Electrical Machines - II
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Lecture – 33
Synchronous Speed and How to Calculate Induced Voltage in a Coil

Welcome to this next lecture and we are discussing one of the most important and also exciting topic that is the generation of rotating magnetic field.

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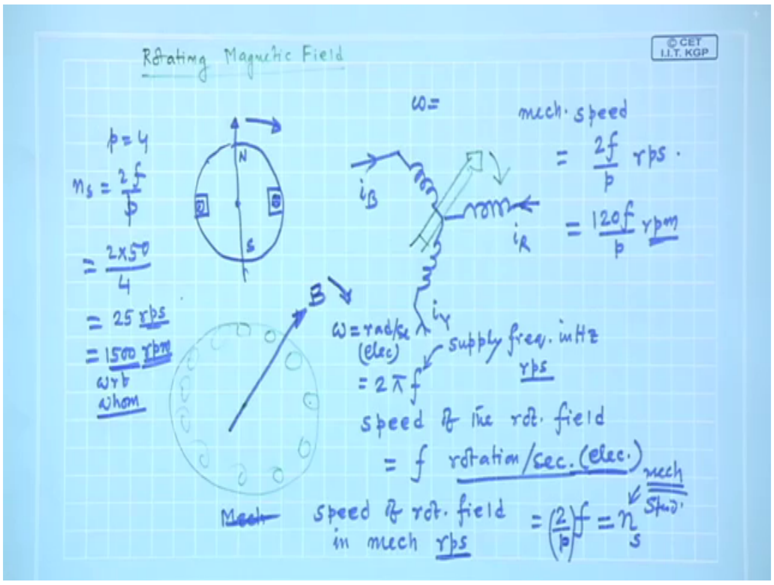

You, I have note that I have used it on exciting why it is let me clarify you. Suppose somebody comes to me and to average people and say that I want to produce a rotating magnetic field. If before Nikola Tesla people would have suggested you do like this you take a say something like cylinder have 2 slots I mean minimum thing you do, put a coil, pass some DC current and it will produce a field in this direction and if you keep it just like this it will be a stationery sinusoidal field. If you neglect harmonics and then you rotate it by some external means that is by a prime mover and you have created a rotating magnetic field this is North this is South and it will rotate that is all.

Because before Nikola Tesla there was no concept of AC supply, it was all DC and people would have created a rotating magnetic field by passing some DC current through the coils and would have told that you now move it by some external means.

Now here comes Nikola Tesla he tells that is a rotating magnetic field no doubt, but I am now telling you an idea by which you can create a rotating field without moving anything that is the most important point and he told that you have a polyphase winding and for that I need these things that is what his requirement. On pen and paper, you he calculated all these things this is how you can create a rotating field.

He demanded that if a balanced polyphase winding is met mind you 3 phase is a polyphase winding, balance 3 phase winding is there and if you have a balanced polyphase supply that is 3 phase suppose and if you excite and these coils are stationary on these slots nothing you do not move anything, you do not ask for any prime mover or things like that only thing he is asking that then you pass some balance 3 phase currents through these 3 coils iR iY and iB.

If you pass then you have created a rotating magnetic field just like this equivalent to this and it will move field will move coils are stationary. So, a average people will give you this solution, but it was left to Nikola Tesla who first told you can create a rotating field like this with the help of stationary coils. Coils need not be moved to create a rotating field coils may be stationary you create that field that is all.

And you know by this time that in fact Faradays laws were discovered in 1830 or so and it was a lone battle fought by Nikola Tesla and ultimately in 1880 or so he succeeded ah, I mean after a long time he started he was telling that if AC supply is there and not only AC supply if balanced polyphase AC supply is available, then he can construct a much simpler motor in construction and that was Induction motor. So, to produce Induction motor he came up with all these ideas and you know after that it was all history that is it is now all 3 phase supply we are using and we are using 75 percent or 70 to 75 percent of the motors to be induction motors that was also his invention.

So, he that is the very nice thing I mean to create a rotating magnetic field you do not require any thing to be rotated, even if the coil is stationary just pass 3 phase current then with respect to this structure which houses the coil the rotating field will be produced.

What do I mean by that that is suppose you have a balance 3 phase winding here I will just show now like this no point in drawing slots this that balance 3 phase winding, suppose this field this fellow can be rotated there are R Y B phase coils pass 3 phase current and suppose this fellow can be rotated also mechanically, but it is stationary now.

You pass 3 phase current, no and a rotating field will be produced B and you can make it rotate either this way or that way depending upon the phase sequence of the supply that also we have discussed.

So, suppose it is rotating in the clockwise direction, now whenever you say that something is rotating 2 things must be very clearly specified, one thing is what is it is speed and in which direction it is rotating. Of course, in rotation here it can be either clockwise or anticlockwise and the direction method is already clear to me it is depends upon the phase sequence of the supply. So, either clockwise or anticlockwise you can make it move suppose it is moving in the clockwise direction.

Now the big question is what is the speed of this rotating field, strength of the field we have seen it is constant how much it is 3 by 2 into b max what is B max, B max is the maximum value of flux density of a particular phase when it carries I max current, each phase carries I max current, but not simultaneously at regular interval of 120 degree they will carry.

Therefore, this is the thing now what is the speed we have seen that the speed is nothing thing but omega radian per second and do not forget to write electrical and what is omega? Omega is nothing but the supply frequency 3 phase supply of omega that is why the currents were omega t cos omega t cos omega t minus 120 etcetera. Therefore omega is equal to 2 pie f, where f is the supply frequency in hertz means what in rps Hertz and rps are one and the same thing rotations per second.

so this is in rps therefore I can say this speed of the rotating field is f rotations per second that is all and this is electrical speed electrical speed. Therefore, you take a 4 pole induction motor 6 pole induction motor 2 pole induction motor, if you say that the speed of the rotating field is 50 rps electrical that is same for all electrical speed is same for all. Now but as you know the speed we want to talk realistic speed that is the speed which can be measured with some mechanical means or the mechanical speed theta by t is the speed mechanical speed.

So, what will be mechanical speed of what speed of the resultant field, so resultant time will not be use anymore it is understood that speed of the rotating speed in mechanical r p s. What should I do with this f with which should I multiply this if I want to calculate mechanical speed this is electrical speed, so I must multiply with this factor 2 by p and this is generally denoted by this letter ns.

The significance of S I am going to tell right now. But the mechanical speed is equal to 2 f by p where p is the number of poles in rps and some people write it like this 120 f by p so much rpm this is one and the same thing you must understand. So, so this is the mechanical speed.

Suppose you have a 2 pole winding then the speed of the rotating field will be 50 rps electrical, 2 pole machine electrical mechanical no distinction p equal to 2 cancels out so 50 rps or 3000 rpm multiply with 60. Similarly if it is a 4 pole machine electrical speed of the field in electrical rotation per second is f, but mechanical speed for a 4 pole machine will be multiplied 25 rps it will become 50 for 4 pole, if p is equal to 4 ns which is equal to 2 f by p and p in our country it is 50, so 2 into 50 by 4 so it is equal to 25 rps Mechanical speed.

So, ns I will reserve for mechanical speed hence forth mechanical speed and 25 rps is nothing but you multiply by 60 it is 1500 rpm because that speed we understand ok. It was a then after mechanical speed is it is making 1500 rotations per minute that is the meaning of that. So, when we talk about that something is moving or rotating as I told you 2 things are important directions, directions we know and what is the magnitude of the speed that is 1500 rpm or whatever it is that is there. Another important thing is that we must follow here so for suppose we say car speed of a car is 60 kilometer per hour.

We of course, go on do not go on telling that it is with respective to a stationary observer it is understood ok, somebody is stationary with respect to whom it is moving 60 rpm a train is moving at 250 kilometer per hour, it is with respect to a stationary observer. Now in this case similarly while talking about the speed of the rotating field do not forget to mention with respect to whom with respect to whom, the speed you are telling 1500 with respect to whom it is moving that this I am writing you also write it down this is very important that speed 2 f by p the mechanical speed or electrical speed which is s.

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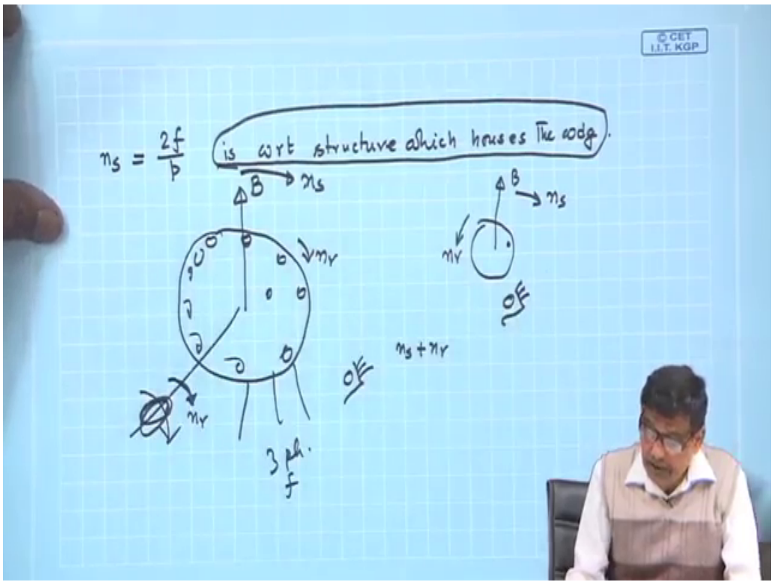

This speed is with respect to the structure which houses the winding this is very important. What is the meaning of that suppose you have a balanced 3 phase winding here and it is on the rotor this fellow can move by some external means you can move it. Suppose you are not moving it this coils you have energized with 3 phase supply, you know a rotating field results B resultant and it moves suppose in this direction with ns.

Now, this n s is with respect to the coils or stationary structure which houses the coil. Now what is the meaning of that meaning is that if somebody is sitting on the rotor he will conclude that on the structure with respect to him it is ns. But you note down that on this rotor I now impose another velocity which is by mechanical means I am also turning the rotor the this body rotor body houses the 3 phase winding and it is energized from f p h supply of frequency f, then I know that is a rotating magnetic field of constant strength and it is mechanical speed is this much and suppose moving in the clockwise direction that is fine.

Now, on the top of it if I move it with a speed say nr another speed, then a stationary observer will conclude that the speed of this field is if it is turned in the same direction, a stationary observer will say the speed of this field is ns plus nr this must be understood. Similarly if the this fellow rotor is moved in the opposite direction this way nr and this is your field which is moving already in ns with respect to whom with respect to the rotor.

Then the stationary observer in this case will conclude that the field is moving with a speed ns minus nr.

Therefore this term is very important that this speed is with respect to the structure which houses the winding. If the structure itself is also moving by some external means mechanically, then a stationary observer will differ he will say if somebody sitting on this rotor he will always say it is moving with ns that is fine absolutely.

But somebody outside observers standing on the feet and suppose let us imagine he can see the lines of forces, then he will conclude that that field is moving with ns plus nr or ns minus nr depending upon whether rotor itself is moving in the same direction or not. So, these 2 things must be very clearly understood and this will be often used in the induction motor.

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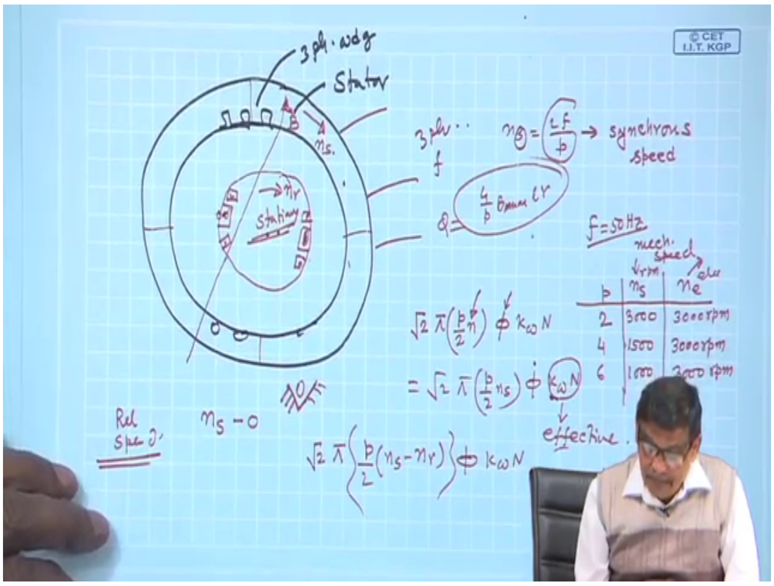

Now before I go to the induction motor let us do some simple exercises. For example, I have a machine I have a machine where they were slots on the stator this is stator it does not moves all around slots are there conductions are there 3 phase winding.

This I you please allow me to draw like this it is a inner surface 3 phase winding and I have planned to energize this by a 50 Hertz source 3 terminals will come out from this windings, 3 phase source we have connected consequences I am telling on switch on this supply and what you will see that a field pattern North South North South if it is 4 pole is created and that fellow is moving in space. Rotating field means that if it is 4 pole machine 1 quarter I know North pole another quarter South pole another quarter North pole, if you pass DC current they will remain stationary.

If you pass balance 3 phase current it will start moving and at what speed it will move that is ns 2 f by p mechanical speed will be ns it is moving and why this turn s that also let me tell you this a language they said this is called the synchronous speed. The speed of the rotating field when it is connected to a 3 phase supply of frequency f it is called synchronous speed, because it is in synchronization with the supply frequency.

Number of poles is machine thing, but essentially for a given machine supply frequency decides what is the value of this synchronous speed, as I told you if you make a table that is speed and ns mechanical speed and also suppose I make a table electrical speed ne, I will say if it is 2 pole and supply frequency is 50 Hertz this table is what memorizing I mean and also it is easy.

2 pole in rpm if I write it will be 3000 r p m, this will be also 3000 rpm electrical speed, 4 pole it will be 1500 rpm mechanical speed electrical speed it will still remain 3000 rpm understood, 6 pole it is 1000 rpm you calculate from this and this will remain 3000. So, electrical speed in electrical degree they are all one and the same mechanical speeds are different.

So, what I was telling so you have connected this stator and you have energized it and these I will indicate by some line and write that resultant field depending upon phase sequence it is moving and it is moving with this speeds ns direction I can decide and suppose it is moving in the clockwise direction, so B pattern will be moving that is all.

Now what I do in the rotor I have a coil and rotor is stationary rotor I will not run. It is stationary stator is a coil nothing is moving in this scenario in this case and you create a rotating magnetic field. Now as this rotating magnetic field is existing therefore there is bound to be induced voltage here in the coils because, flux linkage or each conductor comes under North pole South pole B is there all these we now know.

Now, the question is what will be the magnitude of the voltage I want to calculate in this rotor coils. You know the magnitude of the voltage in a coil is rms value of voltage is root 2 pi p by 2 into n root 2 pi phi and k w into N. Because this winding these coils may be distributed I do not know suppose single phase coil distributed coil it is stationary, so I want to calculate what will be the induced voltage because of this B, then what should I do I will ask what is the number of turns of these.

What is it k d, what is it is k p k w; you calculate. Then what is this phi? Phi is the flux per pole. So, for this stator field what is the flux purpose that also I can calculate if it is a p polar machine and if the peak of this B is B max. So, 4 by B max l r I will calculate that is how it is to be calculated flux per pole produced by this stator and this coil is open circuited I want to know what is the induced voltage generated.

There is induced voltage across any coil if it has a relative velocity with respect to some field and here this coil is stationary this fellow is moving. In this case there is nothing mechanically moving, so 3 phase supply rotating magnetic field coils are stationary. This fellow is also stationary I have not allowed it to move it is held therefore, flux linkage changes there is supposed to be induced voltage and what will be the induced voltage we have found out earlier root 2 pi f phi k w N.

Now what is the n, this n is the relative speed mechanical relative speed between this and this, if this is stationary this is n s mechanical speed therefore relative speed is n s minus 0 that will be the relative speed. But in this expression I must convert it to electrical, so it will be root 2 pi p by 2 n s phi k w N what is n? n is the number of turns k w N is sometimes called the effective number of turns because of the distribution and peak factor of the coil this actual number of turns is reduced that way also people think or take the physically count the number of turns multiply with k w phi is the flux per pole because of B s.

Therefore, I will be in a position to calculate induced voltage in a coil, on the top of it if I say if this router is also moving in the same direction and with respect to stationary observer stationary observer says, the speed of the field is ns speed of the rotor is nr all are mechanical speed it is moving that is what a stationary observer conclude and he wants to calculate what will be the induced voltage he wants to know. Then what you should write root 2 pi this thing which will cause this voltage is the relative speed, if they are moving in the same direction it should be p by 2 ns minus nr this is the star flux per pole k w into N.

If suppose the rotor is rotated in opposite direction as that of the field, then the magnitude of the voltage will be root 2 pi p by 2 n s plus nr that is calculate the relative speed between this and the field, where the coil is there coils sees what? If the field is moving in the opposite direction as the router rotation then relative speed is high. So, you would expect higher voltage to be induced is not.

Therefore, these are the things you please go through it very carefully and always remember while specifying the speed of a rotating magnetic field it is a good practice to always write down ok, this is with respect to this fellow or that. In general this p w rotating field depends upon supply frequency which is 2 f by p and it is with respect to this structure which houses the winding thank you. So, much this is important lecture please go through it.