Electrical Machines – II
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Lecture – 34
Introduction to Induction Motor

Welcome, to this machine course and we are now doing an very important thing that is we are a really now going towards three-phase induction motor and the ground work for that we have already done rather in detail including the windings of a three-phase winding and so on.

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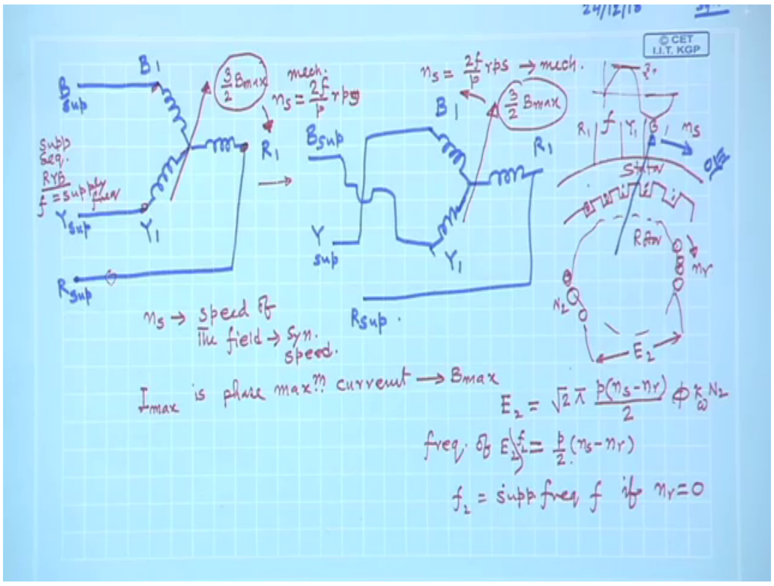

So, recall that the interesting part of a rotating field created by balance three-phase current is this that the windings are stationary. But if the windings are excited by three-phase supplying it will produce a rotating magnetic field and this is the thing we should always keeping mind and suppose, this is R 1, this is Y 1 and this is B 1 which are mutually apart and if you connect it to supply R s, supply Y s and supply B s this is supply sup supply RYB then the result is that a rotating magnetic field and this sequence supply sequence is RYB supply sequence.

Then, what happens is this a rotating magnetic field will be develop whose peak value will be 3 by 2 B max, this is the peak value and it will rotate in this case this way because from leading to lagging phase it rotates, 3 by 2 B max. If the same thing same machine if you do it like this suppose the winding I am not disturbing whatever it is their it was marked R 1, Y 1, B 1, but what you have done is this R supply you have connected like the previous one, but this Y supply you have connected to the B of this Y supply and B supply you have connected it here and then also a rotating magnetic field will be developed whose strength will be 3 by 2 B max and this one will rotate this way and it will be rotating with respect to the coil, so, with respect to the structure which houses the coil.

Now, what is the value of the speed? The value of the speed is 2 f by p, so much of rps and its speed also is 2 f by p so much of rps and these are mechanical speed mechanical speed mechanical this speed we commonly understand. So, this is the thing. Of course, the electrical speed is always f rps. What is f? f is the supply frequency is the supply frequency. So, by interchanging two supply terminals the rotating field direction of rotation of the field may be reversed if you wish. So, this is how things are done.

And, this speed is written n s because it depends upon supply frequency which is constant and this called synchronous speed. So, n s is the speed of the field is called synchronous speed clear [FL] one in interesting thing and what is this B max? Remember, if I max is the phase maximum current because sinusoidal current they will draw phase maximum current corresponding to that I max whatever is B max that is B max that you should remember [FL].

Now, one important thing I we tell which is important thing distance that it suppose I tell you right at this time it is rotating after all; in one of the case you consider, suppose this one it is rotating right now where is that resultant field, ok. I cannot see that resultant field nothing, but about one thing I am pretty sure that you that is what I am trying to tell. What is that thing? If right at this point of time the this currents I can see in the oscilloscope if the R-phase current is maximum value I max then I am sure the resultant field will be along the x-axis that is what I want to tell.

Similarly, when the Y phase current will be maximum at whatever time at that time you can be pretty sure that your resultant field of strength 3 by 2 B max will be along Y phase axis and so on. At least about those three points I can say about those three instants at whatever instant if you will find R phase current is maximum, resultant field will be horizontal; otherwise if Y phase current is maximum it will be like this and it will be like that, but in any case it is rotating.

Now, imagine that this winding is lying on the on a stator structure, like this there was lots I will not symbolically I am drawing it is like this and this is stator iron. This is stator and it houses three-phase balanced winding like this and from this three terminals come out that we are calling R 1, Y 1, B 1 machine terminals and to which I have connected this supply. This supply was connected here and the result is a rotating magnetic field a field pattern, and that is moving.

So, simple way to show it by a line and moving either this way suppose phase sequence is RYB it is moving like this. And, it is moving with respect to whom? With respect to this structure, that is stator. Stator does not move, it is well grouted to the ground it is not allowed to move. Therefore, with respect to that stator structure therefore, with respect to anything which is not moving. So, I can pretty well say with respect to a stationary observer also; stator and stationary observer R 1 and the same thing. So, it will be moving like this.

Then if it is a magnetic field moving sinusoidal magnetic field then I we discussed about one very interesting problem that is supposed on the rotor on the rotor of the machine I have a coil which may be also distributed suppose single phase coil like this distributed this is on the rotor. As this fellow moves and suppose rotar is not allowed to move it is held by hand, then across the two terminals of the rotor there will be induced voltage produced.

In general case this is the rotating field speed is n s and suppose also rotor is moving n r, by suppose some external agency is also running this fellow mechanical speed n r; n s, n r are mechanical speed suppose and rotor is also allowed to move. In that case there will be a voltage induced in the rotor coil how much will be that voltage? That voltage will be root 2 pi frequency; frequency will be decided by the relative speed n s minus n r by 2, if it is rotating in the same direction n r is less than n s suppose, so, it will be this. Then flux per pole how to calculate flux per pole? 3 by 2 B max it is a sum sinusoidal like this, this is 3 by 2 B max.

So, 4 by p that 3 by 2 B max l R will be the flux per pole this is the relative speed between these two. Into the effective number of turns of this distributed coils which will be K w into N 2; suppose the N 2 is the number of turns total number of turns, physical number of turns is a N 2 it gets reduced by a factor of winding factor we know how to calculate K w which is nothing, but K d into K p ok. So, this will be the expression of the induced voltage across this coil rms value of the voltage. This will be the induced voltage. n s, n r are in mechanical rps that is why I have to multiplied by p by 2 and the frequency of E 2 will be equal to p by 2 n s minus n r frequency of E 2 that is say f 2 is equal to p by 2 n s minus n r. So, frequency of the voltage will be this one.

Therefore, we see that your supply frequency was f, but the frequency of the induced voltage in this coil will be p by 2 n s minus n r. If n r happens to be 0, that is suppose you do not allow the rotor to rotate then of course, this will be f 2 will be equal to supply frequency f if n r equal to 0, that is true, but if it is not then the frequency of the induced voltage here will be 0.

See we have looked at transformer. You energize the primary winding with frequency f the induced voltage in the secondary will be of same frequency, but here if you a regard this stator coils to be your primary where you are connecting supply and rotor coils to be your secondary, we immediately notice that if rotor rotates then the frequency of rotor voltages and applied voltage on the stator, this two will be different. In fact, the rotor frequency will be reduced by factor of I mean n s minus n r will decide what will be the frequency of the rotor induced voltage.

So, this is the basic idea that will further buildup, but I hope this point should be absolutely cleared what you add. (Refer Time: 13:48) And also it should be noted therefore, I can now draw this diagram in a much more straight forward manner symbolically I will draw, ok.

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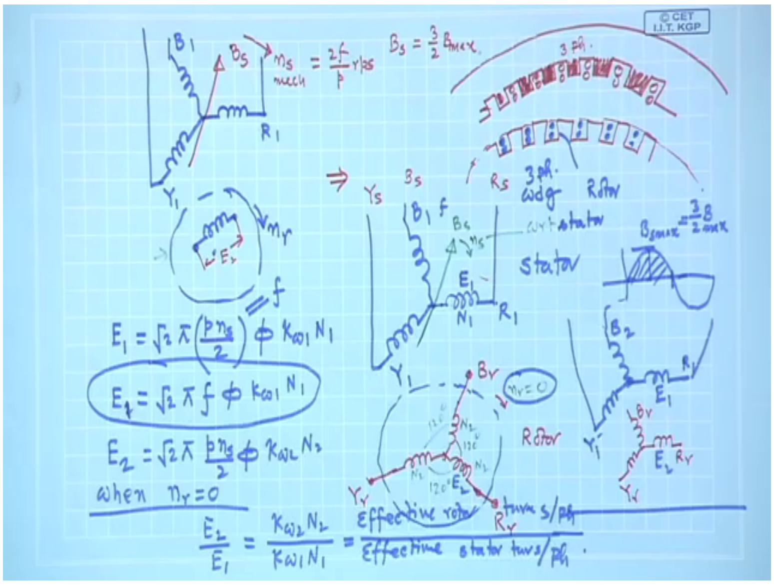

This is your stator and because I am now under should what is going on. So, I will draw the stator coils like this I will connected it to the supply and in the rotor I have a coil I will just show it like this rotor coils and it is rotor I will indicate by putting a circle around it and rotor is moving something like that with a speed say n r and stator field which I will just call B s which is this strength of peak value of this one is 3 by 2 B max.

So, B s suppose let us also simplify that I will write it like this and it is suppose rotating in this direction with mechanical speed mechanical is equal to 2 f by p so much rps multiply by 60 you will get rpm. So, will just simply draw like this and then I was telling what will be the induced voltage here when n r equal to 0.

Obviously, you can easily see if suppose it so happens you are driving the rotor such that n r equal to n s, then no relative speed exist between the coil and the field. So, induced voltage is to be 0; that is what is taken care of by this turn it will be 0. However, the movement there is a relative speed existing between the field and the field which is moving and the rotor, which is also driven as I have told you by some external agency there will be mount to be some induced voltage in this one.

Now, the second thing what I am telling you listen carefully; that is suppose in this rotor at least let me draw this is suppose stator and this stator iron and what I told there are coils or coil size in each slots you know. I am drawing totally wrong. It should be here is not these are slots in this slots the conductors are there the inner surface this is slot this is slot this is slot and here you place the conductors slot here you place like that three-phase balanced winding is around the stator now similarly on the and three-phase winding three-phase.

Similarly, on the rotor which is separated from the stator by the air gap LG etcetera rotor too will have suppose slots and teeth and their also suppose these are the slots I have placed rotor conductors which is also a three-phase coil. So, this is rotor and three-phase winding is also wound on the rotor three-phase winding. So, instead of a single coil on the rotor I will now have a balanced three-phase winding also on the rotor just similar to that of stator and such a scenario can be simplified in its representation in this way I will draw it like this, this is my stator R 1, Y 1 and B 1. Suppose rotor this is stator coil this part is stator and rotor part also it is a three phase distributed coil.

So, this can be also represented as sum R phase Y phase and B phase and suppose this rotor terminals this let me call R r this is Y r and this is B r like this. So, this is the rotor three-phase winding which is also balanced and three-phase time. So, this is the rotor part rotor part and it can be rotated externally or maybe it will rotate on its own when you energize the stator we will see that, but the point is that the sick and suppose the rotor terminals are kept open circuited. What is going to happen?

With rotor terminals open circuited and stator supplies from supply R s supply B s and supply Y s. We know a rotating magnetic field will result teach will be like this B s and it will move in this direction provides phase sequence is RYB it will moves with a speed n s and now it will move in this direction, so that instead of a single coil as in the previous example we have three coils which are separated by 120 degree electrical apart. Therefore, if each coil will become a seat of emf and since it is balanced winding number of turns of this secondary coils are suppose N 2, N 2, N 2 per phase then there will be induced voltage in this coil, in this coil, in this coil and rms values is expected to remain same, why it should change?

All the thing what will change is that, whatever happening is happening now to the R phase coil is going to happen to the Y phase after 120 degree. Because you know maximum flux linkage occurred with R phase when the field is here and that maximum flux linkage will occur to B phase when this B s I am showing it will be here. So, the phase difference of the induced voltage in the Y phase will be lagging by 120 degree similarly the induced voltage in B phase will be maximum after 120 degree Y phase has a got the maximum value. So, there will be once again balance three-phase voltage induced in each of the coil. And, suppose the rotor speed is 0 because it is open circuited and there is no prime over connected nothing; you have simply energize this, this will be the thing [FL].

Let us not forget another thing that as this rotating field moves it is moving with respect to whom always right with respect to stator these n s's and you are sitting in the R phase. You will immediately see that as this field moves in this R phase coil there will be induced voltage because of B s. Similarly there will be induced voltage on the stator Y phase and stator B phase as there is there are induced voltages in R r, Y r and B r in the rotor phases. Similarly why not there will be induced voltage in this coil and what will be the magnitude of that induced voltage.

Suppose, I say the voltage induced per phase in this stator coils rms value is E 1 it should be root 2 pi p n s by 2 because stator is of course, always stationery. So, relative speed between the coil and the field is n s. So, p n s by 2 flux per pole and winding factor on the of this stator into n 1. What is N 1? N 1 is the number of turns of this n r equal to 0 and this is nothing, but root 2 pi p n s by 2 is nothing, but supply frequency f. So, it can be written as root 2 pi f phi K w 1 N 1 and what is phi? Phi is the flux per pole of B s; B s if it is I am drawing like this, do not forget this B s maximum is nothing, but 3 by 2 B maximum. This you should never forget. What is B max? When that phase carry is I max current whatever is B max.

So, do, I can calculate the flux per pole what is the area this that 4 by p etcetera. So, so this is E 1. Similarly E 2 per phase voltage in the rms value of the per phase voltage will be root 2 pi p, since n r equal to 0, p n s by 2 same flux per pole it has not changed into K w 2 into N 2. What is K w 1? K w 1 is the winding factor of the stator windings and K w 2 is the winding factor of the rotor winding.

Therefore, when n r equal to 0 when n r equal to 0, you can easily see that E 2 by E 1 will be equal to K w 2 n 2 by K w 1 n 1 almost like a transformer it was n 2 by n 1, but it is now. So, this K w into n 2 is called effective rotor turns per phase effective turns effective rotor turns divided by effective stator turns per phase here also per phase. So, it is almost like a transformer. What is the frequency supply? f. What is the frequency of this secondary coil? f.

So, it is almost like a transformer why almost it is a transformer it looks like you can step proper step down the voltages having same frequency. But, only problem is I do not now at what is going to happen if the secondary winding also starts carrying current whether it will remain same in its operation like a transformer or it may differ. Earlier what people used to do there was one machine called that is the rotor of such setup with a stator winding and rotor winding and the it is not used as a motor, but what it does is, you can move this by hand where the angles will be calibrated and lock the rotor, so that it does not move, understood? It will be it is not allowed to move.

And, if it is not allowed to move, I am pretty sure that the stator frequency, supply frequency and rotor frequency has to be same because n r in any case I am forcing the rotor also to remain stationary by locking it mechanically. In that case what you can do is this suppose the idea is very simple. This is your stator coils and rotor can be moved by hand before you energize it. Suppose, I could place the router in this way R r is here, Y r is here and B r is here that is I align the stator R phase and rotor R phase stator Y phase and rotor Y phase and rotor B phase like that then I energize this three with a balance three-phase supply and the rotor is not allowed to move.

In that case what will happen this induced voltages will that is the R phase voltage applied here and R phase voltages obtained here in the if you love to call it secondary they will be in phase. In transformer it is always stator applied voltage per phase and corresponding rotor induced voltage per phase were in phase time phase, but here since I have this probation I can move this rotor by hand and then lock it. So, in one position I do it like this. So, this E 2 and E 1 they will be in phase.

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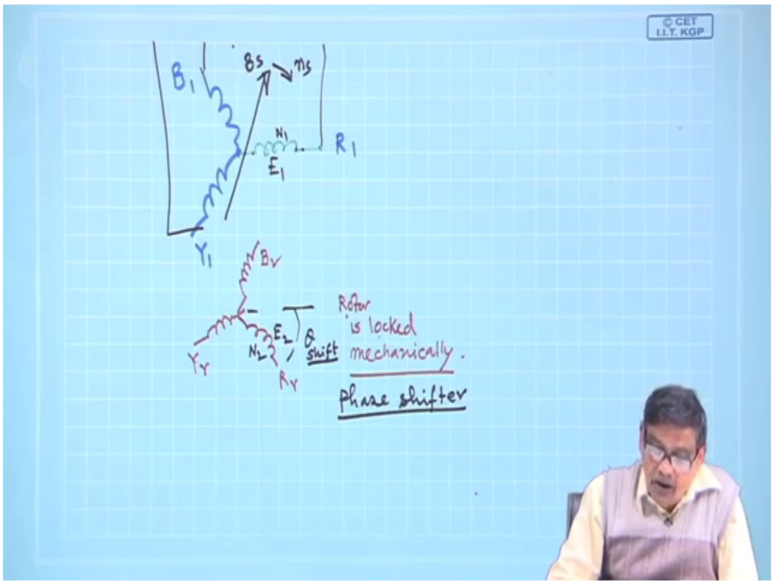

However, if I if I make this, this is suppose stator R 1, Y 1, B 1 and rotor I will move it suppose in this position I keep it. So, rotor is moved and then locked it is not allowed to moved that is what I will always maintain. It will be something like this, this is R r, this is Y r and this is B r, rotor not allowed to move rotor is locked mechanically and you energize this with a three-phase supply has usual this, this, this result is a rotating magnetic field B s, it moves in this direction sequence is RYB and then it will induce voltage.

Obviously, you can see the R phase induced voltage here E 1 and R phase induced voltage here in the rotor this voltage will lag this voltage by this angle theta, is not? Theta is the angle by you have shifted. Therefore, with this arrangement if you say this is called a phase shifter.

Suppose there is a input three-phase voltage for some reason or other you want to get once again balance three-phase voltage and phase shifted with respected to the actual supply voltage by say 30 degree or by say 90 degree, whatever you want if this shift there is calibrated dial it will be there, you shifted physically you are rotating it and they initially the manufacturer will say because after all from outside I can I there can see R phase of the stator, nor the R phase of this rotor they will calibrated.

In fact, it can be done easily even if it is not mark whether I have aligned I will see where this two voltages R in phase, then I will say R phase and this R phase R coinciding otherwise not.

So, that way you calibrate. So, it is called a phase shifter. This was used like this fish phase shifter you can get a desired phase shifter. And also not only that if you choose n 1, n 2 differently you can not only have a phase shift of this voltage, but also a level change of voltage like a transformer. In a transformer say single phase transformer each phase winding voltages are in time phase, but here it is not. You can phase shift that input voltage by whatever angle you desire and also the magnitude can be manipulated if you manipulate n 1 and n 2 if it is so necessary.

But, in any case this is not design for rotations you lock it. Of course, we are not sure whether if this lock is removed, whether this fellow will start rotating or not that is also we have not at learn. In fact, you will show that if current flows in the rotor windings because after all a this phase shifted voltage will be connected to some load know, this windings will carry current and it will hap it must produce it is own field and this two fields may interact and give you torque. But, let that torque be developed, but I will also force the rotor not to rotate that is what the whole idea is. There will be mechanical stresses by which you are locking this rotor because of this torque produced hopefully it will produce a torque.

So, whenever balance three-phase current will be flowing. When it will be flowing? When you load it for some purpose we have change the level of voltage and phase shifted with respect to the supply voltage, then it is to be connected to some load. The movement you connect load like a transformers secondary you are loading currents will be flowing and balance three-phase load you have connected, let us hope.

Balance three-phase current will flow and the movement it carries balance three-phase current oh very nice things happens, then this fellow too will produce a rotating magnetic field and this we will discuss in my next lectures.

Thank you.