Electrical Machines - II

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Lecture – 74

Synchronous Machine Construction

Welcome to the next lecture on Electrical Machines II and today we will start the last topic that is Synchronous Machines.

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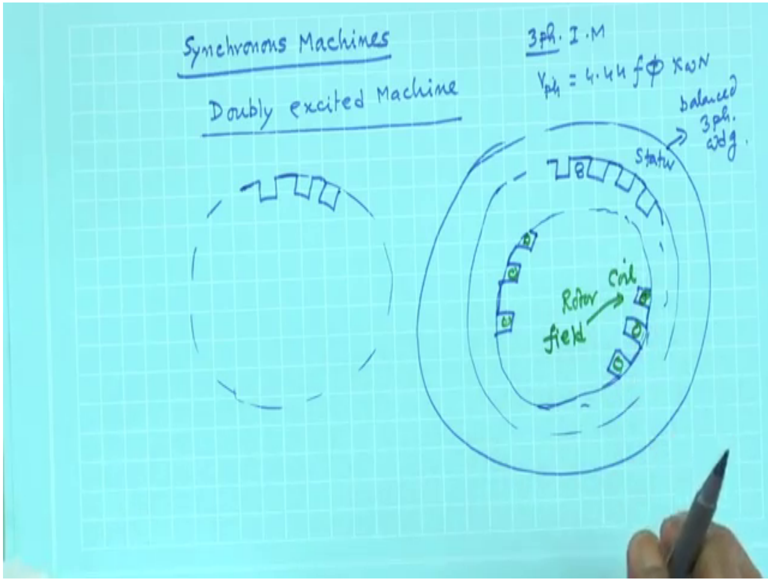

Synchronous machine we will see later that equivalent circuit is much simpler and I mean somewhat easier to analyze, but you must be conceptually very clear. But because so, many interesting thing happens inside the machine; see in case of induction motor when 3 phase induction motor you energize this data, rotor there is no supply required. So, 3 phase induction motor are called singly excited motor. So, whatever magnetizing current is needed it is drawn from the supply itself X M I M those things.

And motor runs and we showed also that, that the net field b net that will remain constant from no load to full load because, the supply voltage in 3 phase induction motor. We have seen that phase voltage phase is equal to 4.44 f flux per pole into K w into N is not that was the thing. So, the moment V phase and supply frequency is fixed level of flux in the machine is fixed. This phi is flux per pole because, of b net we have seen that; in case of induction and it is from the supply side this condition is put. And, in between the supply and the machine coils that machine impedance will be r a and r 1 and x al leakage reactance and resistance per phase on this stator.

And we develop the equivalent circuit, in synchronous machine it will be slightly difficult because, difficult [FL] supply voltage and frequency is fixed. But, we will show you the flux net flux in the machine air gap flux may change, if you do something else. First of all synchronous machine is a doubly excited machine, doubly excited machine. It can operate once again both as a motor and as a generator, we will first take up generator case. So, doubly excited machine; what happens is this on the stator you have a 3 phase distributed winding ok. So, I will just draw now you know what it is I will not draw for all. So, like that sorry stator so, stator is this one. So, here will be the slot and teeth like that, you have a double layer distributed 3 phase winding on this stator, here stator.

On the rotor so, stator is a balanced 3 phase winding balanced 3 phase winding, double layer or whatever it is. Rotor is like this cylindrical structure is there rotor, where you can have some slot and teeth like this on this side also. I mean forgive me for this bad diagram, but it is like this it is no 3 phase winding. What is done simply you take a piece of where, go there at the back you come out, once again go to the next come out. I mean I am sorry it will it does not matter, it goes there comes; like this simple winding no question of 3 phase. And, then this is a rotor, this rotor winding you will connect DC excitation DC current so, and this is called field coil.

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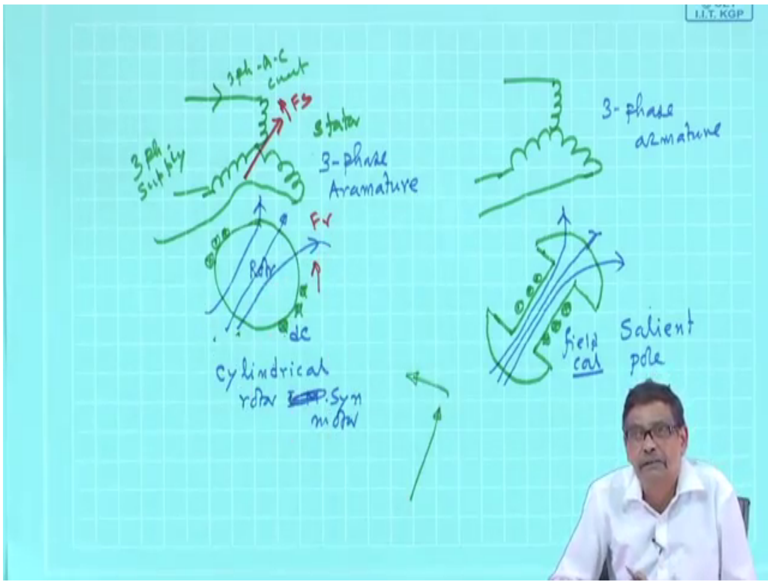

Therefore, symbolically it will look like on the stator you will have a 3 phase winding and on the rotor you pass DC current, say cross this is dot. So, that it will become lines of force will be like this DC rotor. So, you pass current such that this conductors carry cross, this conductor carry dot. So, that lines of force will be like this and it is there of course, these two can interchange their positions. That is you can place this one on the rotor and DC coil on this stator. And, when the rotor is like cylindrical it is called a cylindrical induction motor, cylindrical rotor induction motor not induction synchronous motor.

You can have another variation, this is stator you can have another variation that is this one stator winding remains same 3 phase winding. And, on the rotor instead of a cylindrical structure you can have a projected pole like this. I am drawing a 2 pole configuration because, 4 pole can also be drawn and here you have coils maybe they will carry DC current only and these are dots. So, that lines of forces in this case by the rotor will be like this, here also it is like this at the point. So, it is called salient pole rotor, generally and this is field coil, this is also field coil here. This stator 3 phase distributed winding in terms of synchronous motor it is also called 3 phase armature winding; 3 phase armature coil 3 phase armature and this is called field coil. So, this is 3 phase armature and this is field coil.

So, field coil is excited by DC current fixed and 3 phase winding of course, it looks like you will connect some 3 phase supply here and things like that. First of all let us try to understand whether this machine, if it has to produce a steady electromagnetic torque. Or, before that another interesting point I must tell you that this these two things can interchange role. For example, DC field winding can be put on stator, armature, 3 phase winding on the rotor; here also field winding on the stator armature on the rotor this took can be reversed. Now, the question is which one to prefer? Should I have and they will theoretically work in the same way, there is no compulsion that 3 phase armature coil should be on the stator, DC field winding on the rotor.

But, there are some practical consideration; what is that? Suppose here this field winding so, it is a doubly stated machine 3 phase supply will be there and as a motor if you want to consider and DC should be energized. So, that so it is a doubly here it may be 3 phase supply for motor operation and this one. Therefore, if suppose somebody decides no I will place the after all relative speed matters, therefore, I will place the armature on the rotor and DC field coil on the stator. Now, we know to access any terminals of a coil which is rotating you require slip ring and brass arrangement. Now, if DC field winding is present I need only two slip ring and two brasses.

In contrast if the armature would have been on the rotor you will require three slip rings and three brasses, not only that you will find that the armature is the main power carrying winding power in the DC excitation coil that is very little compared to the total power here. Therefore, size of the slip ring and brasses which will carry the ampere from a stationary supply terminal to the moving rotor coil that values will be very large. Therefore, slip ring brass arrangements only two are needed for field winding whose current ratings will be much less compared to the armature current rating therefore, people always prefer at least for large machines.

For example: all generators in power stations they are synchronous generators, they are invariably field winding will be on the rotor, that is why I have drawn like that an armature winding will be on the stator. Suppose, the rating of synchronous machines could be very large compared to induction motor. Induction motor ratings is much higher, single phase induction motor very low rating f h p, 3 phase induction motor may be also large 100 kilowatt to 100 kilowatt like that. But, synchronous machine its rating could be really large of the order of mega watt level. Why? Because, of the fact the most negative point of induction motor is that it draws the magnetizing current from the grid, from the supply lines and that makes the motor to have to have low power factor particularly during light load condition.

Because, no load current drawn is lagging almost by 90 degree and if the motor is light loaded power factor will be very poorer. So, a 3 phase induction motor draws the magnetizing current from the grid supply, supply lines which makes its power factor lagging always lagging. No question of unity power factor of things like that, it will be always lagging, in lighter load conditions the power factor will be much poorer that was one of the greatest advantage. So, large sized induction motor means large magnetizing current. So, people do not go for high rating induction 3 phase induction motor.

But in case of synchronous motor the excitation is completely from a separate source from a battery bank. In power station you will find there is a battery bank which is exciting this coil. This is also called exciting coil dot field coil, you require DC supply;

DC supply is not there in the power station there will be batteries. Or, one may think that in power station from the lines AC is there I will convert it to DC, give supply here that may be also done, but in that case if the grid fails your this machine will not work. So, as a precautionary measure you can have a battery bank also supplying this DC supply; anyway these are options we will think about later.

But the point is in a synchronous machine rotor is excited by DC and stator winding will carry 3 phase AC current, this will be the normal scenario. It will carry 3 phase AC current AC current and this will carry DC current. Now, the question is if the stator winding or armature winding of a synchronous machine carries balanced 3 phase current, we know what is the consequence. It will produce a rotating magnetic field, suppose moving in the anti clockwise direction with it which is decided by phase sequence. And, if the rotor if you excite it with DC, what it is going to do? It will produce poles like this, but if it is rotary stationery it will not be a rotating field, it will remain stationary.

Therefore, if suppose somebody says I want to operate this as a motor synchronous motor has got these things, rotary stationary; I will excite this with 3 phase winding, a rotating field results, stator field is excited, rotor field is also there. Rotary stationary I have excited with DC current, will it produce torque? No, because we know that for production of steady electromagnetic torque the relative speed between the stator and rotor field must be 0. A stationary observer must conclude that both this field are moving with the same speed, then only angle between them will remain constant and it will develop a constant torque to balance the load torque is not.

Therefore for example, if this is a machine I can immediately conclude; if you want to run it as a motor it has got no starting torque, it cannot have. If the rotor is stationary get your rotor field F r by exciting it with DC current, get your stator field here excited from a 3 phase supply. Rotor field will remain stationary because, rotor itself is stationary, rotating field produced by stator it will sweep us this. So, average torque will be 0.

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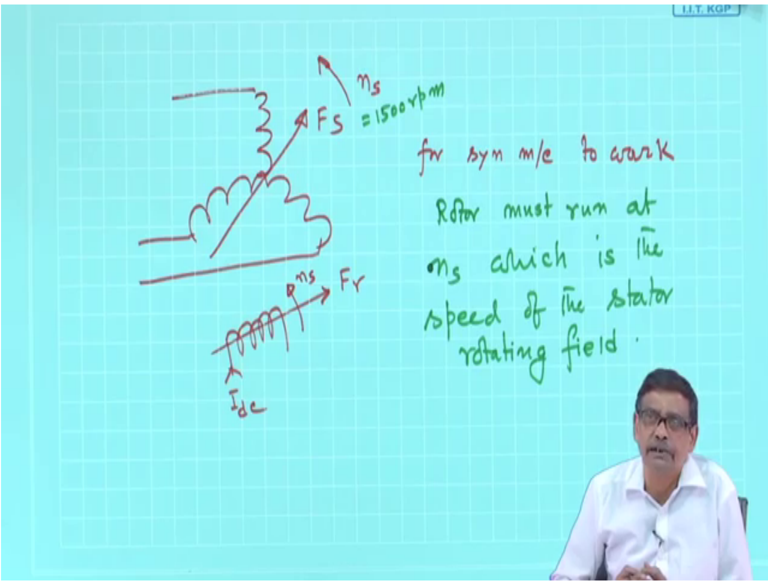

However, if I say that if I say that stator field is moving with a speed n s decided by supply frequency. And, rotor field I will not draw that elaborating, a coil is there, a magnet DC I DC, rotor field. If this machine has to work I must conclude that rotor physically must also rotate in the same direction with same speed then only this motor is going to work because, that is the fundamental requirement. A motor can develop steady torque provided the speed of the stator field, speed of the rotor field are same with respect to a stationary observer.

But, a rotor field which is excited by DC cannot on its own produce a rotating magnetic field. For production of rotating magnetic field either you have a balanced 2 phase winding, balanced poly phase winding excited with a poly phase balanced current rotating field will result. But, mainly by passing a DC current on this coil it is not going to run, a constant field will be produced it will remain fixed. Of course, if I make it to run this will also behave like a rotating magnetic field is not therefore, therefore, for synchronous machine; because this is the structure basic coils in the machine.

I can conclude this much for synchronous machine to work rotor must run at synchronous speed at n s which is the speed of the stator rotating field; which is the speed of the stator rotating field, it has to nothing doing. These two speeds must be for example, if suppose 4 pole machine, this is 1500 rpm, stator rotor speed is 0 no torque, rotor speed is suppose 1400 rpm I am running it, but at 1400 rpm by external agency I am running it. Can this machine develop torque? No, because with respect to rotor field this fellow will be running at 100 rpm, there should not exist any relative speed between stator and rotor field.

Then this machine is not going to produce any steady electromagnetic torque and these we have discussed in greater length go through earlier lectures. So, that is the thing therefore, to run the machine a synchronous machine will work at synchronous speed ok. There may be of course, it will not be proper to tell that it strictly always run at synchronous speed both the speeds are same. There may be transient condition where the speed may be momentarily become other than synchronous speed. But, we will see those are the transient phenomena how to tackle with that, machine will be capable try to find out its once again this steady operating point those things are there.

But, in general steady electromagnetic torque a synchronous motor is running; I must conclude that whatever is the speed of the rotor that must be the speed of the stator field. This is there is absolutely this must be followed otherwise it will not work ok, this is the thing.

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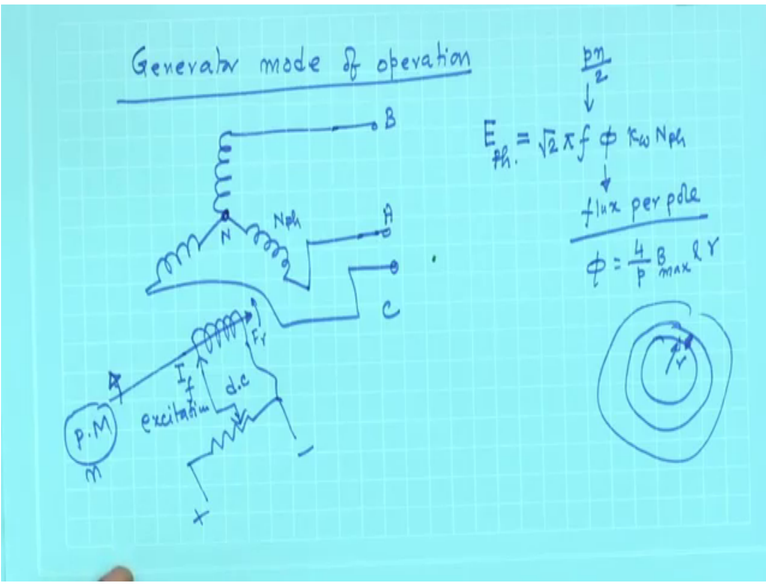

Now, first I will take a generator mode of operation generator mode of operation. So, in a generator what is to be done this is my stator coils, suppose torque connected I have taken and this is your field winding DC. And, let me draw like this in suppose connected a like a potential divider connection. So, that this is called excitation of the motor. Now, if it is a generator mode and suppose this I will run it in the anti-clockwise direction, there must be a prime mover generator means either a steam turbine or a diesel engine is running the rotor and suppose these points I have not connected anything. So, stator terminals are open ok, as it moves like this.

So, this is suppose A phase, this is B phase, this is C phase as it moves in the anti-clock; suppose this is a phase then after 120 degree B phase C phase. So, whatever is happening to this coil after 120 degree same thing will happen to this coil and so, on we know that and this is the rotor field. So, I expect there will be induced voltage in these 3 coils ok. And what will be the magnitude of the induced voltage, r m s value of the induced voltage per phase; suppose n phase is the number of turns. This expression I know from induction motor, it is equal to root 2 pi f, what is f? f is p n by 2. What is n? n is the speed in rps of this prime mover. So, it is prime mover, it is driving it with a speed n root 2 pi f.

Then there is a term called phi and then K w winding factor and then N phase very simple. What is this phi? We recall it is flux per pole. How to calculate flux per pole? Phi 4 by p B max l r. What is p? Number of poles, B max is B max, l is length of the effective length of the machine working length, r is the radius of the air gap or rotor because, air gap is small. So, in our periphery of the stator radius of B rotor these are all can be this is suppose stator. So, this is air gap is small so, this is r same. So, this is how I can get flux per pole and I can get the induced voltage per phase. Therefore, induced voltage and the this flux is produced by DC current here because, stator is now not carrying any current, it is open circuited.

Although it is open circuited if you take a voltmeter you will get voltage between these points, a balanced 3 phase voltage will be induced and with respect to this neutral and any of the phases this will be the magnitude of the phases. And, these voltages will be equal because it is balanced 3 phase winding N phase and this one; [FL] at this point tell me how much is the torque prime mover has to exert on the rotor to rotate it? 0 torque because, there is no opposing torque, if you neglect friction, if it is friction, if you want to rotate this rotating mass then a little power is required. Suppose let us assume there is no friction absolutely.

So, to run the rotor at some speed no torque is acting on this therefore, torque developed by the machine is also 0. Torque in the machine electromagnetic torque will be 0 because, of the fact there is no stator field rotor field is present. For production of steady electromagnetic torque there must be stator field, there must be rotor field and the angle between them will remain constant with respect to a stationary observer these are the condition. Now, I find there is a rotor field, there is no stator field. So, electromagnetic torque will be 0.

But so, far as prime mover is concerned to rotate this rotor mass there will be bearing friction, a little torque prime mover has to. So, prime mover will face a opposing torque a little bit of that and in a you can neglect that, if you assume that is absolutely no frictional torque present, that torque will be 0. And, your prime mover is also not doing any work, anyway we will continue with this next class.