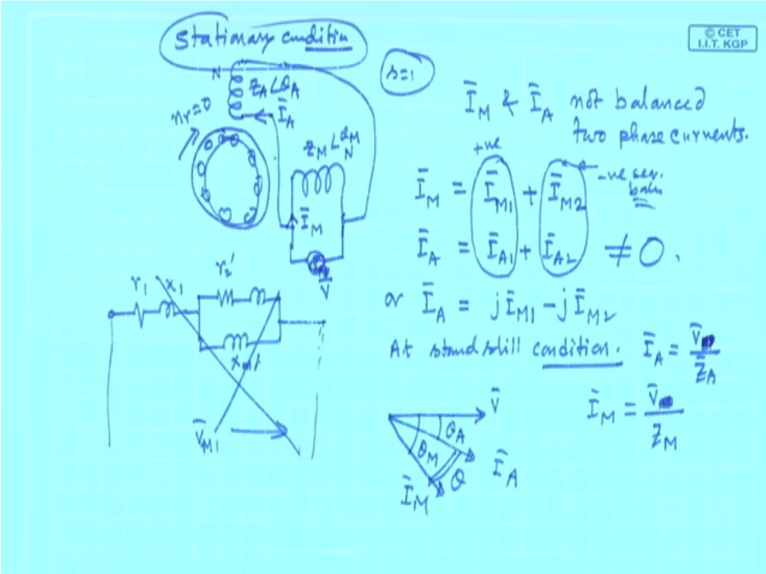

Now, the thing is then first we will see what is happening how this starting torque depends on the main and auxiliary current. So, I will draw like this. This is my rotor this is my rotor and here is your main winding, ok. It is connected a to a single phase source suppose it is drawing a current of I bar M and there is an auxiliary winding which is physically present now forget about the analysis where I assumed I a is 0 not like that I will also connect it to this supply.

Suppose, that connection I am not showing and this current is I bar A. And, I will examine with both the coils present whether this thing can produce a starting torque. So, here I will assume n r equal to 0, straight that is s equal to 1, forward wave speed. So, what is the condition I have been imposed? Two coils are there, main and auxiliary they are connected to single phase source same source parallel and at stationary condition stationary condition; mind you, this is no stationary condition. And, in stationary condition I know forward slip and backward slip are same is not 2 minus s. So, s equal to 1, this is I m [FL].

Now, obviously, these two currents, let us not assume that this two coils are balanced or things like that, except that suppose number of answers are same, more general case will be doing. What I am trying to tell that this main winding current and auxiliary current they may not be balanced, ok. That is, I m and I a; I m that will be the most general case I m and I a not balanced two-phase current not balanced two-phase current.

If that be the case then I bar M can be written as it is positive sequence M 1, this I have done earlier, but let me do it so that once again it is negative sequence. Similarly, auxiliary current I bar A is equal to I bar A 1 plus I bar A 2 and this time this is not equal to 0 in our that imagined machine I I brought in auxiliary winding to understand what is going on actually and I assumed I bar A is equal to 0, but here it is not like it is. But, nonetheless, these two currents I M, I A are unbalanced two-phase current.

Therefore, they have their own positive and negative sequence of current of which this I bar A then can be written as j I bar M 1 and minus j I bar M 2. I bar M 1 and I bar A 1 is a positive sequence, balanced system; this is negative sequence balance system, that is the thing ok. And, I will not allow the rotor to rotate. I want to examine really starting torque can be available or not. So, it is a forward motor and once again a backward motor at s equal to one operating with the condition that I bar A naught equal to 0, I bar M is also not equal to 0 and then this is the current.

Now, the question is on the first place the equivalent circuit of the forward motor r 1 x 1, is not? And this is r 2 dashed by and this is X m by 2. In fact, that first one where for the forward motor there is V bar M 1, it is applied is not forward motor. And there will be anyway I let us not complicate the issue. So, it is like this.

Now, the question is the this two currents if it is connected across the from the same supply like this then at stand still condition, at stand still condition auxiliary winding current will be that applied voltage V bar M by the impedance of the auxiliary winding what is seen by this supply get bar A at stand still condition. Similarly, I bar M will be V bar M. No question of telling V bar M. Now, V is the supply V by Z V by because to the same supply I am giving the one. What is needed we will see later, but I am now telling you that these two currents I bar A and I bar M at s equal to 1 must have a phase angle difference between them.

For example, what I am telling this is suppose the supply voltage V bar, V bar then this is the main winding current at s equal to 1, mind you, stationary condition all things what I am talking now at stationary condition I M and auxiliary current may be like this. So, this is the power factor angle of the auxiliary winding, this is the power factor angle of the main winding, that is what it means ok. Now, if that be the case and the angle between these two is some angle theta. Therefore, there must be a phase difference between the main and auxiliary winding impedance so that things will work it will become clear after few steps that is if you see that this I bar M and I bar A their power factor angles are same then it will not give any starting torque. That we will see.

But, the point is it is it offers an impedance Z A theta A and this impedance is Z M theta M it is like this, ok, that that will be the case [FL].

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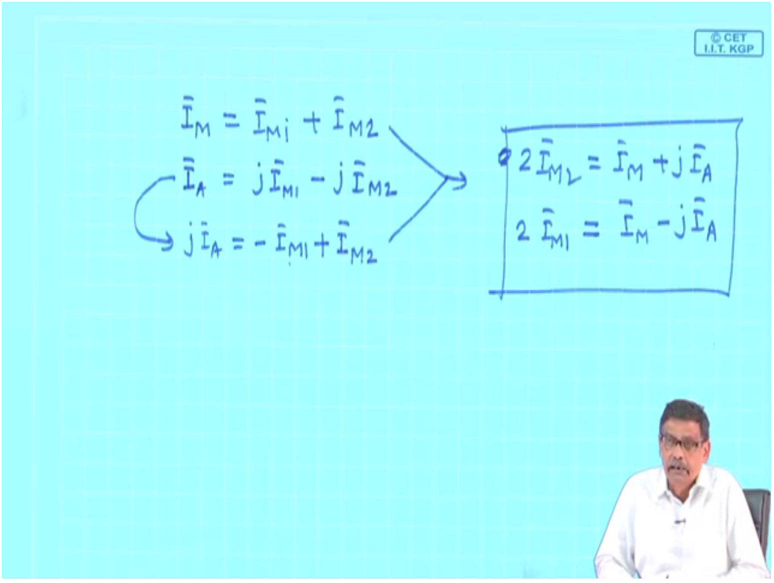

Now, let us do a little bit of algebra. So, we have seen that I bar M at least this much I can do in this lecture, I bar M 1 plus I bar M 2. And, A and I bar A is equal to j I bar M 1 minus j I bar M 2 let us try to express I M 1 and I M 2 in terms of I M and I A. So, what you do is this you multiply this equation with j. So, it will be j I bar A is equal to minus I bar M 1 and this will become plus j j minus minus minus plus I bar M 2, this will be the thing. So, from these two equations if you add you will get 2 add this two you will get 2 I bar M 2 from the right hand side. This will cancel out, and you will get I bar M plus j I bar A.

Similarly, if you subtract these two you will get I bar M 1 minus minus I bar M 1. So, 2 I bar M 1 is equal to I M minus j I bar A. So, these two are the main thing. Then what we will be going is doing is that torque will be proportional for the forward motor that I M square into r 2 dashed minus I M 1 square into r 2 dashed minus I M 2 square into r 2 dashed, like that we will proceed.

So, for today please go through this. We will continue with this next class starting. So, starting is very important.