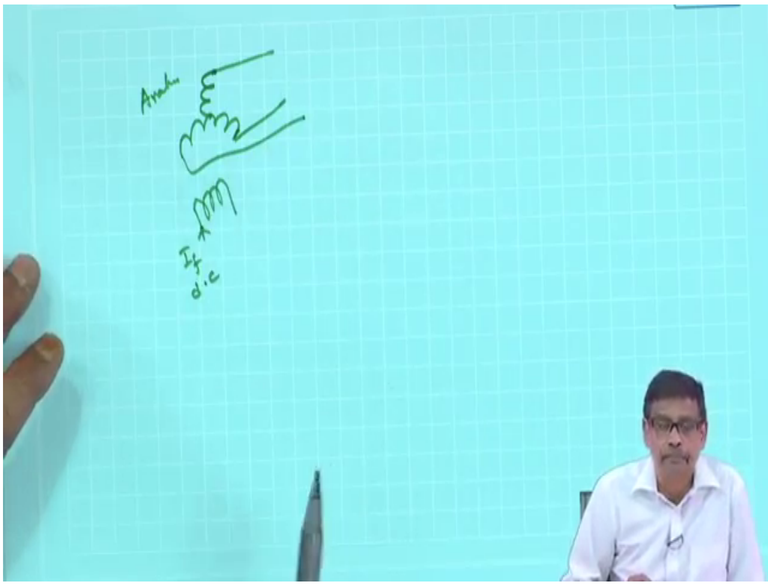
Electrical Machines - II
Prof. Tapas Kumar Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 75
Synchronous Generator Introduction

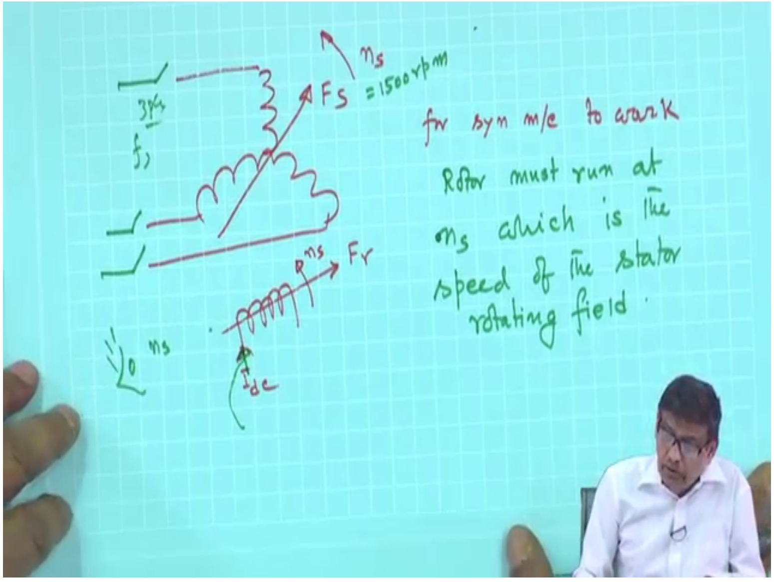
Welcome and we were discussing about synchronous machines. Synchronous machines are huge capacity machines. It may be 100 Megawatts ok. Voltage is also higher, maybe 10 kV voltages of that level of power we are talking about. Which, in case of induction motor it is? Because induction motor operation, three phase induction motor operation, large motors are there. But, it also draw you cannot go beyond a certain capacity because of the fact that it draws magnetizing current from the supply. In case of synchronous machine because there is a armature winding and a DC winding which is called field winding.

(Refer Slide Time: 01:11)



This is armature and field winding which is DC, called excitation current. Excitation current is totally independent of the AC voltage that will exist here; quite independent. One thing I was telling and before doing any mathematics several things we now know about synchronous machine.

(Refer Slide Time: 01:41)



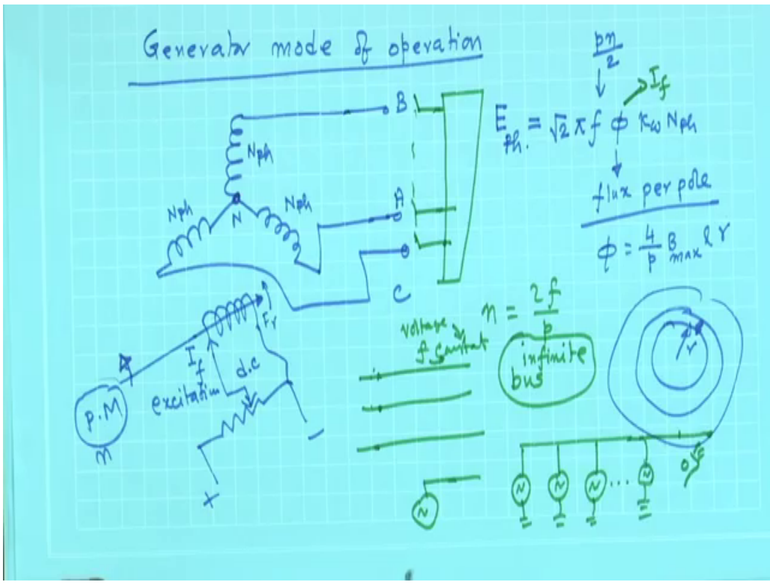
One thing is this; I am going to excite this field winding with a DC. It will produce a stationary field. Stator, if it carries three phase current, three phase winding it will produce a rotating field. This two cannot produce any torque if it is stationary. Or if the speed of the rotor, physically you have to run the rotor to make this field F r a rotating magnetic field. That is the thing. And therefore, it must be, rotor must be running at synchronous speed, n s where the frequency on this side is f, three phase supply, then only this motor will machine will work; there as a motor or as a generator. And another thing should be also interesting to note that here this DC current is flowing. All the fields, a stationary observer will conclude, they are moving with a speed n s with respect to him in such a scenario.

Now, this field if you see, will there be any AC voltage induced in the field winding ? Can there be any AC voltage induced in field winding? No, in steady operation because there is no time varying field moving past it. However, there will be induced voltage in this stator coils because with respect to stator, stationary observer, F s, F r are present. Therefore, there will be induced voltage in all of these stationary coils, but in the field coils there will be no AC voltage induced. Current in the coil will be simply that v dc divided by whatever resistance of this coil is there. See, these are the things we can immediately conclude of a synchronous machine, what it is. Then, I was telling you that suppose, I now know that a synchronous machine, stator winding, some three phase supply to be given. I want to run it as a motor. I know there is a rotor coil which is to be excited by DC. And if the rotor is stationery initially, if I energize this from the supply, I want to run it as a motor. So, supply is to be given. So, I will connect this supply and also you will excite the DC field. Is the machine going to rotate? No. Why? Because, rotor field is will remain stationary because rotor itself is at stationary condition, but stator, the moment it carries three phase current, a rotating field is produced.

Therefore, torque production will not be there. Therefore, how to run it as a motor? One very crude way I am telling, that way your thought process will improve. What I am telling? However, because I know how, when the torque will be produced; I can do one thing. This rotor, first I will connect it to a prime mover and I will make its speed equal to this stator field n s. Then I will switch on the stator supply. Then it will work and then I will remove the prime mover. Are you getting? Not a very good way of starting synchronous motor, but physically it should work.

Suppose, it is a 4 pole machine, 50 Hertz supply, 1500 rpm is the stator field I know. So, I have this one stator supply. I want to run it as a motor whatever little I know about synchronous machine. What I will do? I will excite this with DC, but I am sure it is not going to work. So, I will first run this with the help of some external agency and bring its speed up to 1500 rpm. And then, I will excite this field and then I will close this switch. You will see it is running fine. Torque is produced which will balance the load torque. This you just, without any mathematics these things can be easily understood. Anyway, so this was the thing we was discussing. So, this is the basic structure of the synchronous machine. And I was telling you about the voltage equation of the machine. This was the last slide.

(Refer Slide Time: 06:49)



Generator mode of operation, it has developed this voltage. Now, this is the prime mover. You run the machine, this is stationary. So, rotating field will, flux linkage will take place. There will be induced voltage, per phase induced voltage will be this. This phi will definitely depend upon I f, flux per pole, is not? 4 by p B max l r, but it will defend depend upon this field current. Therefore, if field current is 0. Suppose, this pointer is here, field current will be 0. It is a potential divider connection. There will be no induced voltage.

So, increase the field current by moving this jockey. Your flux per pole will be created. And induced voltage is directly proportional to this. Speed I am keeping constant ok. If you want to generate 50 Hertz voltage, how speed get constant? I know what is the speed I have to drive this machine so, as to generate 50 Hertz. I will calculate it like this, n is equal to 2 f by p. So, you can generate any frequency. Suppose, I want to generate 40 Hertz; if I know the number of poles for which this machine has been wound, I will be able to calculate it like that. Suppose, I want to, 4 pole machine, I want to generate 50 Hertz. Then, I can calculate what is this speed? it will be 1500 rpm. If it is a 2 pole machine, you have to run the prime mover at 3000 rpm to generate 50 Hertz. So, the frequency consideration decides what should be your prime mover's peak if you know the number of poles of the generator. That is what I am trying to tell.

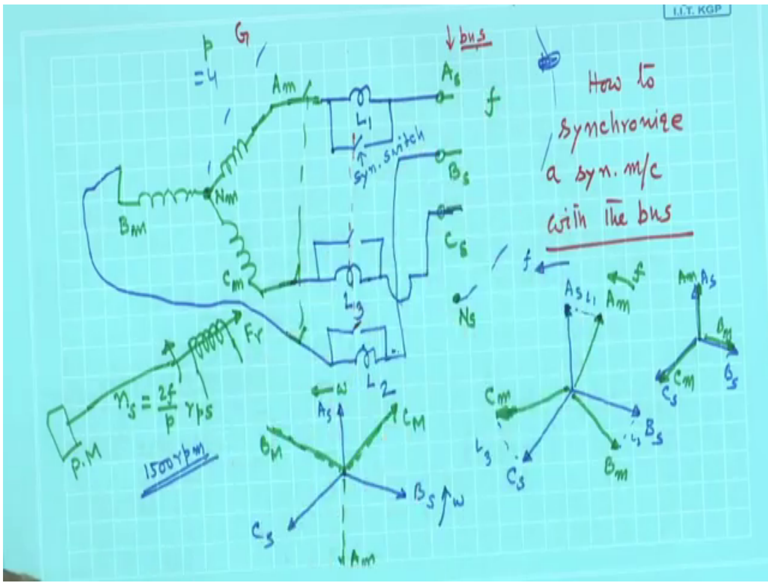
So, anyway, I have been able to generate AC voltage here which will be balanced three phase voltage, but nonetheless it is not carrying any current ok. It will not carry any current. If you wish, you can have a three phase load. What for I have generated the power? To supply some load, three phase load which may be inductive, capacitive, whatever it is, balanced load we will consider. So, if I close this switch now, there was some voltage. I would expect there will be balanced three phase current. And balanced three phase current means that rotating field will appear. And in case of generator mode, electromagnetic torque will be opposite to prime mover torque. So, prime mover torque has to increase, there will be some dynamics and your load will be supplied with some load angle. This is a picture I am telling you. But you see, we in this class, we will consider the operation of the synchronous motor which will be connected to the bus. What is a bus? First, let us try to understand your three phase supply system. Here, bus and infinite bus. What is the meaning of that? It means that there is existing three phase supply already available.

Who are the fellows who are making this alive? There are so many generators already connected in this system in parallel. And not only that, the eastern region have hundreds of generators. They are connected in parallel. Western region, southern region of India, there are hundreds or more than thousands power stations are there. All the generators you will find, they are connected in parallel. And they are making this voltage alive. And when many generators are connected in parallel, these voltages, existing three phase voltage, whatever is available now in my lab for example, in your lab. This can be considered to be a almost like a infinite bus. Now, the question is what is the property of infinite bus? Property is this, the voltage of this, line to line voltages; I will not be able to change by sitting in my lab. That is decided by so many generators. I will draw a single line diagram to give you the idea. So many generators are there connected in a bus, many ok. If you find out the Thevenin's equivalent of these, this bus voltage, what it will be? It will be I know how to find out. Suppose, all the equivalent impedance, all the impedances will be in parallel.

So, equivalent impedance will approach to 0, is not? And then I know how to calculate the open circuit voltage. Suppose, Thevenin's equivalent I am finding. Therefore, the series impedance of this whole thing equivalent will be almost like a constant voltage, that is all. So, infinite bus is one where the voltages will be constant as well as frequency is constant. Voltage constant, frequency constant, then such a available voltages is said to be a bus voltages. Loosely it is called bus voltage, that means, voltage is constant. Terminal voltage available here. And what I am telling is that by doing something sitting in your lab you will never be able to change this voltages and the frequency of this supply system. It is decided by so many generators already connected in this system.

So, we will assume a bus, like a three phase supply.

(Refer Slide Time: 14:39)



Suppose 440 volt supply in your lab. It is ultimately coming from the existing power system by stepping down the voltage etcetera using transformer but, this voltage suppose, the phase sequence is A B C. In my lab this is supply, A s, B s, C s, supply three phase 440 volt is available. And this voltage and frequency is constant. And I will connect my synchronous machine to this bus and we will make it operate either as a motor or as a generator. Not that a synchronous motors is locally supplying some load here. That you can do, but this is not the purpose of this course. Is that clear? So, first thing is what should I do? Suppose, you have, I will draw it like this.

Suppose, I have my motor here. This as I told you, I will not do any mathematics. First let us try to understand the idea. And here is your field winding; here is your field winding. And it has produced some field, rotor field. And I know the supply frequency; I know the number of poles of the machine. So, I know at what speed this rotor must be rotated so that here 50 Hertz voltage will be generated. This is stator coils.

So, suppose I say this is a phase of the machine A m, B phase must be here because rotating field is moving like this. What is, whatever is happening to this, that is why I call it B phase. And then this is C phase. This m is machine. Suppose, in your lab you have a small synchronous machine, so A m, B m, C m. Now, I will run it at a speed which is equal to 2 f by p, so much r p s by whom, by a prime mover I will run it. And then I am sure there will be induced voltage in each of the coils which will be balanced three phase, fine. Now suppose, I say I would like to connect this with the bus. What do I do? You must be knowing, to connect two voltage sources, this becomes voltage sources, this to this you just with your eyes closed you cannot connect A m with A s, B m with B A s and C m with C s. Because, you must make sure the instantaneous voltages existing at those points, they must match and the phase sequence must be same. Then only a successful connection will be there, otherwise there may be disaster. Is that clear?

So, that is the thing. So, what I do? I first, I will connect it in parallel. I will do like this, I will take 3 lamps. See, the topic is how to synchronise a synchronous machine with the bus, with the existing bus. These are the bus, this side is bus, bus voltages three phase. So, I am telling, how do I connect this? So, it is I have first, I will operate it as a generator by prime mover at a speed which I have taken help of this frequency 50 Hertz, whatever it is I will run it. I am sure AC voltages has been produced, here also exist a balance three phase AC voltage. But, should I directly connect A m with A s, machine A phase, machine B phase, machine C phase? No. One simple way to do this is, I will take 3 lamps, incandescent lamp. L m and this B m, I will connect another lamp L 2, connected there, another lamp I will take, L 3.

So, first thing I identify the phase sequence correctly, that I will do. Some phase sequence meter is there and it is easy to identify the phase sequence. So, A m, C m, B m I will write, then between A m and A s, I will not directly connect, I will connect a lamp. Similarly, between C m and C s, I will connect a lamp L 3, identical lamps I will connect. And then, what I will do, across the lamps I will connect switches. This is the very interesting method. And these switches can be operated together, triple pole switch that is indicated by this dotted line. They will be operated together, it is like this [FL]. Now suppose, and let us take a concrete example p equal to 4, number of poles of the machine is equal to 4. Then, I am running it at 1500 rpm.

Now, the question is, question asked is, what will be the lamps? How they will glow? That is the question asked [FL]. First of all, you see, you have your, this point carefully note what I am telling. This is your bus voltage, supply side A s, B s, C s. This is the and all these phasors are moving with supply frequency f, that is 1500 rpm or 3000 rpm electrical, it is moving. I have connected a lamp between this and this point. I must know what is the voltage which is appearing across each lamp, then only I can say ok, what is the voltage. And suppose, this is the supply side neutral which I have not connected, N s. This is the machine neutral N m.

Now, there will be similar phasors indicating the machine voltages. Three phase balanced voltages are there. This I will use a different colour for example, I will use a green colour, A m, B m and C m. These are 120 degree apart, you must understand. And these phasors too is rotating with same frequency f or ns, whatever you call it. Therefore, what will be the voltage between these two points A s and A m? It is this length, it is across this is the lamp L 1 voltage. This is the lamp L 2 voltage, this is the lamp L 3 voltage, is not?

Now, the question is, when this suppose, there was a switch here. I generated the AC voltage A m, B m, C m was independently existing moving with frequency omega, whatever it is. A s, B s, C s also existing separately with A s, B s, C s moving. Now, at some point of time and this was open, this switch this switch was open. Therefore, ok, that was there, independently they are existing. The moment you close this switch, because these voltages are balanced, it can be thought of N m and this N s, with respect to this I am measuring the voltage. I can go by loop, but I do not know really, when I have closed this switch, where A m, B m, C m, where? Compared to your A s, B s, C s, it could be anywhere. I am not sure. This point must be understood. What I am telling, that is another switch here which was kept open earlier. A m, B m, C m existed, A s, B s, Cs existed, both of them are rotating with same speed, that is fine.

But, I am not sure about one thing. When I close this switch, where should I draw A m, B m, C m, with respect to A s, B s, C s. That information is not there. It could be anywhere, for example, another it may so happen, that your A s is here, B s is there, C s is there. And when you have closed this switch, A m was passing through this point, just opposite. I am I I am not sure. A m, then it was your B m and it was your C m. You must try to understand this point. That is, it could be anywhere, I do not know. It may so happen, they were overlapping. That is, A s, B s, C s and it so happen that your machine A m was here, they were overlapping, B m and C m. I mean hundreds of thousands possibilities are there, anywhere they could lie.

So, I have drawn any arbitrary position ok. It is like this. What do you think L 1, L 2 and L 3 are going to do? They are incandescent lamp. Mind you, our old filament lamp. Voltage across L 1 will be this length, voltage across L 2 will be this length and voltage across L 3 will be this length. So, all the lamps will grow glow with equal brightness. They will glow with equal brightness and it will continue to glow. Question is, should I close, this is called synchronising switch and this switch, synchronising switch. Should I close this switch now? Suppose, it is in this position.

Suppose, it so happened that I have closed this switch and it was like this. In this case, what is going to happen? L 1, L 2, L 3, will be equally bright and very bright because the voltage as minus A m is twice this length across the lamp L 1. Highest voltage will be in this position. And both of them are rotating at synchronous speed omega. This fellow is also rotating at synchronous speed. So, voltage across the lamp is the difference between length, difference between the tip of this supply side phasor and the machine side phasor. Neutral may not be connected, may be connected. With the other things it will come back, other supply side, there is a coil there. Anyway, but what I am trying to tell you is that, if you imagine N m and N s are connected, neutral to simplify matters. n f and n s are that I can do. What is there? Neutral and neutral connect.

So, they are connected. So, it is like this. Now, the most interesting thing is if the bus frequency and the rotor speed are exactly and what will be the lamp voltage across the lamps? If it so happens that, when you have closed this switch, they are overlapping. It will be 0, 0, 0. All the lamps will be dark. Therefore, what should I do for synchronisation? Which of these three instant is favourable? Obviously, when the lamps are dark then I am sure instantaneous potential of A s, A m are same, B s, B m are same, C s, C m are same and there will be no risk involved. You can close this switch and lamps will be bypassed and it will be truly parallel to the machine terminals with the supply terminals, is not? That is the thing we are looking for. But, as I told you, you please think over. We will continue, but I want to tell you one interesting point. But, if the speed of the rotor and supply frequency are same, exactly same, if you close this switch, it is very unlikely that this situation will prevail. It is a matter of chance and matter of chance that probability is remote. Every likely you will get a situation like this because so, every instant is there. Therefore, I know the correct instant of synchronising the machine terminals with the bus terminals is that instant when all the lamps will be dark that is known. But, making the speed of this rotor exactly same as the supply speed, remote chance of getting that correct instant appearing. Anyway, we will continue next time with this, interesting.

Thank you.