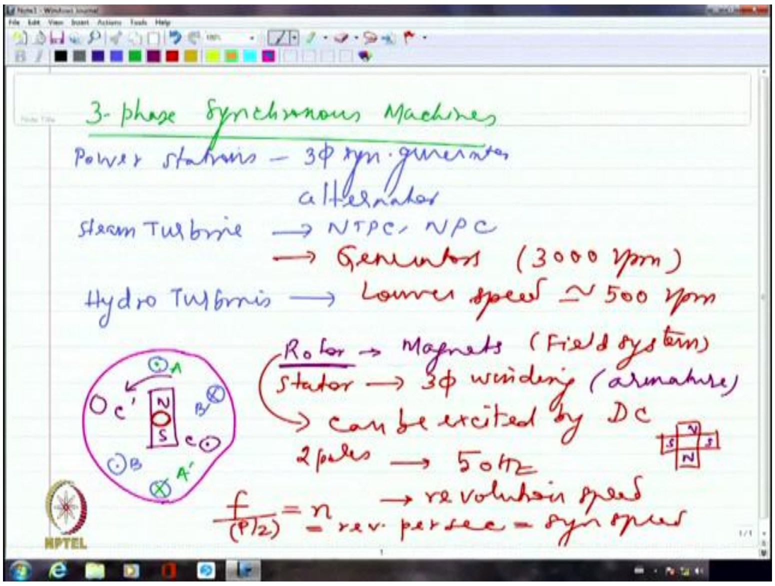
Electrical Machines
Professor G. Bhuvaneswari
Department of Electrical Engineering
Indian Institute of Technology Delhi
Lecture No. 33
Synchronous Machines: Introduction

(Refer Slide Time: 0:18)



So this is the synchronous machine or one of the most important machines which are commonly used, especially as a generator. So, I would say all the power stations generally used synchronous generator or we may call that as alternator. These are commonly used for generating three-phase power in all the power stations.

And generally, if we are looking at the stream turbine driven power station like NTPC or NPC – Nuclear Power Corporation and NTPC, both of them generally use the generators which work at 3000 rpm. Whereas, if we are looking at Hydro turbine, which are there in generating stations, which correspond to NHPC National Hydro Power Corporation. All of them work normally at lower speeds.

So, I would say around 500 rpm it can be sometimes less as well. So it is really, really a lower speed at which they work as compared to the steam turbine power stations. The basic principles of operation, if you look at for a generator, let me first of all, look at the generator because that is the primary application. So, if I am going to again, again, I will have a stator and a rotor.

So in the stator I am probably going to have three-phase windings, so let me call this as A and A^{l}. I am going to have one more pair which is actually B and B^{l}. I am showing them as not distributed winding. I am showing them as though they are concentrated but they are not concentrated, they will be distributed normally, distributed meaning it is going to be distributed over several slots.

But I am showing it as though it is concentrated. So this is going to be again B and B^{l}. And the third one, I am going to have is C and C^{l}. These are the three phase voltages, so there are going to be three phase voltages that are generated. If I assume that this is going to be the magnet, please note I am going to have an electromagnet or permanent magnet in this particular machine. So, the rotor will consist of magnets, maybe electromagnet, maybe permanent magnet, whereas I am going to have the stator having the three-phase winding.

So, the rotor will house the field system, whereas I am going to have these as the armature. The stator is going to consist of armature normally. That is the way I am going to have the structure. Why is it that way? We will also discuss a little bit, but if I am having an essentially the structure somewhat like this. I will have if I assume that it is rotating in anticlockwise direction.

First, I am going to have induced EMF in A and A^{l}, then after 120 degrees because exactly B phase winding is displaced by 120 degrees, I am going to have induced EMF in B. Then I am going to have the induce EMF in C. So, I am going to have three-phase induce EMF in all the three windings, independent of each other because of one signal magnet rotating. So, what I can say even without really going into great analysis, the rotor can be excited by DC.

Even if I excite this by DC, I would create rather a North Pole and South Pole which will be, a constant value of flux that will be created because of these two poles, North Pole and South Pole. Only thing is I have to arrange to physically rotate it at a particular speed. So, maybe 3000 rpm, maybe whatever is the speed according to which I am going to get the frequency.

So, I would say that here is the shaft. I am going to have the shaft here. The shaft is going to rotate the magnet in the speed whatever is dictated by the prime mover and the prime mover speed will be controlled by the power station authorities, according to the frequency that needs to be generated. So, for example, if it is going to be a two pole machine, I am going to have basically this particular North Pole facing the phase winding A every revolution, during every revolution.

So, if I want is 50 hertz, basically I should also have these North Pole coming into contact with A phase winding corresponding to 50 hertz. So, it should happen 50 times probably in 1 second. That is when I will be able to get exactly 50 hertz verse the induce EMF in my actual, the winding itself. So the revolutions per second or revolutions per minute indirectly decide what is the frequency which is being induced in individual phase windings?

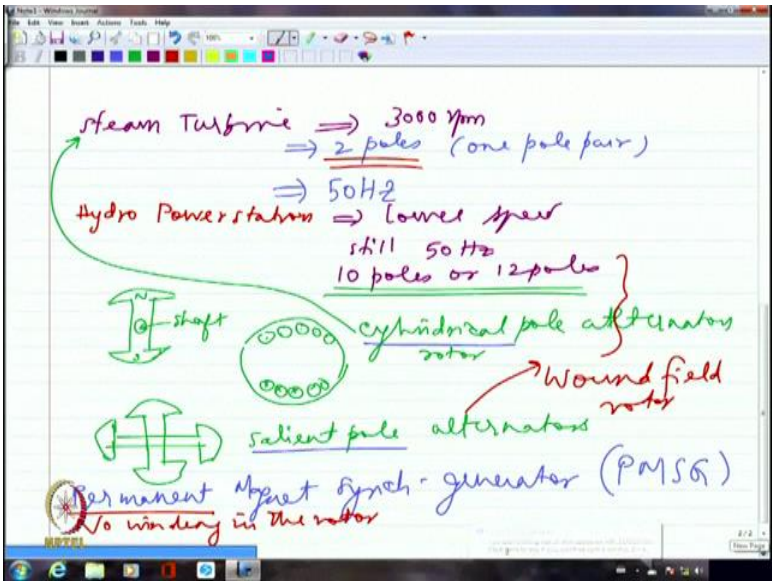
So, if I have two poles, I should have this rotating in such a way that I am going to have basically positive half cycle is induced here and negative half cycle is induced at the same point in A^1 at the same instant of time in A^1. So, I am going to have essentially, if it is a two pole. I am going to have actually 50 hertz will be induced, if I am going to have revolution or revolution speed corresponding to this particular 50 hertz itself.

$\frac{f}{(p/2)} = n$, which is the revolution per second. This we wrote as the synchronous speed in an induction motor. The same thing holds good in this particular case as well. So essentially the speed at which my prime mover is rotating the magnet that is basically known as the synchronous speed, which will decide what frequency is induce in each of the phase windings.

If I have only two poles I am going to have for every revolution only once A phase is going to face the north pole of the system. Instead, if I am going to have a North Pole and South Pole, actually repeating itself twice. So maybe this is North Pole, this is South Pole, this is North Pole and this is South Pole. Then what is going to happen is the North Pole is going to be faced by A phase winding itself twice in which case the frequency of the induced EMF can increase further.

So, I would be able to get more and more frequencies, if I rotate the field system at a higher speed or if I multiply the number of poles. Either way, I should be able to get a higher frequency. Normally the steam turbine based alternators, which are working in thermal power stations work at extremely large speed, normally which is 3000 rpm.

(Refer Slide Time: 9:18)



As a rule, the steam turbine based alternators are going to work at 3000 rpm, which means I will have only two poles in this case or one pole pair, which means for this 3000 rpm I will be able to get 50 hertz directly, whereas if I look at the hydro alternator, generally all the hydro turbine based alternators are going to rotate only around 500 or 475 and so on, very low speed, which means if I want to get 50 hertz I necessarily need to have more number of poles.

So, generally, this will be two poles system, always when I talk about NTPC power station or NPC power station, whereas whenever I am going to talk about hydropower station. I will have lower speed yet 50 hertz. Still 50 hertz is needed, which means I will have may be 10 poles or 12 poles or whatever. Larger numbers of poles are going to be seen, normally in hydro alternators.

So, whenever I am talking about smaller number of poles. That means I am talking about higher speed and if I am talking about higher speed. If it is a large structure rotating at a very high speed and if you actually look at the linear velocity what is going on around the rim of or around the peripheral surface of the rotor that is going to be enormously high. So you are going to see that generally you will have some kind of deformation, if I am going to have the rotor having a protruding structure like this.

Let us say this is my rotor with protruding structure, this is the shaft. So, I am going to have probably North Pole here and South Pole here. If it is having a protruding structure like this, I will have basically huge amount of centrifugal forces acting towards the ends. So if they are acting towards the protruding surfaces they can deform the winding, we do not want the deformation to happen, especially when they are working at very large speeds. That is the reason why invariably we may simply have a cylindrical structure as the pole. But we will only play is the winding here and place the windings here.

Then what will happen is if I pass dot here and cross here, maybe I will create North Pole there and South Pole here, that is it. In the middle portion I will not have any winding at all. So, this is having a cylindrical structure, at least and it will not have much of opportunity to get deformed. So, cylindrical pole rotor is normally used in high-speed alternator which is corresponding to steam turbine.

Whereas this is salient pole, so salient pole if I show actually 4 poles. I am going to have essentially a structure like this and I am going to have one pole here, one more pole here. Of course, there will be of uniform thickness not like what I have shown one more pole here and one more pole here. So, I am going to have essentially 4 poles protruding like this. So, in which case, we call that as salient pole because they are having specifically some portions highlighted. So that actually protrudes and that portion is known as the salient portion of the pole. So this is a salient pole alternator.

So, we have cylindrical pole alternators and salient pole alternators. Synchronous generators are in actually known as alternators, so I can have a single phase or three-phase alternator, what we are discussing is three-phase alternator. So if three-phase alternators can have cylindrical rotor structure or salient rotor structure. Cylindrical rotor structure generally conforms to very large velocity, whereas salient pole structure generally will correspond to smaller velocities and smaller speeds are generally in hydro alternator and larger speeds are normally in steam turbine based power stations that is NTPC and NPC power station.

So, much so for the basic structure of an alternator that are used in most of the power station. Instead of having windings, create the magnetism in the field system. We can also have permanent magnets rather than having winding, I can also have a real magnetic which is naturally available, I can try to make a magnet properly shaped and I can put it in rotor structure, in which case I do not have to really depend upon any winding for the excitation.

So, I am going to have the third type, apart from cylindrical pole, salient pole there can be permanent magnet synchronous generator. So, generally this is known as PMSG. So Permanent Magnet Synchronous Generator until almost recently even before about 4-5 years ago there used to be available only for about 30 kilo watt or 40 kilo watt rating. Lately they have been produced for megawatts levels of rating. 5 megawatt is one of the generators that are being used along with wind energy conversion system.

So, Permanent Magnet Synchronous Generators have one of the major advantages, no winding in the rotor. So, there is no problem, even if it is actually running at a very high speed. It is not going to throw away any winding due to centrifugal force. So, it is not is going to be a problem whereas in the case of wound field rotor, we have to be careful whenever it is working at a very high speed. That is the windings can come out of the rotor slots due to the centrifugal forces.

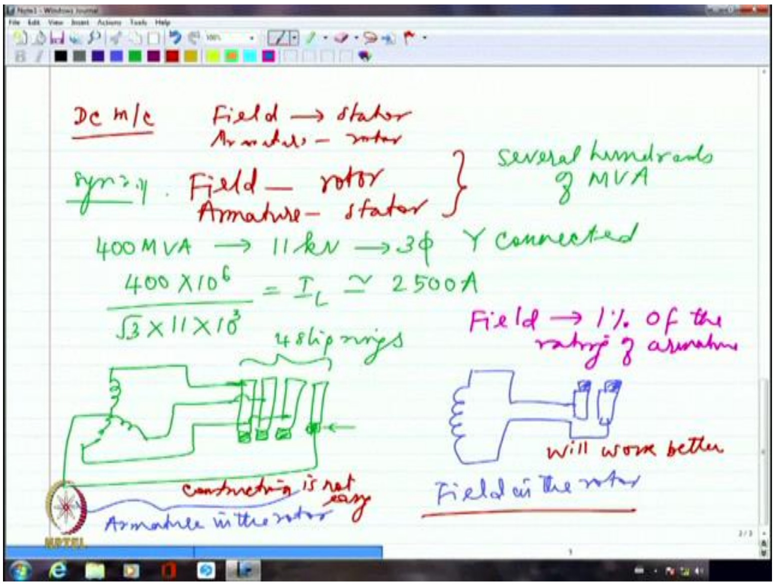
So, that can be a major is problem, when I make the machine work on extremely large speeds. So, permanent magnet synchronous generators are very-very advantageous in that sense. But this definitely has the disadvantage as well. One of the major disadvantages is in cylindrical pole or salient pole. I am actually injecting a current, DC current and I am making the magnet, so magnetic fields strength can be varied in the case of cylindrical pole as well as salient pole alternator.

In general, I can call both these things together as wound field rotor, which means I am going to have field winding whereas in permanent magnet I do not have to have this field winding. So, I would call wound field rotor as the common terminology for whether it is salient or cylindrical pole rotor, only thing is I am going to make an electromagnet by injecting DC current. Whereas in permanent magnet rotor I do not have to inject any DC current, it is inherently magnetised because I am going to use a natural magnet that is available in nature already.

So, that actually gives me definitely the advantage of not having any winding, I will not have any I^2R losses corresponding to the field. But I am going to have definitely no control over the excitation; the excitation is almost like a constant value. And second thing is permanent magnets are not very freely available and it is actually horded by China. So, we are really, really, and our world is having a lot of problems with purchase of permanent magnet and a monopoly is from China because of which they can raise the price to any extent they want.

So we are really finding it difficult to construct permanent magnet machine. Otherwise permanent magnet machines are really, really good in terms of not having any winding, although they do not have much of control over the excitation.

(Refer Slide Time: 18:32)



So, we are going to see why we are having the armature in the stator and fielding the rotor, please remember, in the case of DC machine I am going to. I was having field was always in the stator and armature was always in the rotor. Whereas if I look at the synchronous machine field in the rotor and armature in the stator. Why are we having it this way? First of all, will have to kind of justify this, otherwise, why should the structure be the other way round?

First of all, I want you guys to understand that whether the field is housed in the rotor or stator it should work, there is no problem. All you need is a rate of change of flux. So, it should not matter whether I house it this way or that way. It is essentially due to logistics, due to the ratings and so on. Normally, most of the synchronous machines are going to have a rating of several hundreds of MVA.

So, if I am going to several hundreds of MVA – Mega Volt Ampere, maybe I am going to have 500-400 MVA minimum. So, if I am talking about a 400 MVA alternator with let us say 11 kilo volt generating voltage, maybe three-phase star connected. So, I am going to have actually the current to be $\frac{400*10^6}{\sqrt{3}*11*10^3}$. This is going to be the phase current or line current because it star connected, phase and line currents are the same.

So this is going to be I line. So this will be definitely close to some 2500 ampere or something. I should be getting quite a large value flowing as it is, if it is something like 2500 amperes, and if I am having, by chance, the armature in the rotor, if I just wanted to construct it for the heck of it with the armature in the stator.

Now, what is going to happen is, I will have the three-phase winding deciding in the rotor and windings will be brought out and I have to put 3 slip rings. So, I have to connect this here, the next one here, the next one here, 3 slip rings will be connected to the three phases. Maybe, I will have to bring out the neutral as well; very often I might have to bring out the neutral because the neutral will be normally grounded and the ground will also be connected to the body of the machine.

So, I do not have to get a shock when I touch the body of the machine, by any chance, all of them will be at ground potential. There will not be any floating value anywhere. So, I might have to bring the neutral also which will correspond to the 4 slip rings. So, I have to bring out first of all 4 slip rings and every slip ring will have a brush arrangement. And from the brush I will have to collect the current to the external world.

So you are going to have basically the brushes connected through the slip rings back to the winding. So there will be a moving contact. The brushes are going to make a contact on the top of the slip ring, the slip ring is rotating along with the rotor winding and a have to collect 2500 ampere of current from every phase. And apart from that neutral might also have current depending upon whether the load is balanced or unbalanced slightly.

So, 4 slip rings, 4 brushes along with that, moving contact, there can be a huge opportunity for sparking. So the construction becomes much more strenuous and cumbersome, when I am actually looking at all the 4 conductors being brought out to the external world through slip ring and brush arrangement. This is generally not a very good thing to do, especially considering that the field is going to have only about 1 percent or less, of the rating of the armature.

So if the armature is having 400 MVA I may have the field to be only about 4 megawatt or even less. It will not have a power rating more than that, which means the currents and the voltages; everything will be somewhat limited in the field. So, if I had to bring the field connections out, if it is residing in the rotor I have to bring the field connections out and the field connections when I bring out again, it will come through slip ring and brush, if I am talking about it sitting in the rotor.

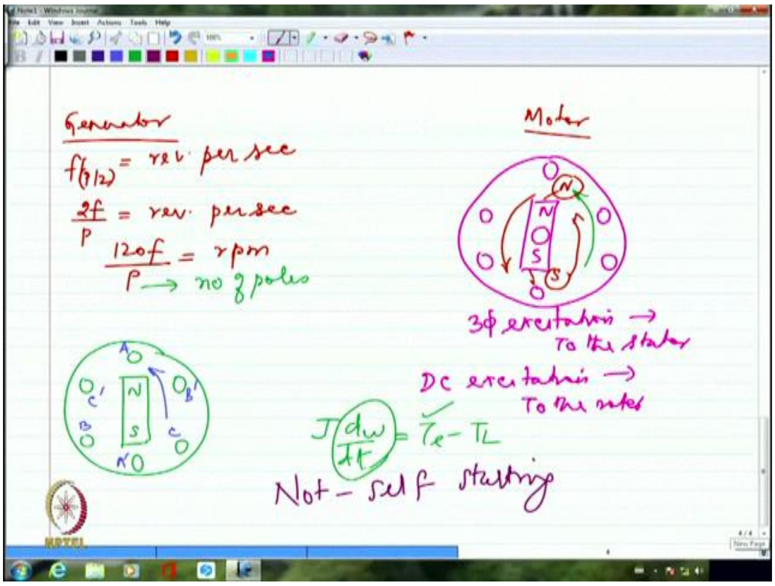
But that brush will carry lower current and it will be rated for lower power and I have to bring out only 2 brushes in all probability, because it is only DC, I will require only plus and minus, nothing more than that, if I am talking about, even 2 pole or 4 pole or whatever, all the windings will be wound in series basically. All of them are going to carry the same current. So, what I require from the rotor, if I say that this is essentially armature in the rotor.

Whereas, if I am going to have field in the rotor, I will only have basically the field winding which is a DC winding probably and I am going to only bring out these 2 and then I am going to connect them to slip ring. So this is connected to slip ring, this is also connected to another slip ring. And I will have 2 brushes, one brush here and one brush here.

I am telling you why armature should be in the stator for that I am giving so much of justification. In the DC machine we had field in the stator, armature in the rotor. But I told you that here it is going to be exactly vice-versa. Why it is vice versa? I am trying to give a justification. Otherwise we could have constructed it the same way as DC machine. In fact, many of the machines in our laboratory are that way, we are going to have the armature in the rotor and field in the stator.

So, we can have the other way round also it would have work. But this will be very-very cumbersome. So the construction is not easy when if it has to be in the rotor. Whereas here field in the rotor will work better because of the rating being lower, the terminals are only 2 and the currents are smaller. So, obviously field in the rotor works better in terms of the constructional details. So that is the reason why we normally have in the alternator always the field sitting in the rotor and you are going to have actually your armature sitting in the stator.

(Refer Slide Time: 26:48)



Now, that we have at least seen the construction basically. Let me try to look at this operation as a generator and as a motor. We said that $\frac{f}{(p/2)}$ is going to be the revolutions per second or I would say $\frac{2f}{p}$ is the revolutions per second or I can say $\frac{120f}{p}$. So $\frac{120f}{p}$ is the revolutions per minute. This is the synchronous speed, what we were talking about, even in the case of induction machine. It is the synchronous speed, where p is the number of poles not pairs of poles.

So, if I am having actually the machine working as a generator. I am going to have a North Pole and South Pole which is actually created either with the help of the permanent magnet or because of the current flowing through the rotor windings. I am showing a 2 pole machine. And I am going to have the A phase, B phase and C phase windings sitting here. And maybe the magnet is rotated in this direction. So, I am calling this is A, A^1, B, B^1 and C, C^1.

So, I am going to have essentially the voltages created which are shifted from each other by 120 degrees. They are independent windings. So, I can connect them in star or delta as per my requirement. Most of the alternators are connected especially large capacity alternators are connected in star, generally, most of the alternators will be connected in star and the neutral will be grounded.

So, that we are not going to get any shock because you are going to have the body of the machine also being grounded. So, if somebody touches it, there will not be any floating voltage or anywhere, anything will be coming. So, you can definitely touch the machine. So, this is the way generally it is going to work. The moment I start rotating the magnet am going to get induced EMF.

But it will be at a different frequency, if the speed is different. The speed has to be precisely 3000 rpm, if it is a 2 pole machine for me to get 50 hertz. And after all, all the power stations are going to be connected to our power grid, which corresponds to 50 hertz. So, we cannot have any variation in the frequency whatsoever, all of them have to be completely synchronised, they all have to be simultaneously at 50 hertz.

So, the sprain is very precisely controlled for the prime over in all the power stations normally. Let us try to look at the synchronous motor, in the case of a synchronous motor; I am going to have basically the same structure. I am probably going to have North Pole and South Pole; this is the rotor. So, if I am going to have the rotor here and I have the three-phase windings sitting here. So, you are going to have the three-phase winding here, unlike what happened in the case of an induction machine.

In the case of synchronous machine, I am going to give three-phase excitation to the stator and DC excitation to the rotor. So, I have excited both stator as well as rotor windings. Now, three-phase excitation given to the stator will create a revolving magnetic field. We already talked about this, when we were talking about the induction machine. So, now this creates the revolving magnetic field.

This revolving magnetic field will rotate at 3000 rpm if I am giving 50 hertz. It will rotate at 1500 rpm if I am giving 50 hertz. But it is wound for 4 pole and so on and so forth. So if it is rotating at a very high speed. But the rotor is just sitting down, it is not even started. The rotor has to catch up with the stator revolving magnetic field, which it will not be able to do right away because it has certain inertia. It is at zero speed.

So, I am going to have $j\frac{d\omega}{dt} = T_e - T_L$, maybe I have generated certain amount of torque, maybe the load torque is smaller or if it is even no-load condition, it does not matter. But still there is a specific rate at which the speed will increase; it is not going to increase right away from 0 rpm to 1500 rpm. It is not possible. So what is going to happen is the revolving magnetic field probably has a North Pole here and South Pole here at this point.

So the North Pole and South Pole will look at this North Pole and South Pole and it will repel. So it may start moving in some other direction, within no matter of time, I am going to have this South Pole suddenly reaching here and this North Pole suddenly reaching here. Because it is working at a very high speed, it is working 1500 rpm. The rotor is wanting to catch up with the magnet, but it cannot catch up with the magnet which is created by the revolving magnetic field because the rotor has a finite inertia.

So, the rotor is not going to be able to get up to speed right away because of which it will face repulsion sometimes, attraction sometimes. So, there will be only a dwindling motion, if at all you look at the rotor of a synchronous motor, if you start off with 50 hertz right away, you are going to see that the rotor will not be able to catch up with the revolving magnetic field speed right away. Because of which there will be only attraction and repulsion alternating, taking place and that is going to actually make a dwindling motion or leave, if at all you see.

So synchronous motor is not inherently self-starting. Induction motor is inherently self-starting because it works on induction principle and the induced EMF that is happening actually in the rotor circuit is dependent upon the relative velocity. So the relative velocity is constantly being opposed by the torque. So it is trying to catch up with the revolving magnetic field. Whereas here in synchronous motor the rotor and the stator field both of them are independent of each other. In one sense, they are not induced. It is not because of induction.

So, I am going to have to somehow synchronise the rotor speed with that of the stator speed. Unless, I probably give it a push, let say initially I give it a push and I get it very close to synchronous speed, which is actually not manually possible, very often we do this with the help of another prime mover, we try to get it up to speed close to synchronous speed. And then we say here you go, go and lock with the revolving magnetic field. That is the way synchronous motor is generally started.

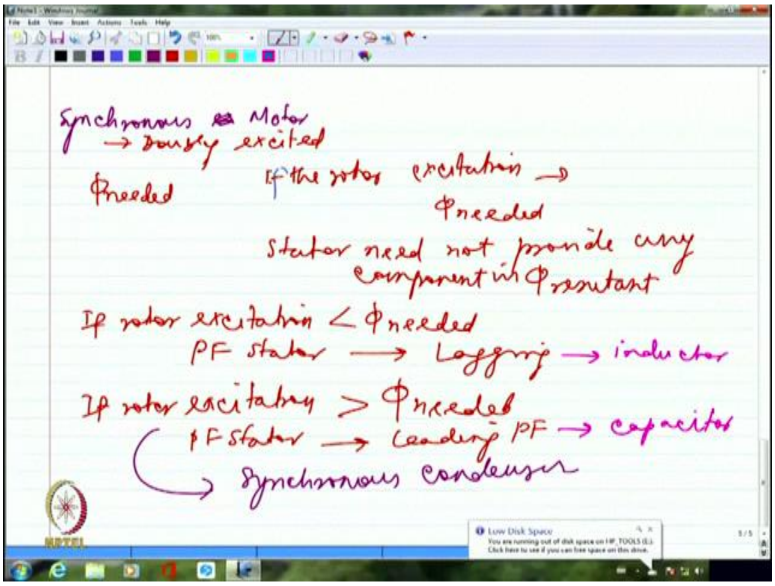
So, synchronous motor has one major negative point that is, it is not self-starting, especially, I am trying to start with 50 hertz. If I start with 0.5 hertz, then 1 hertz, then 1.5, 2, 2.5, if I go slow, then I gave rotor enough time to catch up with the stator revolving magnetic field. So if I do a variable frequency starting, if I have variable frequency starting with 0.25 hertz, 0.5 hertz, 1 hertz, 1.5 hertz and so on. I will be able to make the rotor catch up with the stator reporting magnetic fields speed.

Student: If we increase the number of poles will it help in starting?

Professor: See even if you actually increase the number of pole pairs correspondingly you would also have increased the number of poles in the stator winding because you want every time, all the poles to lock up properly. If I have North Pole South Pole, North Pole South Pole created by the revolving magnetic field, correspondingly, I should have North Pole South Pole, North Pole South Pole in the rotor. So that north and south match with each other and lock up with each other.

So, generally I am going to have definitely, a problem of starting in the synchronous machine, especially when it is working as a motor unless I kind of bring it very close to the synchronous speed and then allow it to lock up. So, synchronous motor is not going to be self-starting. So, this is one of the major negative point of the synchronous machine. But there are definitely plus points as well. I am trying to first of all discuss qualitatively the plus point, minus point, the basic working operation and things like that. Then we will go into the mathematical details, equivalent circuit and so on and so forth.

(Refer Slide Time: 37:17)



Now, if I look at actually the synchronous machine, please understand that I am going to have excitation, especially in the motor; excitation is provided from the stator, excitation provided from the rotor, both sides. So, I would say that synchronous motor is a doubly excited machine. It is not singly excited. So it is excited from the stator as well as excited from the rotor.

What I give is the excitation from the stator is three-phase, what I give is the excitation from the rotor is DC. So I am going to give excitation in both the cases. So the overall flux in the air gap or magnetism in the air gap is resultant of the stator flux and rotor flux. So that is something definitely called armature reaction here also. Armature reaction here is much more complex than what we see in a DC machine because it is a phasor. So we have to actually look at the air gap MMF or air gap flux as a resultant of stator plus rotor MMF or stator plus rotor fluxes.

Now, this flux, when they are aligning with each other that is what actually creates my overall torque. When they are trying to align with each other, that is what is creating the torque in my machine. So I am probably going to have basically some amount of current drawn from the stator, some amount of excitation given from the rotor. And I am ultimately going to look at the torque produced because of the interaction between the rotor flux and maybe the stator current.

If I give just sufficient amount of flux from the rotor then the stator might draw very minimal current to produce the overall torque that current might basically go towards producing real power, because the flux and the stator current both of them interact to produce the torque. If I do not provide sufficient amount of flux from the rotor, it might have to produce excess or more amount of flux by drawing more amount of current from the stator, which will fend for production of torque, as well as any shortcoming in the flux.

So, it will draw actually, if the flux is not sufficient from the rotor side, it will draw some amount of inductive current or reactive current from the stator side to make up for the shortfall in the overall flux. If I provide excessive amount of DC current and produce excessive amount of flux in the air gap. Rather, I might see that some amount of reactive power is returned actually from the stator side towards the supply.

So, I am looking at it this way, the total flux needed, I will call this as Φ_{needed}. If the rotor excitation, so if I am going to have the rotor excitation providing Φ_{needed}. Then stator need not provide any component in the air gap flux or in the resultant flux. In which case the stator may not really draw any reactive current at all, it may just draw the current which is sufficient enough to produce the torque.

Whereas if I am going to have rather, if the rotor excitation is less, it is less than Φ_{needed}, in which case it will require definitely to draw some amount of reactive current from the stator side as well, which will actually make up for any shortfall I had originally in the flux. Now, it is going to draw reactive current, which means the power factor of the stator side is going to be actually lagging.

Whereas I am going to have, if the rotor excitation is in excess, that is greater than Φ_{needed}, the flux needed. Please understand, unless I have a certain amount of flux. I will not be able to produce the torque because in the alignment process also the magnitude is very much involved. It is not only a North Pole and South Pole per se. It has to have certain magnitude, unless it has sufficient magnitude. I am not going to be able to pull the rotor. The rotor has some weight; it is not weightless.

So, I will need definitely particular strength of the flux, particular strength of the current from the stator side, all that put together only will develop a torque. So, I will have depending upon how much is the excitation, the excitation is in excess some portion of the reactive power will be returned back to the main, three-phase mains. Which means it is going to work like a capacitor. Here it will be lagging power factor, whereas here, I am going to have leading power factor.

So, which means I am going to have this work as an inductor, whereas here, I am going to make this work as a capacitor which actually tells me that I will be able to control the power factor on the stator side of a synchronous motor by adjusting the DC excitation. So the DC excitation actually is going to allow me to adjust the power factor of the stator side of a synchronous machine. Unlike, what I had in the case of an induction machine.

In an induction machine, no matter what I need the magnetising current, there is no other source of the magnetising current or flux, stator is drawing, magnetising current. Stator is also supplying the rotor current. In this particular case, it works, as though the rotor current component is actually drawn from the armature three-phase supply. And the magnetising current is provided by whatever is my rotor side, which is actually field.

So, the field is providing the flux component and the stator is providing something similar to the rotor current components in an induction motor. So both of them put together ultimately makes up for the torque production. So, if I do not provide enough flux from the rotor side, I have to supplement it from the stator side, which becomes like a magnetising current. So because of which I am going to have the power factor lagging.

If I provide excessive amount of flux, then I might have to return some portion of the magnetising current in one sense, which means it is going to work like a capacitor, if I provide just sufficient amount of flux. I am going to have unity power factor, so synchronous machine has this greatest flexibility, which is not there in any other AC machine, which will allow me to adjust the power factor by adjusting the excitation.

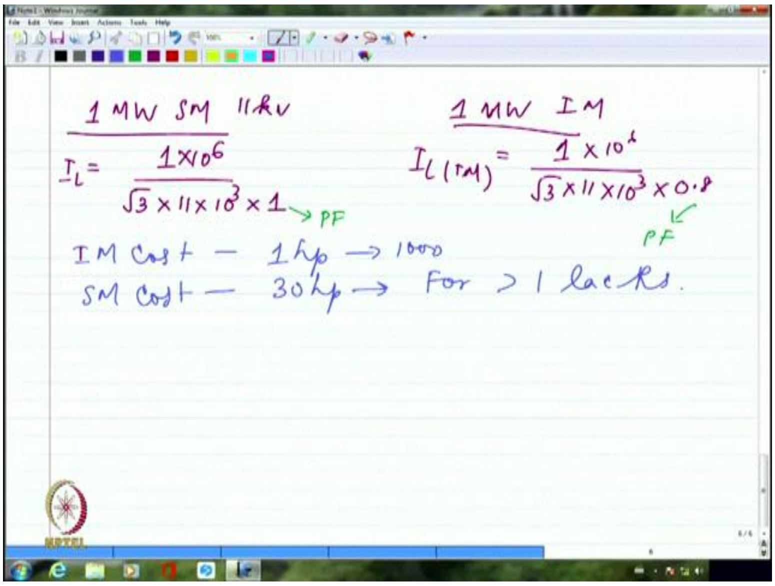
So, when I was a synchronous motor in a factory, which is, having N number of induction motors, all those induction motors will pull down the power factor. They are all going to draw inductive current; I can put one synchronous motor, which will probably draw leading current. So, the leading current and the lagging current will essentially cancel out with each other because of which I might ultimately get unity power factor.

So, my synchronous motor, when I employ in a factory which is insisted with induction motors, I would be able to nullify any reactive current that are being drawn by the induction motor, provided I put a synchronous motor which is having excess excitation. When I use a synchronous motor for providing for the reactive power, we may call that as synchronous condenser, condenser is a word for capacitor.

In older days we used to call them as condenser, we never used to call them as capacitor. So, whenever I am going to have a leading power factor operation of the synchronous motor it may work as a synchronous condenser, which will compensate for any reactive power drawn by any of the other induction machines and so on, or any other inductor in my factory. So this is one of the greatest advantages of the synchronous machine.

We talked about disadvantage, so I wanted to tell you about the advantage as well. Because of this particular property of the synchronous machine which can work at unity power factor. I can have basically lower current being drawn by a synchronous machine of the same capacity to deliver the same amount of power as that of an induction machine. Because induction machine, the power factor can be only 0.8 or 0.85 at the most.

(Refer Slide Time: 47:54)



So, if I talk about two machines induction and synchronous both of 1 megawatt capacity. So, I say that 1 megawatt synchronous machine and 1 megawatt induction machine. If I look at the current drawn $I_L = \frac{1*10^6}{\sqrt{3}*11*10^3*1}$. Let me assume that they are working on 11 kilo volt. Where, the power factor, which will be corresponding to 1 in the case of synchronous machine. If I want, I make it 1.

Whereas in the case of induction machine. I am going to have very clearly $I_{L,IM} = \frac{1*10^6}{\sqrt{3}*11*10^3*0.8}$. Here the power factor might be 0.8 or 0.85. Please note, very clearly induction machine is going to draw a higher current as compared to the synchronous machine. So, whenever I employ a synchronous machine of the same rating, I can put conductors which are thinner as compared to the induction machine case. I can also say if I am putting actually, higher current through the entire cable, entire distribution system.

I am probably going to have more losses as well, in all probability. So induction machine will bring down the efficiency quite a bit because of the power factor considerations whereas synchronous machines will be able to have a better efficiency because of the fact that the current drawn itself is somewhat lower. So, we are going to generally see that wherever very large capacity applications are talked about, where I am extremely concerned about the efficiency, synchronous machines generally are the first choices.

But if I do not care soo much about the efficiency, but I am worried about the initial installation cost, I will rather employ induction machine. So, if I actually look at the induction machines cost and synchronous machines cost. Induction machine cost is normally 1 hp cost Rs. 1000, generally. I am not saying you will be able to go on purchase in the market 1 hp machine for Rs. 1000. I am rather saying if it is 50 hp machine, roughly it is Rs. 50,000. If it is 30 hp machine, it is roughly Rs. 30,000.

Whereas for a synchronous machine. If I am talking about the 30 hp synchronous motor, it will be greater than about 1.2 lakhs or 1.25 lakhs. So, it is going to be really expensive. So, synchronous machine generally if I talk about a 30 hp machine. I am going to get it only for more than 1 lakh rupees, so it is very costly compared to the induction machine. So, if I am going to install machines in my factory. I will have to look at several things, I have to look at initial cost, I have to look at operational cost, I have to look at whether they will run on a maintenance free basis.

So, both these machines are generally tough competitors in many cases because the efficiency is really, really better. But invariably synchronous motors are used only in constant speed application because I have only 50 hertz. If I have 2-pole machine, it is going to run at 3000 rpm or not run at all. If it has to run at 1500 rpm it has to be a 4 pole machine, it will run at 1500 rpm or not run at all. I will not be able to get variation in the speed very easily in the case of a synchronous machine.

So most of the constant speed applications will use synchronous machine, most of variable speed applications might use DC motors first and if it cannot be used for some reason, then we may go for induction motors and so on. So, we look at the further constructional details and technical details and equations in the next class.