Electrical Machines – II
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Lecture – 73
Starting of 1 – Phase Induction Motor (Contd.)

Welcome and we were discussing about single Phase Induction Motor starting. The reason for taking starting case as another sort of topic is because of the fact that single phase induction motor running on single winding cannot have any starting torque. So but, we would like to incorporate this starting torques by having another coil which is called auxiliary coil or a starting coil, in quadrature with the main winding coil.

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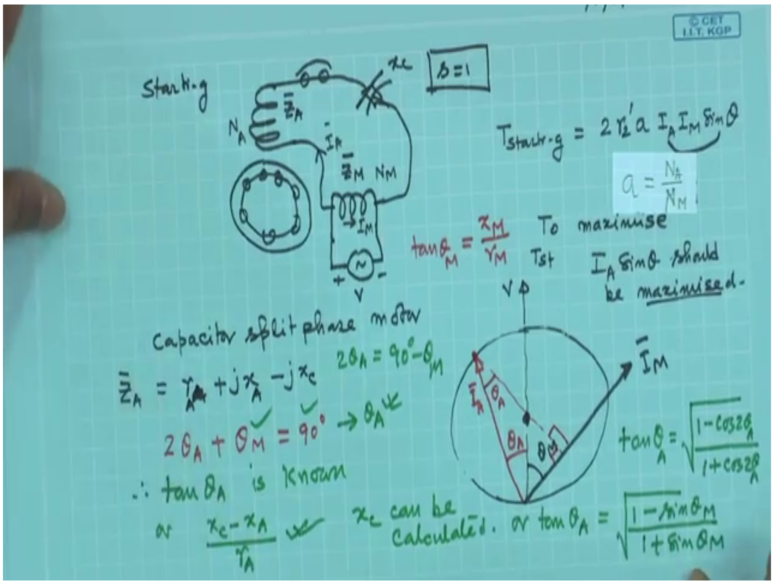

So, starting we were discussing and it was like this. This is my motor and this cage rotor. Single phase induction motor has cage rotor and this is main winding and this is auxiliary or starting winding. Then, we found out an expression.

So, s equal to 1, we are concentrating on, no question of running performance. So, at s equal to 1 we developed that the starting torque will be proportional to in synchronous word as 2 r 2 dash a, a I A I M sin theta. Not like this or what ah? In fact, we derived this and we found that starting torque is proportional to your I A sin theta, that is the most important thing. This is the thing 2 r 2 dash a I M I A sin theta, where a is the ratio of main winding turns is to auxiliary winding turns, N M by N A. Now, the point is that the main winding impedance at s equal to 1, I told it is z M and auxiliary impedance is z A.

And these two will be connected in series and a single phase supply will be connected like this. This was the circuit. This extra element added may be a resistance. In that case, I call a resistor split motor. It could be a capacitive reactance. Then, we will call it as a capacitor split phase induction motor. So, depending upon that so, to maximize hence forth we have done to maximize starting torque; T starting I A sin theta must be maximized, that should be maximized this is the crucial point.

z M we cannot play with because the impedance of the main winding is decided by, from its running performances. Of course, after the machine is started I will connect a switch in series with this auxiliary winding. And it will open up after the machine reaches 70, 80 percent of the synchronous speed. And then, machine will be running on main winding alone. There will be no current. And it will truly run as a single phase induction motor, but to incorporate starting torque we have to do like this. In my last class I was telling you about the capacitor split induction motor. So, capacitor split phase motor.

So, in this case you will connect a capacitor here x c and this current is I A and this current is I M. I did this, but final some formula I did not derive. I will very quickly do it. So, that you get acclimatized with that. So, here the thing is this main winding current and auxiliary winding current. So, the auxiliary winding current locus will be a full circle ok. And it will be something like this. First I draw that thing, circle I draw first and this is your center and this is your supply voltage. And this tip of the locus of phi A will lie on this circle, whether on this side or that side depends upon the nature of the impedance of z A.

z A after you have connected this will become equal to auxiliary winding resistance r A plus j auxiliary winding, inherent reactance, leakage reactance and minus j x c. If x A is greater than x c then the current phasor will be lagging auxiliary winding and it will lie here, but I have suppose connected sufficiently large value of capacitance. So, that this whole thing becomes capacitive then it will be lying here. And main winding current of course, will lag the supply voltage like this main winding current. And this angle is theta M theta M. And to maximize I A sin theta, the tip of the current phasor should lie, you drop a perpendicular through the center here wherever it cuts. This angle is 90 degree.

This will be your I A here. Therefore, the auxiliary winding power factor angle, effective power factor angle is theta A, that will be the thing. And since it is a circle this is center so, this two will be theta A because this two are radius. So, theta A theta A and this is theta M. Then, I told you that from this right angle triangle, this is 90 degree. 2 theta A plus theta M must be equal to 90 degree. So, the thing is 2 theta A plus theta M is equal to 90 degree. What is theta M? Tan theta M, theta M is known because z M is known. It is nothing but, x M by r M, is not? Therefore, at this point I can stop because I will then be able to calculate tan theta A.

And tan theta A is nothing but, x c minus x A by r A. So, tan theta A is known because this is known, this is known, theta A known, theta A known. So, tan theta A is known and tan theta A is nothing but, therefore, tan theta is known or x c minus x A divided by r A auxiliary winding resistance is known. From which x c can be calculated, can be calculated. That is ok, but sometimes people find out a close form expression for x c in this way, just 2 steps that is why I am doing. So, 2 theta A plus theta M is 90 degree.

So, I can say that um, I can write tan theta M tan theta A. I can write it as root over 1 minus cos 2 theta A divided by 1 plus cos 2 theta A because this will give you sin theta A, this will cos theta A. So, it is like this or, tan theta A can be written as 1 minus 2 theta A is 90 minus theta M. So, I put it here so, it become minus sin theta M divided by 1 plus sin theta M, is it not?

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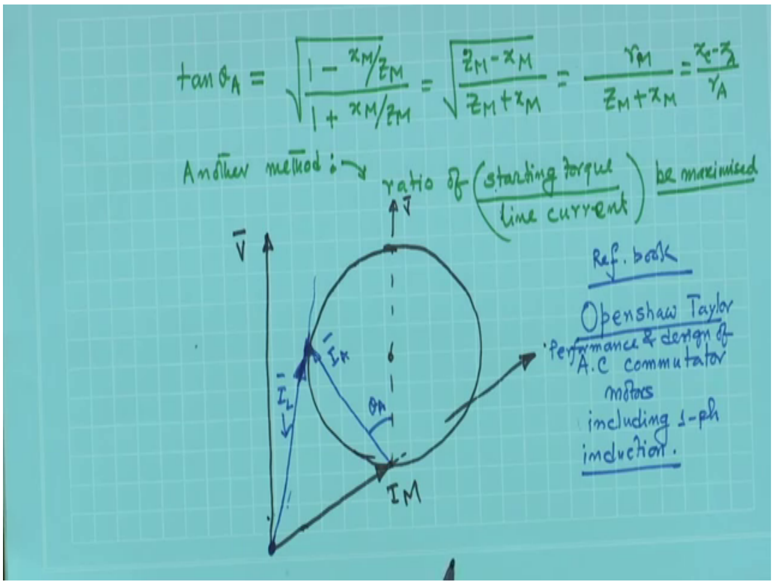

And therefore, your tan theta A will become equal to root over 1 minus sin theta M is nothing, but x M by z M. These are all magnitudes, no complex numbers. Divided by 1 plus x M by z M and if you further simplify you can write it as z M minus x M divided by z M plus x M and so on.

And, further if you multiply this with root over z M plus x M numerator denominator. It will be z M plus x M and this will be simply r M, is it not? Several ways, so, tan theta is known. If you know the main winding parameters from which you can calculate tan theta A and tan theta A do not forget this is nothing but, x c minus x A by r A from which x c can be calculated. Hence, the value of the capacitance can be calculated.

Another method, it is not really maximizing the torque. Capacitor split motor, but the value of the capacitance is selected in such a way that T starting. Another method, that is another condition another liking could be that ok. I will not make this starting torque maximize. What I would like to make is ratio of ratio of starting torque divided by line current this thing be maximized. What does this does this physically mean? That is, I would like to maximize this starting torque is to this current, line current I L.

It means, that every ampere drawn from the supply you are, as if utilizing for improving the starting torque. That is the idea. Here, starting torque alone is not maximized, but ratio of starting torque to line current is maximized. Of course, I will not do the derivations, but the how to calculate this value of x c I will just enumerate. It is also very interesting. It is like this see. Suppose, this is the locus of the auxiliary current and this is suppose your I M.

This line is I M and this is suppose, your supply voltage because I have to show the I M plus I A is your line current. I L is what? I M plus I A, is not? I M plus I A is. So, this is I M and I A will be this way because this is also your voltage axis, I A will be here. So, I M plus I A and this one will be your I L which I am not drawing. Depending upon your capacitance value chosen, your I A could be anywhere, here you will get or here you will get. So, and so far I have told that I will would like to place this I A phasor in such a way that starting torque is maximized. So, it is put in such a way that it is here, drop a perpendicular then I A sin theta will be maximized. This is precisely what we do did earlier.

But, what I want to do now? The starting torque by line current to be maximized, it will be like this. I am not going to prove it, but it will be like this. This line current if you from this point, if you draw a tangent to the circle, wherever the tangent is. From this point you try to draw a tangent. This straight line should become a tangent. Then, that will be the point it can be shown that then, this ratio will be maximized. Are you getting what I am at least trying to tell? And this will be your I L and on this basis I will fix up the position of I A. And then, the ratio of starting torque to this length that will be maximized.

This can also be shown geometrically, which because of time I am not doing it. But, I will certainly give you the reference book from which really I have been handling this starting of induction motor. Reference book you note down, reference book. It is a book by Openshaw Taylor Openshaw Taylor. Title of the book is slightly misleading. It is like this AC commutator motor AC commutator motors. But, here is no commutators in this machine, but it includes single phase induction motor, including single phase induction motor; very famous book including single phase induction motor.

So, for induction motor you can refer to this book ok. Openshaw Taylor is the author. Title of the machine is performance and design of AC commutator machine performance and design of something like this, design of AC commutator motors. Including single phase induction motor is not there in the title, but it includes that. So, you can have a look there. So, what is the last thing I told? That sometimes people opt for, not to maximize this starting torque as it is, but they would like to see current drawn from the supply is also minimum. As well as this ratio you maximize ok. In other case current drawn ok, you get maximum starting torque current drawn will be higher a bit; because position of this auxiliary winding current will be here.

This length will be higher. This is a line current drawn. So, have a look of this also in this particular book. So, one can further go on telling about so many things, but better because time is limited. We will stop discussing single phase induction motor. So, in single phase induction motor if I want to conclude what we have done. We have first found out the, developed the equivalent circuit of a single phase induction motor, which will run on single winding ok. That is what a true single phase induction motor will be. And found out the equivalent circuit. It is similar to that of a three phase induction motor concept. We developed it.

At that time of analysis, we imagined there is another coil is present. Imagined, mind you and that coil is carrying no current, only main winding carrying current. That will be similar to what I am telling a motor running on single winding. Based on that, I broke up the positive sequence and negative sequence currents. And from that we developed the single phase induction motor. Positive sequence currents produce a rotating field moving in one direction, also negative sequence thing produce another rotating field in the opposite direction. And then, once the rotating field is there individually I can draw the equivalent circuit of the machine.

Because, I know what is going to happen just like a three phase induction motor equivalent circuit will be. But, here only two phase is there. So, per phase equivalent circuit all this things we drew. But, I then, we found that from that I found out the torque slip characteristics expression hence performance of the machine. All things can be then found out by drawing the equivalent circuit. And it was shown that rotating magnetic field resultant will not lie on a circle. It will be somewhat like ellipse. Not a very smooth induction motor because of the presence of the backward field. That is why single phase induction motors will be always of, manufactured at small rating, maybe up to 1 kilowatt.

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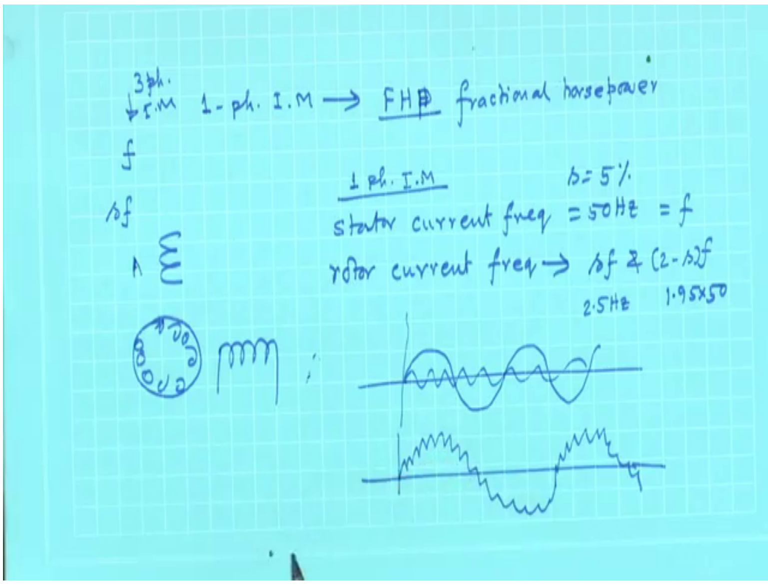

That is why these single phase motors are, also single phase induction motors are also, I will write it on a separate paper single phase induction motor are also called FHP motor;

Fractional Horse Power motor, FHP; Fractional Horse Power motor. Maybe in your fridge it is used, maybe in some water pump in the field it is used where you require very low power because, if you want to make a single phase induction motor of several kilowatts, that backward field causes torque pulsation ok. At this point which I most probably did not tell; one thing I will tell, in single phase induction, see in case of three phase induction motor stator current frequency is f.

And rotor current frequency is s f, three phase induction motor, is not? That is what we have seen. Slip is very small, maybe 5 percent. So, if it is 50 Hertz, rotor current frequency will be purely sinusoidal. And if it is 50 Hertz running with 5 percent slip, the rotor current frequency will be 2.5 Hertz. But, in case of single phase induction motor, this is worth mentioning, single phase induction motor. Stator current frequency is 50 Hertz assuming 50 Hertz is this supply f. Rotor current frequencies, we have 2 components. Suppose, the machine is running at 5 percent slip, one component will be s f. Suppose, s is the slip, rotor current will have 2 components of current. One is s f, another is, and 2 minus s s f, mind you. Suppose, if slip is 5 percent. It will have 2.5 Hertz.

And another is close to 100 Hertz, that is 1.95 into 50, approximately 100 Hertz. Therefore, rotor current will have a 50 Hertz component. If this is 50 Hertz, another high frequency component, 200 Hertz who whose amplitude will be less because induced voltage because of this impedance is higher. So, another current, high frequency current will be there. So, if you can see the oscillogram or in the oscilloscope, the rotor current. It will be somewhat like this. Are you getting? 50 Hertz component is this one, another is about 200 Hertz component, 4 times its frequency.

Therefore, this is what mentioning. And because of that there will be torque pulsation may be there and there will be noise also. A three phase induction motor runs very smoothly, but there will be torque pulsation distance. So, these things must be kept in mind. And single phase induction motors of course, are very widely used and in small power ratings, where you require 700 watt, 800 watt powers, maybe 1 kilowatt, you can do that. And the motors may be capacitor start capacitor run and various category.

But, from economical point of view, single phase induction motor, true single phase induction motor in the running condition should not auxiliary winding should not play any role ok. Only main winding it will run. At the time of starting we take help of that and it is then automatically disconnected. That you must know. Another point, I mean just I am asking you and it is shown like this. This is your motors. And resistors split motors are not very much used. Although, it can be used if you, if you want to economize this starting mechanism.

But, starting torque obtained is not much high. In fact, what happens is this? This auxiliary winding in resistors split motor because auxiliary winding, you know it will be operating briefly. Machine accelerates, 80 percent speed is reached, auxiliary winding gets disconnected from the supply. If that be the case, what is done is, auxiliary winding is wound with thin wires. So that, cost is reduced, is not? Thin wire you use, if you use thin wires, you get 2 advantages. One is, resistance will be higher. Perhaps, resistors split way it can start with respect to main winding.

At the same time, you can after all it will not continuously carrying current, so you can afford to have that high resistance. Knowing fully well, after some time we this fellow will not be there, no power loss extra will take place. It will not hamper efficiency as well. Therefore, auxiliary winding I mean gauge of the wire is thinner compared to main winding wire. Apart from that of course, you can incorporate capacitor split phase way of starting the induction motor, which is very widely used. So, I have included a note. You go through that and also read this book. I mean go through this book together with the note and this book. It is a very famous book. AC commutator motors are nowadays not used.

But, this book also contains a very nice treatment of single phase induction motor. In fact, all this starting mechanism that I have discussed here are found there also. So, please go through that book, as well as see my notes. And whatever tutorial problems will be given, try to solve them ok. With that I somehow conclude this single phase induction motor. Of course, no nothing is exhaustively covered, but I hope it has given you a very basic way of how to treat single phase induction motor which is rather difficult compared to a three phase induction motor. So, read it. Try to have a idea ok.

Thank you.