Electrical Machines
Professor G. Bhuvaneswari
Department of Electrical Engineering
Indian Institute of Technology Delhi
Lecture No. 34
Synchronous Machines: Constructional Features

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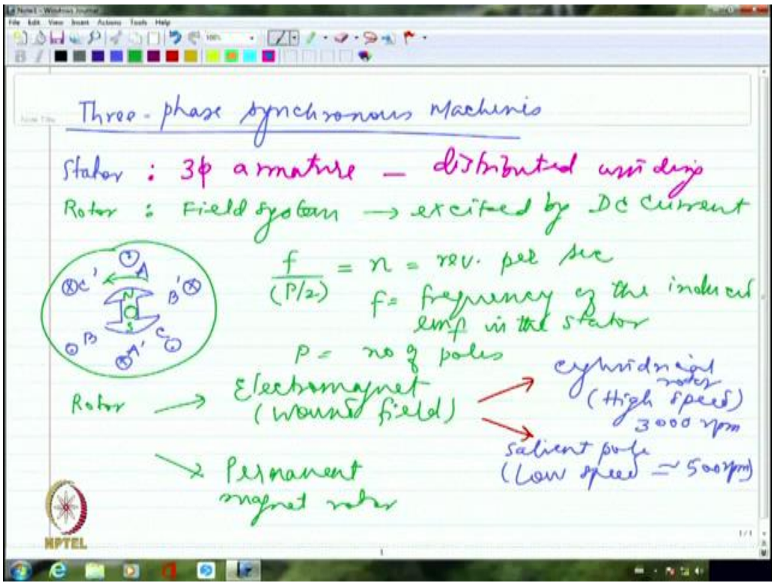

The three-phase synchronous machines will also have a stator which will actually house, the three-phase armature which will have distributed winding. And we said that the rotor will have the field system, which will be excited by DC current. So, if I have DC current I am going to have fixed North Pole and South Pole created and I am going to have that being rotated by the prime mover.

So, when that is rotated by the prime mover the armature windings which are placed in space distributed manner. They are going to face this magnetic field. So, I am going to have may be A A^l, B B^l, C C^l. This is the way I am going to have the windings that are located. I am showing them in the form of concentrated winding. So, I am going to have B B^l and C C^l. And then I am going to have the magnet, probably I can show the magnet somewhat like this.

So, I am going to have the North Pole and South Pole, maybe being rotated in this direction. So, it is excited with DC current, it is excited and it is rotated in a particular direction, mostly anticlockwise we take as the conventional direction of rotation, this is the shaft. So, once this is rotated, I am going to have A phase, B phase and C phase having induced EMFs, which are time shifted from each other by 120 degrees.

Instead, of having two poles I can also have multiple number of poles in which case the stator winding will also have multiple A phase winding, multiple B phase winding, multiple C phase winding like what we talked about in the case of induction machine. If it is 4-pole, we said A A^l, A_1 A_1^l, B B^l, B_1 B_1^l and so on. Similar thing will happen in the case of synchronous machine as well. That is why I said when we discussed with respect to induction motor stator structure.

The stator structure is absolutely similar when I compare the induction machine stator structure with that of the synchronous machine stator structure. So, I would say the frequency of the induced current will depend upon the number of poles. So, f=p/2 will also give me whatever is the speed. If I have a particular frequency of current injected into the stator, I am going to get a revolving magnetic field which is governed by the frequency.

The speed of the revolving magnetic field, and if I have a prime over rotating at n revelations per second then correspondingly I am going to get an induced frequency in the stator winding which will correspond to $n = \frac{f}{p/2}$. So this is revolution per second, my f is going to be frequency of the induced current or induced EMF in the stator and p is going to be equal to number of poles, number of poles is true, I mean it is going to be equal if I look at it from the stator side or rotor side, both of them are going to be equal to each other, there is a problem as such.

We said the rotor can be of two types, it can be made up of electromagnetic in which case we call it as wound field. So, in which case, it is going to be excited by DC current, so we call this as an electromagnetic or wound field. And in this itself, we talked about two types, in one case, the rotor and the stator in between whatever is the air gap that is going to be uniform, completely in which case we call it as cylindrical rotor. There is no protrusion from the rotor side.

So you are going to have essentially the air gap being uniform in the case of a cylindrical rotor. So this is generally used in high-speed alternator or high-speed machines. So about 3000 rpm, whereas the salient pole system is going to be used only in low speed, maybe close to 500 rpm. That is how it is used normally, so that the centrifugal forces do not play a major role especially in deforming the rotor structure completely.

Then we also talked about one more which is actually a permanent magnet machine or permanent magnet rotor. So, it is going to have permanent magnets in the rotor structure, we do not need any excitation. So, this is going to essentially allow the machine to have its own excitation with the help of permanent magnet. So, on the whole the machine will have a revolving magnetic field physically created it because of the rotor magnets.

And electrically created because of the stator induced EMF eventually, which will cost induced current that is also a three-phase current that we definitely create a revolving magnetic field. So, ultimately both these fields align themselves with each other. That is what happens whether it is a generator or motor. The fields essentially align themselves with each other.

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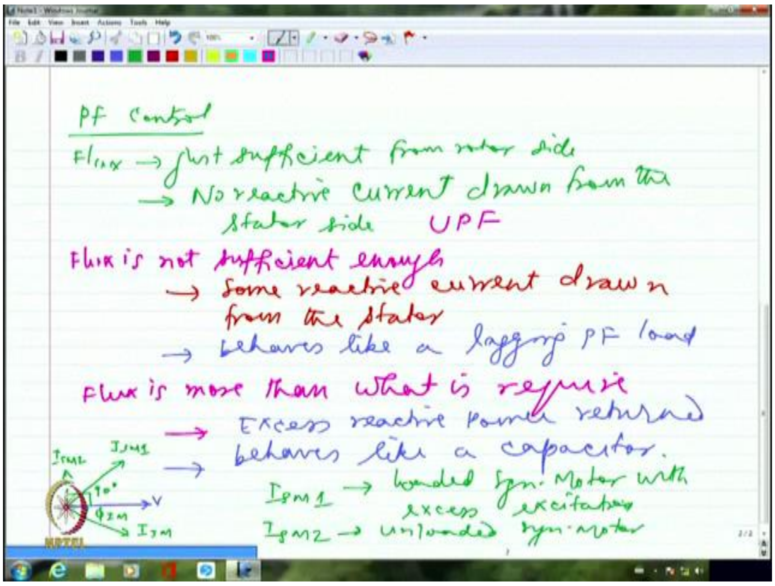

Now, we also said that there is a possibility of power factor control in general, in a synchronous machine because I am going to give excitation, especially if it is a motor. I am going to give excitation, both from the stator as well as rotor whereas in an induction motor I am going to give excitation only from the stator. So the stator draws a magnetising current fundamentally to establish a flux. Whether there is load or not, that is immaterial, it is going to essentially establish a flux. The same thing happens in the case of synchronous machine as well.

So, if I am establishing the flux only from the rotor side, which is sufficient enough at this juncture, it does not have to draw anymore magnetising current from the stator side. So whatever is the current drawn from the stator side only will go towards producing real power, which is in manifested in the form of torque, which is rotating the motor. So, if the flux is just sufficient from the rotor side. Then I am going to have no reactive power. So this is from the rotor side.

So in which case there will not be any reactive current on the stator side from the stator side. Due to which I will have unity power factor. So, it will behave as though I have connected a resistance, basically in the system. That is three-phase supply if I have created three resistances for example. It will draw a unity power factor current. So, it will essentially behave somewhat like that, depending upon how much torque, it has to develop.

Rather if I am going to have flux is not sufficient enough. Then I am going to have essentially some reactive current is drawn from the stator side to make sure that the shortfall is actually taken care of. So, in which case, the stator is going to behave like an inductor so behaves like a lagging power factor load. On the other hand, if I am going to give more flux, so flux is more than what is required at this juncture. So, in that case, it is going to draw, definitely it is going to rather supply excess amount of reactive power back to the grid.

So, which means I am going to have excess reactive power returned to the three-phase supply. So, in which case I am going to have essentially this machine behaves like a capacitor. So, especially a synchronous motor, which is probably employed in a factory, which has N number of induction motors, which are all drawing lagging current, I would be able to make one synchronous machine compensate for all that reactive power by actually providing a large amount of excitation to it.

So that it behaves like a capacitor. So you can imagine if this is my voltage, I am just showing this as a form of phasor diagram. I am going to have the induction motor current probably somewhere here, if it is loaded. So, this is going to be the power factor of the induction motor. So this is the current of the induction motor.

Whereas synchronous motor current I would be able to adjust in such a way that, if it is hardly having any mechanical load I may have only a reactive current, hardly having any real load. In the case, the real power delivered will also be really, really minimal. So I am showing the current to be completely reactive, it is that 90 degrees. So it is like a pure capacitor drawing a current or if it is having some amount of load, then I may have a current somewhat like this, depending upon. So, this can be I of synchronous machine, one let me say this is I of synchronous machine two.

So, I_{SM1} shows loaded synchronous motor with excess excitation whereas I am going to show here, I_{SM2} is floating or unloaded synchronous motor. So it is not at all loaded here. That is why you are not seeing any real power or real current being drawn by the machine. Please understand this is at 90 degrees. So, if I try to write $VI\cos\phi$, $VI\cos\phi$ per phase will be basically the real power and real power in this case is 0. So the synchronous machine is literally on no load, it is not supplying any power to any of the loads, that is what it means.

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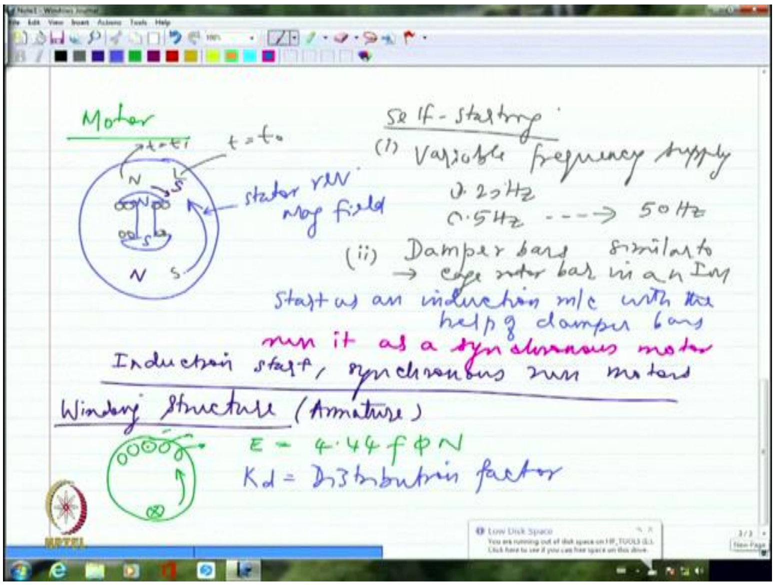

Just come back to the principle of operation of the machine, especially as some motor. I told you that I am going to have a revolving magnetic field created because of three-phase windings. That are space distributed in the stator, which are being injected with time distributed current, three-phase current. So, this is going to be the stator revolving magnetic field.

I have the rotor, which is actually going to have, maybe the North Pole and South Pole created. Because of either a permanent magnet or because of the electro magnet, electricity that I have injected, DC current that I have injected. Now, if this is actually the revolving magnetic field. I am probably going to have South Pole and North Pole, at this instant somewhat like this. Because of which the rotor will be attracted towards the South Pole.

So it may try to move in the clockwise direction. It will try to move in the clockwise direction to lock up with the pole of the stator. But by the time the rotor moves even slightly because of its inertia, it is going to take a while. But the revolving magnetic field is really running at a very, very high-speed. If it is running at a high-speed, within no time, you are going to see that suddenly North Pole comes here and South Pole comes here.

So it is going to move soo fast that, maybe this was at time $t=t_0$. This may be at time $t=t_1$ because it is after all only half revolution. So by the time the rotor things of picking up speed, even aligning with the stator field, it is not even able to do that before that the stator field has already crossed almost 180 degrees. So, now it will field repulsion. So you would see that continuously there will be attraction and repulsion taking place and that will cost only some kind of dwindling motion or vibration in the poles.

So inherently the synchronous motor is not self-starting. So this will not be self-starting inherently like an induction motor. So, either we give variable frequency supply, where we actually give initially may be 0.25 hertz, then 0.5 hertz and so on and so forth. And slowly increase it to 50 hertz. So, what will happen is at every incremental frequency, you give sufficient time for the rotor to catch up with the stator revolving magnetic field. So, it catches up further and further because of which it will be dragged along with the revolving magnetic field of the stator.

So, the rotor works exactly at synchronous speed or does not work at all. That is the way it is going to function, the synchronous motor will run at synchronous speed or will not run at all at any other speed. That is the reason why it is called as the synchronous motor. Because it is going to run only at synchronous speed, it is exactly opposite of induction machine. Induction machine cannot run at synchronous speed, it has to run at always or speed, which is less than synchronous speed.

So this is one of the methods of starting the synchronous motor. Another method normally that is used because some of your classmates yesterday asked, why cannot you have some kind of winding in the rotor which can be short-circuited, in which case it will exactly behave like an induction machine. So, it is really done in a synchronous machine, the winding what is actually residing in the stator, maybe you will have a few bar kept here.

Those bars are very similar to the rotor bar of the squirrel cage. And those bars are again going to be short-circuited, maybe with the help of endearing or it simply put copper conductor, which is going to short-circuit the complete bars, all the bars which are being used. Those bars, generally is known as damper bars. So, damper bars are basically similar to cage rotor bar in an induction motor. So these are going to get induced current, induce EMF, induced current, when I am actually trying to start the machine.

When I am trying to start a machine, I am going to have basically hardly any speed. Because of which there will be a relative velocity between the rotor conductors and the revolving magnetic field speed. So this relative velocity is going to cost induction of EMF, induction of current that is going to make the machine actually develop a torque because of the interaction between the rotor damper bar current and actual current of the stator winding or the fluxes of the two windings.

Those two are going to actually interact with each other to get whatever is the torque that is required. That torque will accelerate the machine almost close to the synchronous speed. The moment it comes very close to the synchronous speed, at that point I can turn on the DC supply. Until then I do not have to turn on the DC supply. So at that point, if I turn on the DC supply, immediately the rotor poles will go and lock-up with the stator pole or the revolving magnetic field poles.

So, both of them are going to lock up with each other and because of which now the damper bars whatever they are sitting, they are not going to have any more currents, because now the rotor is rotating at synchronous speed. If the rotor is rotating at synchronous speed, you are not going to see the damper having any induced EMF at all; they are not going to see any relative velocity. So, if there is no relative velocity the damper bars are just sitting there like a dummy. Every time there is going to be some disturbance, some speed coming down or going up due to some reason.

Maybe there is a frequency fluctuation, maybe there is some kind of load fluctuation, if the speed fluctuates at that point damper jumps into action. The damper will not have any action when the speed is synchronous speed, whenever the speed is different from synchronous speed the damper bars are definitely going to get induced currents, depending upon how much is the difference in the speed between the rotor speed and the revolving magnetic fields speed.

If there is any difference immediately there will be an induced current in the damper bar. And that damper bar current is going to produce a torque, which is similar to one induction motor torque. So that will try to push the machine back to synchronous speed. So damper bar gets that name because they damp out any oscillation in the speed, it is going to make sure that it is going to aid the rotor always goes towards synchronous speed.

So if there is any oscillation in the speed, it will always try to damp out the oscillation and push it towards synchronous speed. So that it goes back to the locking action between rotor poles and the stator revolving magnetic field poles. So this kind of mechanism where I am going to run it initially or start as an induction machine with the help of damper bars and I am going to run it later as a synchronous motor.

So, these are generally known as induction start synchronous run motors. So these are generally used only at lower ratings, you cannot use them at very high ratings as it is we said induction machine is going to carry a current, which is corresponding to almost 6 to 8 times the rated current when I am starting them, this will be even more. Because I have less number of induction bars. I am not going to have so many cage rotor bars.

So, I might have to actually look at the whole thing in the viewpoint of how much torque I will require? How much current I will require to start this machine that may be enormously high when I talk about very large capacity synchronous motor? So induction starts, synchronous run motors are generally used only in somewhat lower capacity, some of the clocks, microwave turntables where you wanted to rotate at a particular speed, constant speed.

Those things are run with synchronous motors; those are all small capacitive motors. For example, tape recorder if I want that to run at a particular speed only obviously. If you try to run it too fast or too slow music will not be music anymore. So, if you want the constant speed in those cases synchronous motors come in really, really handy, so much so, for the basic action of the synchronous motor.

Now, let us go a little bit into, the winding structure because we never talked about winding structure in the case of induction machine as well. I am talking about armature winding. I am not going to really get into the detail of how the winding diagram is drawn like what we did in the case of DC machine. I am trying to give you an idea as to when I have distributed winding versus when I have concentrated winding; it is going to introduce some factors when I actually get the voltage being induced, when I try to derive the voltages being induced. It is going to introduce a few factors.

Let us say I have a concentrated winding. If I have a concentrated winding, I am probably going to have all the A phase winding here, all the A phase returned windings or conductor here. So, if I look at actually A phase winding, A phase winding the entire number of turns are going to face the North Pole at its peak at the same instant. Similarly, South Pole at its peak at the same instant, it is not going to be any different at all in terms of the time delay, there will not be any time delay.

So, if I actually look at, if there are normally we write the equation again similar to what we wrote in the transformer. We would say $E = 4.44 f \phi N$. I am talking about for every phase. So the flux will be corresponding to flux per pole and number of turns will be corresponding to every phase. So this is going to be the voltage induced if I assume that all these N turns are facing the maximum flux or minimum flux at the same time.

But I know for sure, when I am going to have a distributed winding, I am probably going to have this distributed all over the place. So probably this will face, if especially if I am talking about a field rotating in anticlockwise direction like this. I am going to have this facing the flux first. Then this is going to face it, then this is going to face it and so on and so forth. So there will be definitely different in terms of the induced EMF quantity in each of these turns. I am not going to get the same value of the induce EMF in all of them.

So, when I add them. I cannot say it is N times whatever is the induce EMF per turn that is not correct. So when I distribute, how exactly this gets modified. Let us try to take a little bit of look into that and then that introduces a factor called K_d which is actually a distribution factor and K_d is generally less than 1. Obviously if I make scaler sum, I am going to get N times EMF induced per turn. Maybe if I do the vector sum because they are all delayed, I am going to have them as phasers which are delayed from each other by certain angle.

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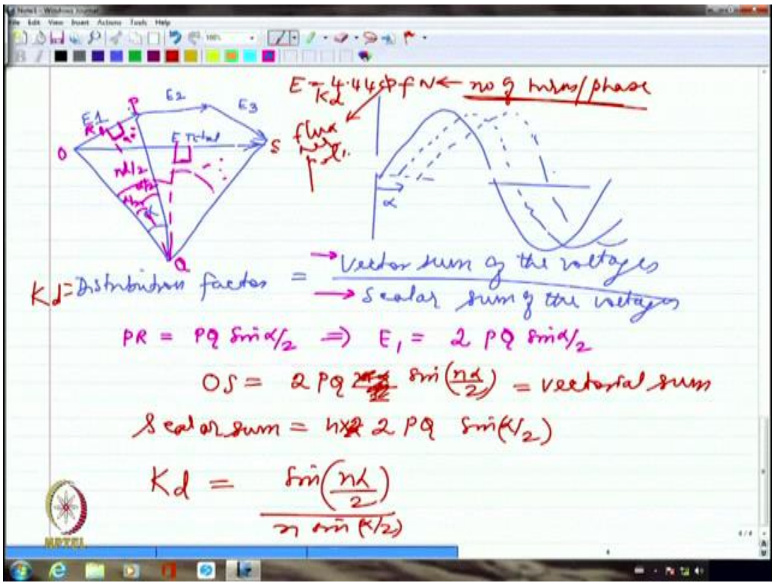

So, let me take maybe about 4 slots. So let us say I am going to take one slot here, one more slot here, one more slot here and one more slot here. If I try to look at actually how much is the EMF induced in this that will be actually leading the EMF induced in the next slot by certain angle. Because first the flux actually faces, a particular slot, corresponding to particular slot the North Pole is aligning itself. After sometime, it is coming to the next slot, after some more time it comes to the next slot and so on and so forth.

So, I am going to have each of them getting the peak of the EMF slightly delayed from each other. So, if I actually plot each of them I may have actually one of them. So, if I say that one of them is having a value like this. The second might have a value, which is delay from the first one like this. The third one will have value, which is again delayed from the second one like this. Each of the induce EMF in the consecutive slots will be delayed from each other by certain angle. That angle will be corresponding to the angle subtended by the line or the radius that is joining it to the centre of the armature.

So, between the two adjacent slots if I try to see what is the angle, if I may call this as some α, each of these are going to be delayed from each other by an angle α. This is going to be the delay; I would encounter when I am looking at the voltage B forms of each of these turns. So I am going to have these delay α which I can actually show it somewhat like this, maybe one EMF is like this. The next EMF is like this; the third EMF is like this. All the EMF will have the peak value or the magnitude to be the same.

But they are time delayed because of the fact that the North Pole faces each of those windings after a little bit of time delay. Because it has to travels as angle an α before it faces the next set of slots. So, I am going to have this as let us say E_1 maybe, this is E_2, this is E_3. I am showing them a vectorially. So, I am going to have three EMS which are corresponding to three adjacent windings which are in adjacent slots. So, I am going to have this. I am just taking for heck of it, just three slots. I could have taken more, but we are just trying to look at the whole thing.

When I add them vectorially I am going to get this as the total EMF, vectorially I have to had all the three EMF at any instant of time, that will be the total EMF. This is the total EMF per phase. If I assume that these are the windings belonging to a particular phase, A phase or whatever. So, I am going to have now the distribution factor will be the ratio of the vector sum of the voltages divided by the scalar sum of the voltages.

Please remember that in transformer, there is no space distribution of winding, all the windings were concentric and so on and so forth. Because of which all of them were having the induced EMF as the peak as the same instant of time, there was no phase shift. Whereas in the case of a synchronous machine there is a phase shift because I am going to have them specially distributed that is the reason. So, I have to this scalar sum is similar to the transformer voltage, whereas the vector sum is whatever I get in induction machine or synchronous machine.

Now, if I try to just draw perpendicular bisecting this angle and this is the perpendicular, this is 90 degrees. So this is going to be α/2, this is also going to be α/2, and I am trying to now look at what is the value of half of this voltage. If I may call this as OPQ I want to get what is OP/2 from the midpoint to P or midpoint to O. That is what I am trying to look at. So, I can say maybe let me write this as R.

So, I can say PR is going to be whatever is the radius of the complete circular structure of the stator, the inner rim of the stator multiplied by whatever is the angle here. So, I am going to have $\sin(\frac{\alpha}{2})$, multiplied by whatever is the radius. This is the radius which is the hypotenuse.

So, I should say $PQ\sin(\frac{\alpha}{2})$. So, I can say that the voltage $E_1 = 2PQ\sin(\frac{\alpha}{2})$.

So, if I have such n number of such voltages. I have to say scalar sum basically is going to be n times whatever is the total number of such vectors. Whereas, if I try to look at the vectorial sum. Let me again draw perpendicular here and I am looking at actually this as, the 90-degree point. I understand that this is not exactly equivalent to the radius but assuming that it is a big circle. It is not going to really have so much of difference between whatever is the radius and whatever is this length. It is not going to have so much of difference.

So, I should be able to write this as nα/2 and this also has nα/2, here I have considered only three of them. But there will be n number of such things in a bigger machine. So, I should be able to write this as, so I am going to have nα/2 multiplied by whatever is PQ or OQ all of them are radii basically of the machine. So I should be able to write $PQ\sin(\frac{n\alpha}{2})$.

So, this is going to be 2 times, this will be the overall length of. If I say this is OPQR and then this is S. So, I should say OS will be $2PQ\sin(\frac{n\alpha}{2})$. So, this is actually the vectorial sum.

Whereas the scalar sum is going to be $n2PQ\sin(\frac{n\alpha}{2})$. So, I can write $K_d = \frac{\sin(\frac{n\alpha}{2})}{n\sin(\frac{\alpha}{2})}$.

Where α is the angle subtended at the centre or the angular shift between the adjacent slots. I can calculate what is the, if there are 360 slots, very clearly I am going to have only 1 degree between 2 adjacents slots. So depending upon how many slots are there spread over the complete 360 degrees I should be able to calculate what is α. That is the angle subtended at the centre by the 2 adjacent slots.

And N is how many slots are allocated per pole per phase. So, I should say this flux what we actually originally wrote $4.44 f\phi N$. I should say this corresponds to flux per pole because there are N number of poles I can have; that multiplied by so many poles. Because for each of the pole there will be one A sitting, A, A, A_1, A_2 and so on. If I have more and more number of poles, correspondingly for the South Pole I will have A^l, A_1^l, A_2^l and so on and so forth.

So, we are looking at the voltage, ultimately induce which corresponds to flux per pole. But we are, ultimately when we are multiplying by this, this will be the number of turns per phase. So, all of them are ultimately added together clearly because I assume that all of them are connected in series, ultimately.

And I am going to have this multiplied by K_d, where K_d is the distribution factor because we assume that all of them are located in the same slot. That is why we added them, simply multiplied them by N. But they are not located at the same slot; they are located at adjacent slots and I am going to have definitely of phase shift between them. So, I cannot make a scalar sum rather, I have to make a vector sum.

So we are going to have this creeping in, this K_d will creep in every time I have distributed winding in induction motor and synchronous machine, both of them, if I look at the induce EMF they will have this factor K_d.

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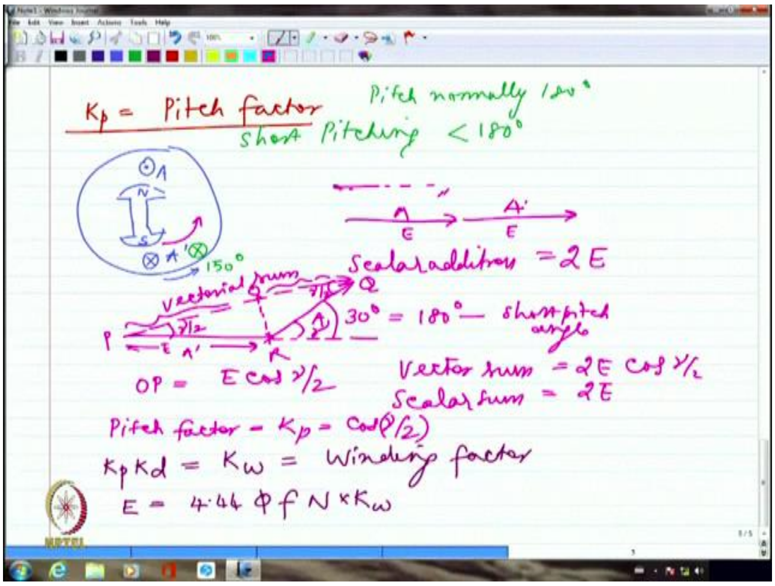

There is one more factor which we normally considered, which is known as K_p, pitch factor. Normally we assume that between the forward and the returned the complete angle is about 180 degrees, especially if it is wound for two poles it is going to be 180 degrees. If it is wound for four poles, it will be 90 degrees. But electrically it will be still 180 degrees that is what we assume. So, I am going to have normally in a stator if this is A and this is A^l I am going to have between these two I will have exactly 180-degree shift.

So, when this is actually facing the maximum flux of the North Pole, this will simultaneously phase the maximum flux of the South Pole. So, when I look at the induce EMF I can directly add two of them together, I can say two times E is the overall voltage induced in A and A^l, that is what I am going to assume. But that need not be the case, most of the times in design; they try to actually make the pitch slightly less than 180 degrees.

What they do is A is here, A^l maybe actually somewhere here, maybe 30 degrees or 15 degrees ahead of whatever should have being the position of A^l provided I have exactly 180 degrees phase shift. So, I may have this at some 150 degrees or 170 degrees or something like that, depending upon how I am designing the machine.

This is done specifically to eliminate some of the harmonics in the waveform. I am not going to get into the details of how the harmonics are eliminated. If you guys want to read it, you can do it from PCs and appendix, there is one appendix given completely on the armature winding. If I get into that, that will take up another one and a half hours. So, I do not want to get into the harmonic elimination, but generally this kind of pitch is known as short pitching.

The pitch is normally; normal pitch is 180 degrees. But I am going to reduce the pitch which is less than 180 degrees, so we call this as short pitching. So, whenever I do short pitching I cannot say that I am going to have actually, originally I should have E+E, I should have had one of them as E another one also as E. So, So, when I do the scalar addition, this is corresponding to A, this is corresponding to A^l.

So, when I do the scalar addition, it is going to be simply 2E, assuming that both of them are facing the maximum strength of North Pole and maximum strength of South Pole. This will happen only if I have 180-degree pitch. Both of them are going to face the maximum strength of North Pole and maximum strength of South Pole at the same instant. Rather than that, if I am going to have, maybe this is facing the maximum strength of South Pole a little later than, when A faces the maximum strength of North Pole because it is going to rotate in this direction.

Because of which I am going to see that both of them are not facing the maximum strength of north poles and south poles at the same instant of time. So, the two maximum voltages or peak voltages are going to be time shifted again, so I might say, one of them probably is like this, the other one is somewhat like this. So, maybe this is A^l and this is A. The voltages of each of them I am showing it as though they are shifted.

Now, how much ever is the angle of this shift depends upon how much is this short pitch angle. If I say that A^l is placed at 150 degrees rather than 180 degrees. I am going to have this angle to be 30 degrees, which is corresponding to 180 minus whatever is the short pitch angle. So, I am going to have this as my phase shift between the voltages induced in A and A^l.

Let me call this angle as some γ. Now the vectorial sum would be this. So, let me write this as PQR. This triangle I am mentioning as PQR. This angle is 180- γ. So, I should be able to say this should also be γ /2, this should also be γ /2 by geometry. Because if this is 180- γ, then I add all the three I should get 180 degrees. So this, this two should be equal, this is an isosceles triangle.

So, I will have γ /2 as the angle here, γ /2 as the angle here. Let me write this as the midpoint. So, maybe this point I can mention as O. So, I should be able to write OP as whatever is E, if I call this length as E. So, this will be $E\cos(\gamma/2)$. So, if I want the vector sum, I am going to have the vector sum to be $2E\cos(\gamma/2)$. Because I have to eventually take this length and take this length as well.

Whereas if I look at the scalar sum, we already wrote that is 2E. So pitch factor or $K_p = \cos(\gamma/2)$. Where γ is the angle by which the pitch is shortened. Instead of having 180 degrees, how much I have shortened it? That is going to give me how much is the pitch factor. So these two put together, that is K_p and K_d the product of these $K_p K_d = K_w$ called as K_w which is the winding factor.

The first one is essentially due to the distribution of the winding. The second one is due to the short pitching of the winding; I may not do it exactly at 180 degrees. Because of which is again that introduces some kind of reduction into voltage. So overall, I should be able to write the voltage as $E = 4.44 f \phi N K_w$. So, when I look at the transformer vice versa and I look at an induction motor or synchronous machine I will get slide reduction into voltage because of the distributed winding.

But we would like to utilize the maximum portion of the iron effectively. And that is the reason why we are trying to put the windings throughout the slot basically. If we are able to do that then we are essentially utilizing the entire surface of the rotor as well as the stator. That is the reason why generally we distributed.

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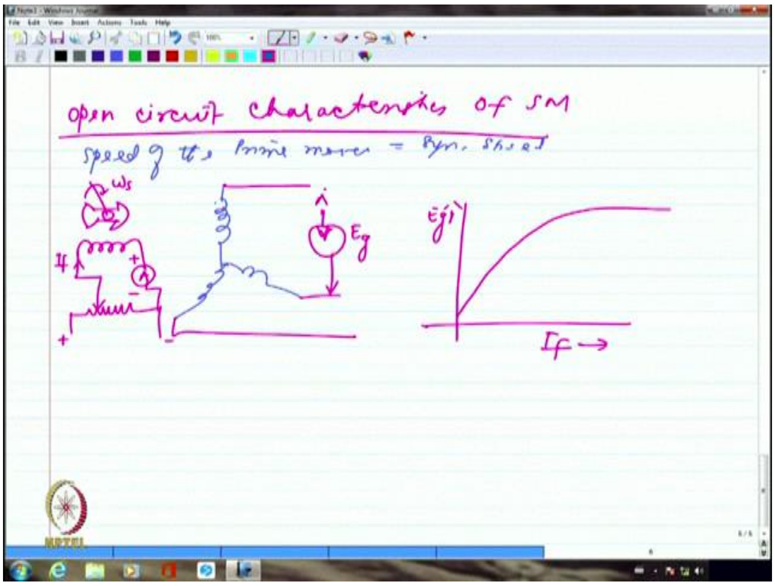

Now that we have at least seen what is the difference between the structure in terms of its winding for a transformer and for an induction motor or synchronous machine. Let us try to first of all, look at the open circuit characteristics of a synchronous machine. It is very similar to what we did in the case of a DC machine. In the case of a DC generator what we did was to run the DC generator with the help of a prime mover at a particular speed. And then we gave field excitation.

The field excitation was slowly increased, and then whatever is the voltage generated was measured with the armature on open circuit. So, we are going to do the same thing for getting the open circuit characteristic. So, we are going to run, so the speed of the prime mover will be synchronous speed. And we are going to have maybe another motor or another IC engine or any other prime mover, basically to run the machine and that speed should be kept as a constant.

And that speed should be exactly corresponding to synchronous speed because most of the synchronous generators are designed for 50 hertz. If they are designed for 50 hertz and if it is a 4 pole machine, you have to run it at 1500 rpm. If it is designed for 50 hertz, but if it is a 2 pole machine you have to run it at 3000 rpm. So, we are going to keep the speed as a constant. So, we have actually the armature here. This is the three-phase armature and here is my field, so this is the field.

So, field I am going to give maybe a current, which is continuously varying. So, that I would be able to measure what is the induced EMF at different values of field current. So, I am going to have the field, here I am just showing the field as though it is separate, it is not the winding should be along with that. But I am going to rotate this at synchronous speed.

Now, I am going to inject the current which is actually the field current and I will put an ammeter so that I will be able to measure the field current. And invariably what I am going to actually supply as the voltage will be a variable voltage. So, I am going to have this as a potential divider. So, I am going to have a potential divider, which is actually connected to a DC source and I am going to have this ammeter connected here and this is going to be connected with the help of a jockey point.

So, I will have essentially a variable voltage being applied to my field system because of which I am going to have the ammeter reading different values of currents, depending upon how much voltage I am applying. Now, I will measure what is the voltage that comes out either across line to line or across or between the neutral and the phase. So, the voltage is measure what I am going to plot here at a given speed how my V_G or E_G let me call this as generated voltage is varying with respect to the field current.

So, I may have similar characteristics like what I got in the case of DC machine. So, I will be getting some amount of, maybe very meagre amount of residual voltage. But eventually it will increase and it will saturate at some portion of time. So, this is giving you an indication of what is the internally generated voltage in a synchronous generator. So, will look at further characteristic of the synchronous generator, synchronous machine, in general, and the equivalent circuit.