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

Lecture - 69
Introduction to Starting of 1 Phase Induction Motor

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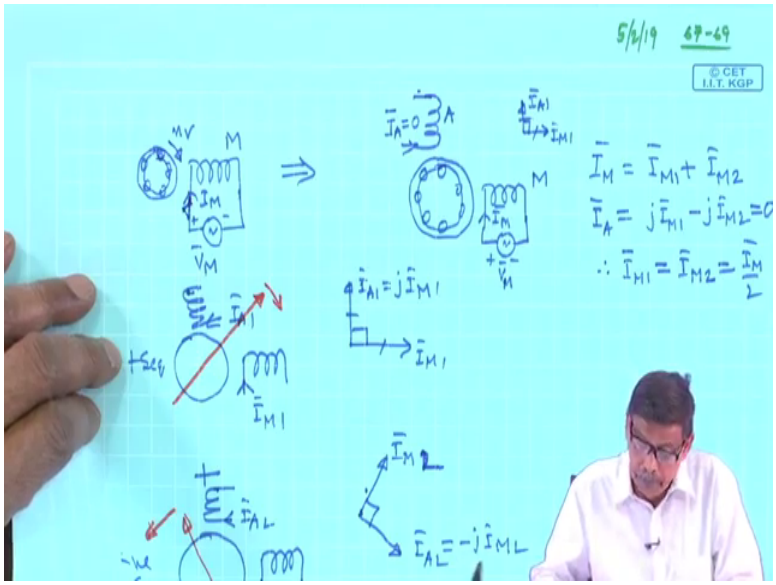

Welcome to this lecture on single phase induction motor and you recall that a single phase induction motor is there will be a cage rotor and there will be a single phase winding which I called winding M, coil M main winding it is called and we will connect a single phase voltage across this that voltage is V bar M and we know that if you just and suppose initially if the machine was stationary, if you switch on this supply nothing is going to happen, motor will not run because of the fact explanation was this single phase current will produce a pulsating field and this pulsating field can be shown to be equivalent to two rotating field of equal strength rotating in the opposite direction and therefore, each one we will try to pull the machine with same torque in the forward as well as in the backward direction as a result it will not run.

Another way of explaining it will not run because of the fact this alternating flux here along this line will induce voltage in the secondary. There will be current in the secondary, it will be just like a transformer and the distribution of the current will be upper if at a given instant if it is crossed the other one will be dot like that and therefore,

the rotor field is also there, but it is along the same line as that of the stator field. So, no torque can be produced. There must be some separation of angle. However, the observation another observation I told that suppose with this switch on if this rotor is given a rotation in any direction say clockwise direction or anticlockwise direction by some external agency, suppose some initial rotation is given then we will observe that the motor will speed up even if you remove that initial help to the rotor. After giving some help it will continue to run.

Therefore, the conclusion was a single phase induction motor will have no starting torque, the explanation of which I have told. However, the induction motor after observing not yet proved, but the observation is it will have a running torque working on a single winding that was the case. Now the analysis part what I did was that you imagine that here is single winding only. So, this motor I can think of that there is a another coil, coil M and there is another coil which I call coil A which is not existent, but I can imagine there is another coil existing, but carrying no current. So, that is why it is equivalent to this one.

So, this current what I am telling is assumed to be 0 and here I have applied a AC voltage V M and this is going to draw some current I M bar and this is the rotor. So, these two situations are identical because I will never assume any current flowing in this so called assumed winding in the quadrature axis because the axis of these two coils are at quadratures 90 degrees. Therefore, anyway based on that then the argument was therefore, I have got as if 2 windings at 90 degree, one coil carries a current of I bar M another coil carries a current of I bar A which is equal to 0. So, this is a unbalanced 2 phase current and therefore, this currents I wrote it like this, a positive sequence current, a negative sequence current.

And similarly the auxiliary winding current will be see I bar M 1, I bar M 1 and I bar A 1 is positive sequence current. They will be at quadrature, their lengths are same. So, this is nothing but j I bar M 1 and this will be minus j I bar M 2 etcetera of which this thing is 0 because of the fact that it is 0 because of the fact I A is 0.

So, after breaking this up then we come to know that this we got. I M 1 is equal to I M 2 and if you substitute in equation 1, it is equal to I M bar by 2 that is what we got last time, but it is better to repeat because first time you are doing single phase induction

motor. Single phase induction motor is slightly difficult to comprehend what is going on, it is better. So, it is like this.

Now, the moment you do like this then I can say that you have on this motor 2 balance source say 2 balanced currents are flowing. One is I bar M 1 and its auxiliary winding current is this one, so I bar A 1. These two currents magnitudes are same 90 degree apart because of the fact this I bar M 1 and I bar A 1 which happens to be equal to j I bar M 1.

So, this is a balance system fine, plus another balanced 2 phase current which are 90 degree apart that is I bar M 2 and in the auxiliary winding I bar A 2 and what is the relationship here? Here the relationship is because it is negative sequence, this is positive sequence motor. So, the relationship is if this is I bar M 1, I bar A, I bar M 2 negative sequence component it will be auxiliary winding current will be I bar A 2 this is 90 degree and I bar A 2 is minus j I bar M 2.

That is what you have used here. So, then I am comfortable because it is then a balanced 2 phase induction motor and then and it is also a balanced 2 phase induction motor. Only the thing is in this case the auxiliary winding current leads the main winding current by 90 degree. In this case main winding current leads the auxiliary winding current by 90 degree. So, each one of them if you consider them separately and then I will superpose the results, assuming linearity all these things. So, in this case the rotating field will be moving from the leading to the lagging phase and in this case the rotating field will be moving from the leading to the lagging phase because in this case the main winding current is leading.

And two sets of electromagnetic two sets of rotating fields will be produced which will be moving in the opposite direction and therefore, the strategy is that I will then find out the toque developed for this machine it is a balanced 2 phase induction motor. This is also a balance two phase induction motor, but for physical reasons I know that the torque developed by this two sets of magnetic field will be in the opposite direction that was the idea and after doing that I told you that ok.

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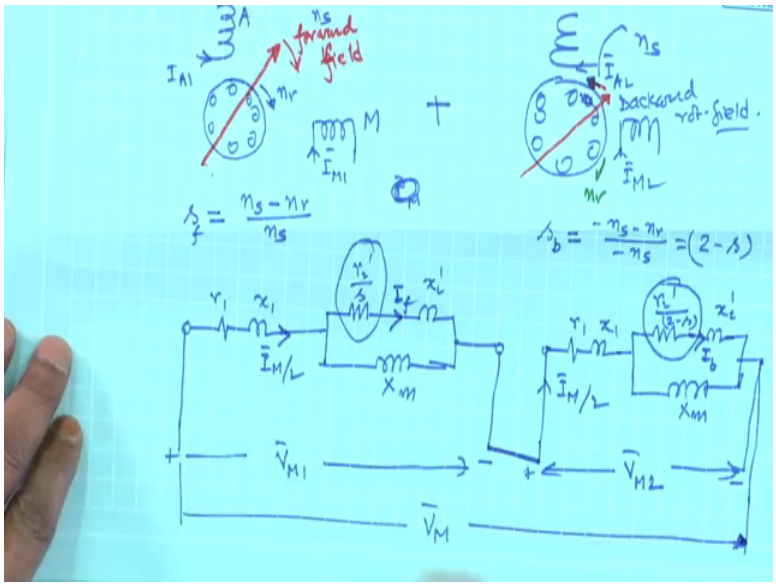

Let this induction motor whose rotor is this whose rotor is this and suppose the rotor is moving at some speed n r and this is your main winding and this is the assumed auxiliary winding having no current.

So, the field these two fields, one field is moving along the direction of the current it has to be one of them whichever moves along the direction of the rotation. How this n r is obtained? I told you observation wise it was n r, let us assume it is having some speed at that time I have switched on the main winding like that you can also think. Suppose the rotor is given a rotation n r and then you switch on the supply then you will see it is running. So, n r may exist because of some external disturbance like helping the rotor initially.

So, let us assume then the general case when the rotor is moving n r and then you have got two machines, I M 1 and this is I A 1 and plus this machine and here it is the direction of the field is like this and this field will called forward field, forward field and similarly here it will be like this and this is the I bar M 2 and this is I bar A 2 positive and negative sequence component, but in this case this current leads auxiliary winding.

So, rotating field will be moving in both the directions. So, this both these fields are simultaneously present and rotor of course it is rotating in this same direction n r. Therefore, I will find out the torque of this machine and this machine. So, let us define that this slip of this forward motor, this is backward rotating field in this direction,

backward rotating field. Therefore, slip is n s minus n r by n s. What is n s? Depends on the supply frequency and number of the poles of the machine we know that. And what will be the slip in this case? Backward field will be also moving with a speed n s, its speed is n s in the clockwise direction, this speed is also n s, this speed is n s in the opposite direction.

So, in this case this slip of the backward motor s b ok, you can write s f if you like forward fields forward motor slip. It is equal to minus n s minus n r by minus n s and this we have shown to be equal to 2 minus s. Is not? This is 2 minus s. So, then I say that look here this is the situation. So what will be the equivalent circuit of this balanced 2 phase motor? Its equivalence circuit will be r 1 x 1, r 1 x 1. Then here is at any slip when it is running it will be r 2 dashed by s and then this is x 2 dashed, x 2 dashed and this is X m. This is the per phase equivalence circuit of the forward motor and what will be the per phase equivalence and what is the voltage applied here? Is it V bar M, is it V bar M? No, it is the positive sequence voltage here V bar M 1.

Similarly, the equivalent circuit of the per phase equivalent circuit of this motor will be the parameter values are same stator resistance leakage resistance and then you have, here you have to be careful r 2 dashed, but this slip is 2 minus s and then, then this is x 2 dashed and this two are X m and these are the per phase equivalent circuit of the backward motor and its polarity will be plus minus, but this voltage I must call negative sequence voltage per phase whatever you have applied.

Now since I bar M 1 [FL] after I get this, it looks like it is now I can calculate torque ok. How I can calculate torque? That is I can stop everything here and say what will be the torque of the expression I can find out without proceeding further. How?

The torque will be this is these are the resistances where air gap power is involved, this is the resistances where air gap power is involved.

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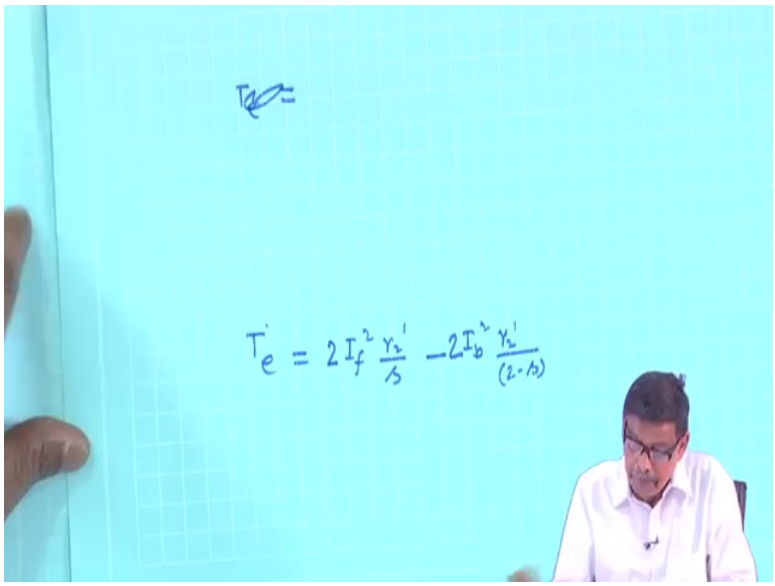

So, I will say torque developed by the machine will be just see here this is the thing it will be this current square. Let this current be called I f forward field current this branch current. So, it will be simply I f square or I will write it at the bottom T e, T e will be in synchronous what will be I f square r 2 dashed by s. What is I f? I f is the current in r 2 dashed by s this branch. Then I will calculate this current suppose this current is I b, I b and this torque will be I b square into r 2 dashed by 2 minus s.

This is the expression of the torque what else because these are the air gap power and from physical consideration I know they are moving in the opposite direction. So, I will put a negative sign. You can divide by 2 by n s to get the torque in Newton meter that is there of course. Anyway this is the thing, but the question is you have to calculate this I f and I b if you know. So, for that V bar M 1 and V bar M 2 is necessary. It is important to point out once again that while assuming our original machine is, just this machine there is no auxiliary winding here only main winding you have applied a voltage these things I know. I will be knowing V M, I will be knowing I M, actual current positive sequence negative sequence is our own thought process led to that.

So, that I can analyze the machine like a balanced 2 phase motor that is there, but neither V bar M 1 and V bar M 2 is known. When you come to this concept this is the abstraction assume an auxiliary winding it is not carrying a current I A, 0, but this voltage about this voltage I cannot comment, I have not assumed V bar A equal to 0.

What I am sure about I bar A is 0 then only it resembles this one as if nobody is there, nobody is there means even if you consider there is a winding it is not carrying any current over, but if this fellow rotates there is rotating fields produced by the main winding, I cannot say there will not be any voltage even in this winding assumed winding. This is stationary.

Therefore how to calculate V bar M 1 and V bar M 2 because that will be necessary to calculate this current and that current I f and I b there is a nice way out about this. I know this much, this is I bar M 1, but that current is nothing, but I bar M by 2. This current is nothing but I bar M by 2. Therefore, these two circuits can be connected in series this is the connection i will make and this was positive sequence voltage, this was negative sequence voltage. Therefore, this voltage must be your V bar M that is the, that is the thing. This will be V bar M that is this is the V bar M and this is the current because this voltage I can record with a voltmeter this current I can record with a ammeter.

And therefore, these two can be connected in series because I bar M 1 and I bar M 2 are same and once you do that everything is now in place because V bar M will be known to me, all the parameter values are known to me, I know at what slip I am calculating the torque, I have to simply analyze this circuit and then calculate this current and this current, current in a 2 by s terms and then you say that the torque developed torque developed will be this one got the point, but only one still whether something can be done about this circuit.

See in the original machine you apply a voltage only main winding is existence, no auxiliary winding is there. You apply a voltage, you connect an ammeter, you know the current or seeing the oscilloscope you know at what phase, but completely I bar M is known. Then if you so calculation of I f now is possible because I know I M, I M by 2 is also then known, then series parallel this current division in parallel circuit I can do, but nonetheless whether something better can be done.

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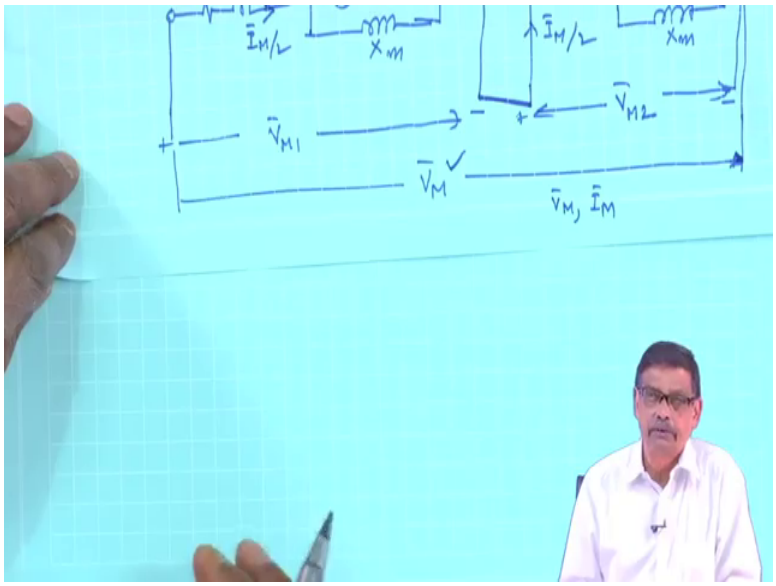

The next step is that I will be knowing this voltage V bar M I will be knowing, I will be knowing I bar M whether this circuit can be translated to that, let us see.

So, can I make this current I bar M by 2, it is now I am going now from machine it has nothing to do with the machine the next step what I am doing. What I am simply telling you have applied the voltage V bar M current is I bar M. What is I bar M by 2? It is equal to this voltage by this whole impedance. Then why not divide all the impedances by factor of 2, same voltage applied then the current will be I bar M.

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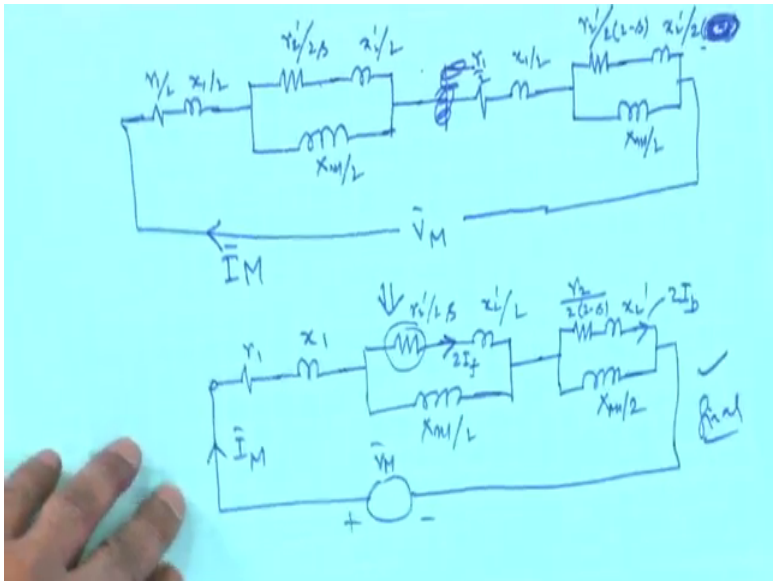

So, divide all the impedances by a factor of 2 and redraw the circuit that is I will do very quickly x 1 by 2, but this is a very important stage and then I will make it r 2 dashed by 2 s, all impedances I will divide by 2, x 2 dashed by 2 this is magnetizing inductance X m by 2 and then once again that backward motor it is connected in series oh. So, there will be another r 1 by 2, another x 1 by 2 and this two parallel branches that is r 2 dashed by 2 into 2 minus s that is what I am doing.

And this is x 2 dashed by 2 into 2 minus s. I have divided all the impedances. No, x 2 dashed by r 2 dashed by 2 s x 2 dashed by, this will be x 2 dashed by 2 and then you have X m by 2 and then you have this voltage V bar M. Now what will be the current in this one? It will be I bar M now because I have simply divided all the impedances by a factor of 2 and then what we will do after this, this r 1 by 2, r 1 by 2 you can combine you get a singular one, you combine, you get a single this one, then this is of course r 2 dashed by 2 s this is x 2 dashed by 2, this is X m by 2 and this is this r 1 2 s by 2 I have taken here and then these are this is r 2 dashed by 2 into 2 minus s and this x 2 dashed. This is X m by 2 and then this is V M and this is I M.

Got the idea? So, this is the thing [FL]. Now you tell me if this current was I f which I indicated and this current I indicated I f I b what will be this current now? It will be twice I f, this will be twice I f and this current will be twice I b backward motor current. Is not? This will be the thing while writing this torque in from this machine what I did, I calculated the air gap power here and the air gap power there and multiplied with I f and I b in fact there are two phases. So, it should be multiplied by 2 and 2, is not? Total torque it was per phase torque, but total torque is this.

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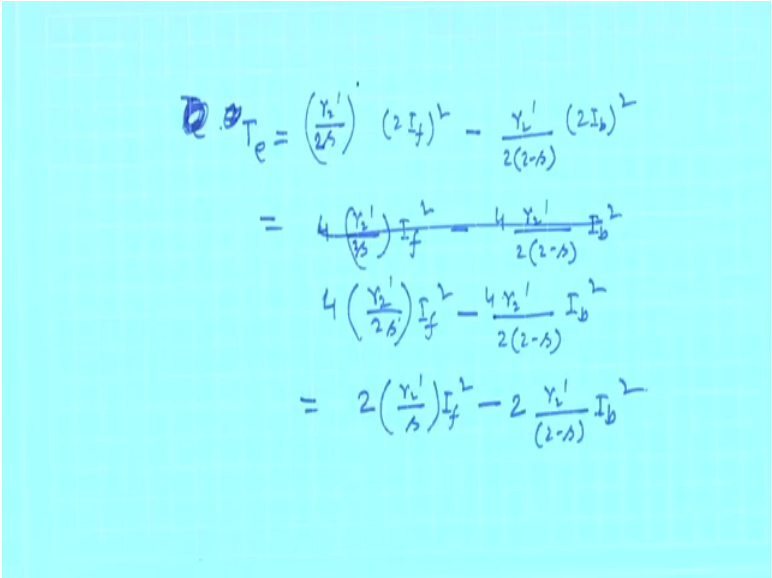

Now, what do I do with this? This one this one if you see I want to calculate torque. So, it will be power in this resistance. So, r 2 dashed by s into this current square 2 I f squared and minus r 2 dashed by 2 into 2 minus s into 2 I b square, but I f I b are this currents mind you in that current in terms of this current I have calculated and this is the thing.

If, you simplify this, if you simplify this it will be 4 r 2 dashed by s into I f square minus 4 r 2 dashed by 2 into 2 minus s into I b square.

Student: r 2 dash by 2 s.

r 2 dash by 2 s and here it is correct. So, I will rewrite because this is an important step. Thank you, r 2 dashed by 2 s. I missed this 2. So, r 2 dashed by 2 s into I f square minus r 2 dashed by 2 into 2 minus s into this 4 into I b square. Is not? And this will be equal to 2 r 2 dashed by s I f square minus 2 r 2 dashed by 2 minus s into I b square. Is that clear? So, I will not first write T e here, I will calculate the power in this new equivalence circuit power in this it has something to do with air gap power, air gap power. So, I have calculated this and then I discovered this is nothing, but the torque calculated earlier. 2 I f square r 2 dashed by s, minus 2 I b square r 2 dashed by 2 minus s.

That is in other words what I am telling this is torque, do not multiply it once again by 2 saying that it is per phase. Why, because the moment you divide all the parameters by 2,

all the resistances has become half and current has become twice. So, power will be twice. Understood, that is an important step. Therefore, the final equivalent circuit if you do that is V M and then your I M, this is the final equivalence circuit. You do it, calculate this current and this current and this current square into r 2 dashed will give you total air gap power taken 2 phase together that is what I am telling, similarly that is there and then this power minus this power by 2. Anyway I will continue in the next class.