Electrical Machines - II
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Lecture - 90
O.C and S.C Test on Synchronous Generator

So, we were discussing about the salient pole synchronous machines and we have found out how to draw phasor diagrams very quickly and correctly and that is absolutely necessary and there may be different conditions. There may be a synchronous salient pole motor connected to the bus even with field current 0 because a salient pole synchronous motor can also deliver power or absorb power depending upon whether it is generator or motor mode.

Even if the field current is 0 because of the second term sine to delta terms where there is no E f, V square terms comes; V is finite bus voltage and these are the operations and there are very interesting problems on with excitation 0 or even without any excitation 0.

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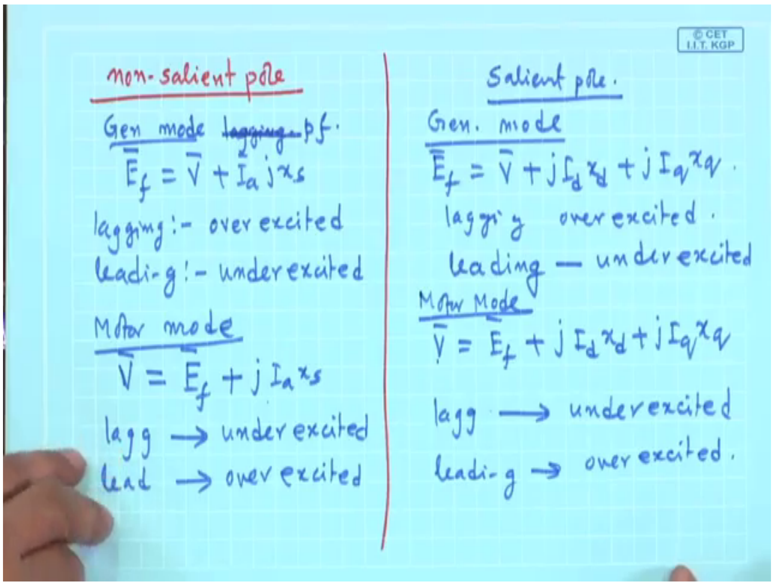

Now, I will tell you we will now switchover between salient and non-salient pole machines. For example suppose I ask you very quickly I will go, so that you can do it. Suppose I will say that it is a non-salient pole machine. In non-salient pole machine that is cylindrical rotor synchronous machine.

Suppose I say it is generator mode. I am revisiting those basic ideas, but in the light of what I have discussed in salient pole machines as well generator mode and lagging power factor. The equations I will be using is E f is equal to in generator mode this is the thing I a j xs is not, and we know how to draw it.

Similarly, in salient pole machine if you see the equation salient pole machine generator mode. The equation is E f is equal to V plus j I d xd plus j I q x q and of course, there may be I r a term that can be also taken into account while drawing the phasor diagram. So, generator mode whether lagging or leading these equations are correct all the time, but only thing is a if it is lagging, then I will say generator is over excited here also lagging over excited. If it is leading equation remains same; leading under excited in case of generator.

These are things you must remember, no other way and leading under excited same. In motor mode it is better you write down the equation V is equal to you start with E f, drawing the phasor diagram plus j I a xs; V and E f are interchanged. In case of salient pole machine I will be writing V is equal to E f plus j I d xd plus j I q x q. See the interchange of these two positions and this is motor mode.

And similarly of course in motor mode lagging power factor means under excited opposite under excited and leading power factor is over excited. Similar is the case here. Lagging power factor under excited it is motor mode, this was generator motor. So, under excited and leading is over excited ok. So, this you must remember. This page is important to draw the phasor diagram and of course, in case of a generator mode be it salient, non-salient if it is generator mode, E f will be ahead of V and if it is motor mode no matter whether it is salient or non-salient mode machine, V will be above E f and these are the clues based on which the phasor diagrams are drawn.

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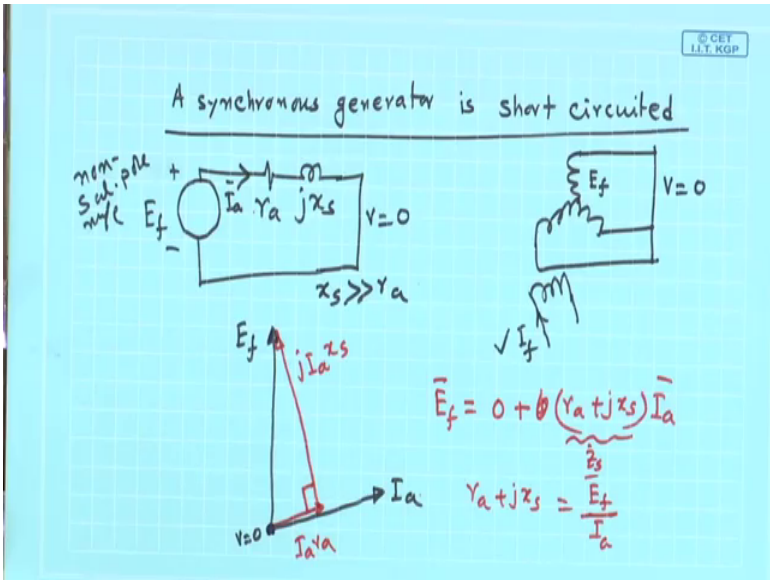

For example if I say a synchronous generator is short circuited that is the situation is like this. The armature terminals are not connected to bus, but it is short circuited which means that V equal to 0 terminal voltage is 0. Of course, there is excitation is present. So, there will be E f is generated.

So, if you look at the equivalent circuit it is plus minus E f and this is ra j xs for non-salient pole machine, and these are shorted; here V equal to 0. So, I want to draw the phasor diagram of the situation. The phasor diagram is like this, there is induced voltage and it is a simple r xs circuit with xs as we know much higher than ra. So, the phasor diagram of these will be simply and there is no question of d, q axis in case of non-salient pole machine. Therefore, if this is E f the current will be lagging almost by 90 degree I a and V is equal to 0 here.

So, in case of generator you start from V which is 0 so, add to it I a ra and jI a xs and this is 90 degree. Therefore, E f in this case will be V 0, V plus j ra plus j xs into I a is not, this will be the phasor diagram. And this current is called the short circuit current of this and this is the direction of the current, understood? Therefore, you see by doing short circuit test and open circuit test on a non-salient pole synchronous machine, you will be able to determine the value of zs.

And if you measure that will be equal to ra plus j xs is equal to E f by this short circuit current I a will give you this magnitude and you will be able to calculate the value of zs.

ra can be measured with the help of some DC supply separately and then, xs and ra can be separated.

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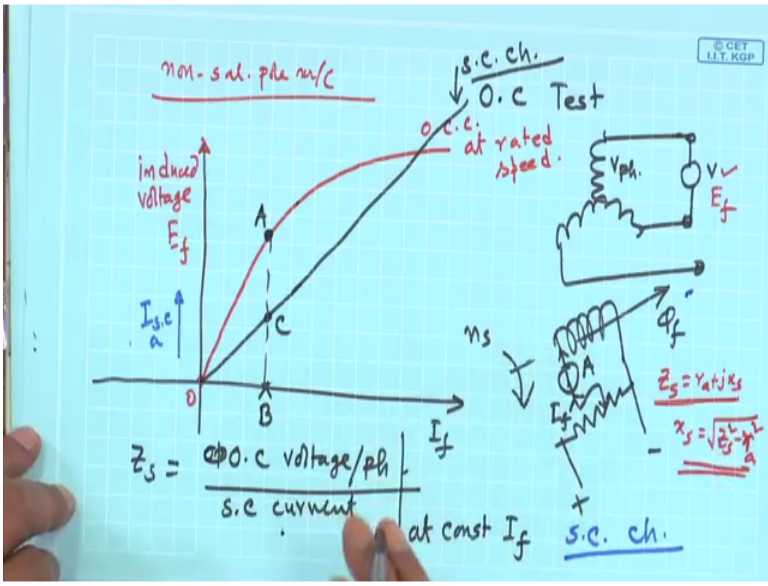

But only thing I will like to say that although I have not told I have always assumed xs to remain constant, non-salient pole machine I am telling non-salient pole machine. Since if you do two tests are generally done open circuit test, what is done in open circuit test is this. You have this generator, run this field coil by some prime mover at rated speed, so that 50 Hertz is generated; run it at rated rpm. And here you connect some circuit like this with DC, record this ammeter reading which is I f and here do not connect to any bus or load, connect a voltmeter that divided by root 3 will give you the V phase voltage; induced voltage.

Now, if you go on changing the field current which decides the flux phi f, the induced voltage will increase ok. How it will increase? It will increase just like the initially you will find it is almost linear and then saturation will take place. What is this axis I am plotting; induced voltage E f which is recorded by this voltmeter. So, magnitude of that field current at rated speed that is important rated speed. Why this characteristics will be like this? Because of the fact that as you go on increasing the field current, a time will come, saturation will take place and it will bend.

Therefore the value of the zs that you will calculate at the initial phase in the linear portion in fact in my discussion I have always used the unsaturated value of synchronous impedance. Of course, zs has got two parts ra plus j x; ra can be separated is not, how? Measure the armature resistance by applying some small DC voltage at rated current V by that current will give you armature resistance, then xs will be; I will not dwell upon this much, but you know this, so xs.

But if you and how do you get this zs, it is called the open circuit characteristics. Now there is another characteristics called short circuit characteristics. So, for that you have to do short circuit test.

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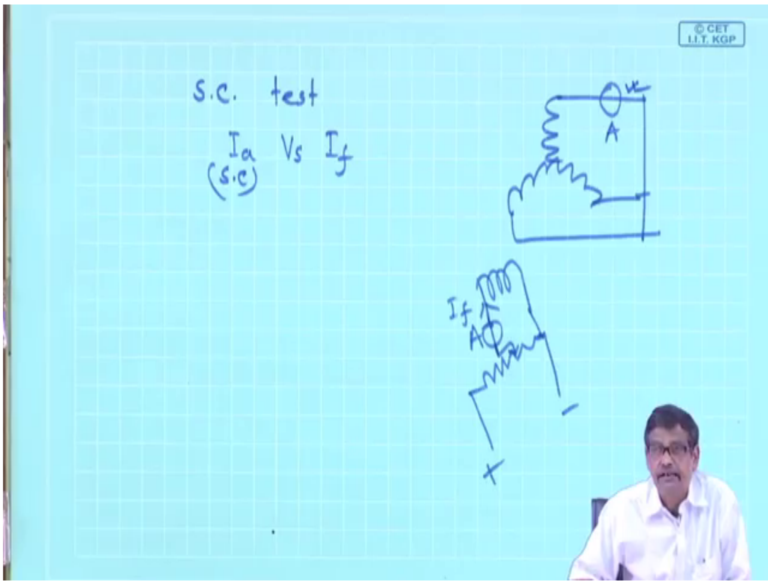

Similar test, short circuit test, what you do same machine you take and you short these terminals, connect an ammeter here I will pass DC current by some potential divider connection, connect an ammeter here ok, this is your I f. In short circuit test what you do is this you increase the field current from 0 value and you know the rated current of the machine, therefore go up to the rated current or maybe 10 percent higher than the rated current and sketch the armature current short circuit armature current versus field current, you sketch them.

You will find during short circuit test and of course, run the machine at rated speed which gives you 50 Hertz supply that is condition you must. So, what you do? If on the same graph you also plot in some different scale I SC short circuit armature current ISC a; you will find that that characteristics will also pass through origin and it will be a straight line and you can then calculate you can say zs you take any field current; this is open circuit voltage, this is short circuit current at the same field current you have to take to calculate zs.

So, what you do this if I call this is AB, this is AC; it will be open circuit voltage, OC voltage per phase divided by short circuit current per phase because torque connected assumed. But this you have to calculate at constant If, that is you should not divide by this voltage with this current obvious reason because at same voltage then only this phasor diagram is correct; is not that that same voltage. So, open circuit voltage short circuit.

You will find short circuit characteristics will be almost straight line although open circuit characteristics will have that saturation property.

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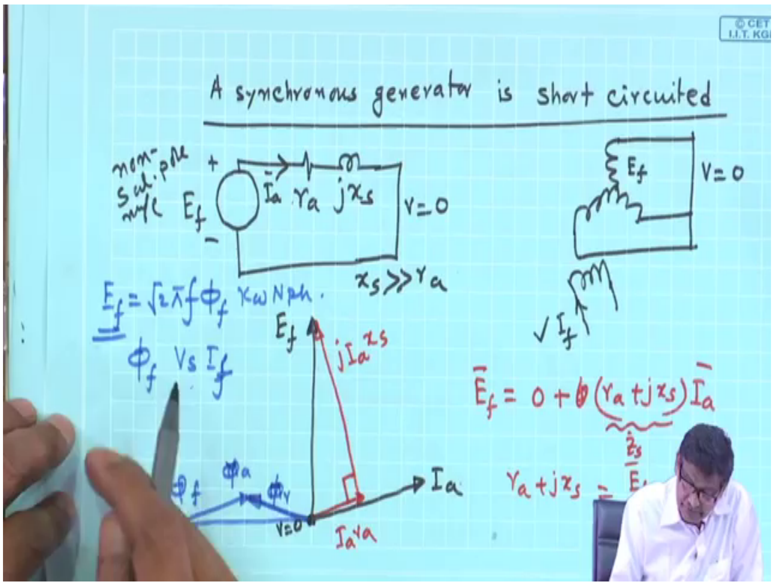

Why it is like that? It is because of the fact during short circuit test you recall in this is the phasor diagram, this is your phi f. Resultant field Mf plus Ma in the machine resultant field will be that is phi a and phi r will be much less because I a is almost opposing phi f demagnetising. Therefore, even with large current because current will be lagging your E f almost by 90 degree. So, it is almost demagnetising this phi ffa and machine will be always under linear zone.

Therefore short circuit characteristics will be always a straight line, but open circuit characteristics; no, open circuit characteristics E f we know it is root 2 pi f flux per pole kw into N phase, you recall that and phi f versus I f whatever will be the nature; that will be the nature of E f, speed is constant, f is constant. So, as you increase I f, phi f increases initially linearly terminals are open, no armature current and therefore, it is linearly increasing. But later saturations will set, therefore it looks like that the value of zs or xs is not constant.

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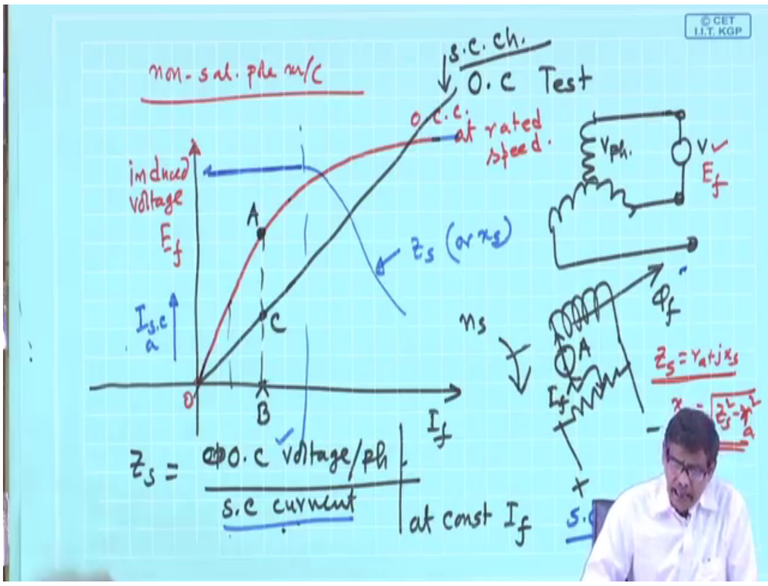

Initially if somebody calculate zs at various field currents here, this voltage by this current, this voltage by this current, this voltage by this current what will happen the value of zs will be almost initially up to the linear zone. It will be like somewhat constant, but later it will fall down. Because numerator, denominator is increasing linearly and this fellow, the numerator it is getting clamped at some value. Are you getting it? So, this is the nature of zs; zs means ra small so or xs.

So far whatever I have analysed in this classes I have assumed xs to remain constant as it. Of course if some; what people do some they calculate some q adjusted value of xs things like that we did not concern here. But I want to point out that if the machine is operating at linear zone, if xs can be assumed to be constant, then you put that constant value of xs. If the when the machine will be loaded, machine may be demagnetising or it may not be demagnetising, it will be also assisting phi f so, that machine may creep into saturation.

Then that value of xs may yield wrong results. So, corrected value of xs are to be used then; anyway we will not go deep into the subject. It can be done way better estimation of xs can be made by zero power factor test and things like that. We will not go into that because we have taken so many lectures, but read the books. You must atleast understand that the value of zs or xs does not remain constant with as the saturation creeps in. Because when the machine operates at different power factor, machine may go into this zone where xs value assumption may be questioned.

Anyway, but the important thing is we must know how to our emphasis was ok, xs is constant. Suppose let us assume can I analyse the machine? Yes, now I am confident I will be able to whether it is operating as a motor, whether it is operating as a generator, whether it is this non-salient pole machine or salient pole machine I will be able to draw the phasor diagram correctly and hence, calculate current, power factor, voltage something is given, some other things can be computed if you draw the phasor diagram correctly.

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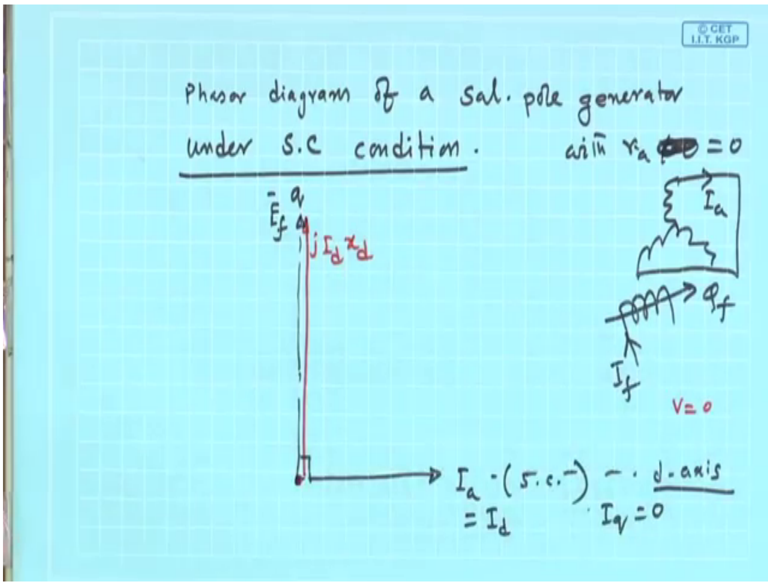

Let me draw also the phasor diagram of a salient pole machine generator phasor diagram of a salient pole generator under short circuit condition. Let us see how can we do it; condition with ra, ra not equal to 0 suppose. So, what do I do; in case of generator so terminal voltage will be 0. There is some field current I f some phi f is produced, ok. I want to find out this one.

Now, terminal voltage is 0, then v plus this impedance drop suppose the ra equal to 0.

Let us do the first simple case ra equal to 0, then this armature current will be almost lagging by 90 degree after all no resistance. So, it will be having inductive effect. So, we will first draw E f, this will be the case. And if it is purely inductive, then the short circuit current will be like this lagging that is this current I a itself will be 90 degree lagging because of only inductive effect.

Therefore whatever is the short circuit current? That will be lagging your induced emf by 90 degree. In other words, this is q-axis and this will be your d-axis; is not. Therefore, this short circuit current will be along d-axis. So, q-axis components; so, this itself is equal to I d with I q equal to 0. Then you see everything is fine. This is the voltage, terminal voltage is 0. So, v equal to 0 plus j I d x d will be only this much is not, this will be phasor diagram.

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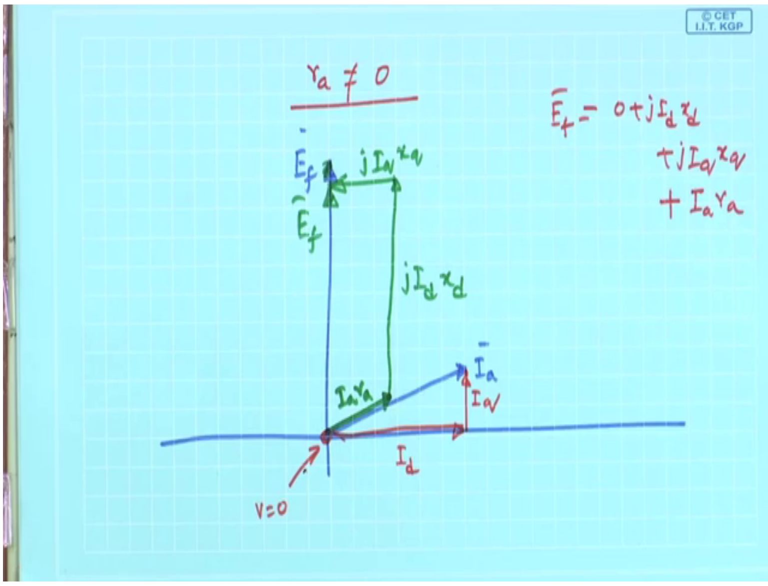

But if ra is not equal to 0, then how it will be we are confident. Now, you can draw if ra same thing not equal to 0, then I will draw like this. I will draw q-axis and suppose this is your E f that I have drawn oh, armature current, it is shorted. Therefore, it is rl type of thing, therefore, armature current will be lagging. So, I will draw this lagging almost 90 degree or slightly less than 90 degree like that E f and then this E f I a can be broken up as I d and I q; is not; terminal voltage is 0 here. So, this will be the thing.

So, generator mode v is equal to 0 this point. So, v 0 plus j Id xd plus j Iq x q and I have not neglected ra this time plus Ia ra this will be the thing and this must be equal to your E f, that is all. So, I start with v equal to 0, then I a r a; I a r a I draw I will draw use a different colour. So, this is your I a ra, I am drawing in a larger scale it is small I a r a plus j Id xd it will be like this and then j Iq xq and this is your E f getting. So, this will be the likely phasor diagram of a salient pole synchronous machine under short circuit conditions. Is that clear?

Therefore friends I have talked to you for a long time rather. Mainly I have considered so far the operations of I began my course with some few lectures on some transformer based on equivalent circuit, not went into detail, but tried to highlight what is the relationship of self mutual inductances with the transformer leakage reactance and the magnetising inductance, how can I find out stress was on that.

Then I discussed about the basic working principle of rotating machines. Of course, a good foundation on that can be only obtained if you have some idea of how the windings are carried out in AC machines. So, I discussed about armature windings not too much in detail, but very basic armature winding 60 degree phase spread, 120 degree phase spread, three phase distributed winding.

In case of induction machine in the stator and rotor, this type of three phase windings are used and in the rotor of three phasor induction motor if this type of windings are used, they are classified as slip ring induction motor and then the concept of rotating magnetic field, basic principle of operation of three phase induction motor some ideas about its torque slip characteristics which is very important, equivalent circuit development. Then I took up single phase induction motor.

The analysis of single phase induction motor was based on three phase induction motor only although it is slightly involved because I showed that a single phase induction motor develops a pulsating field which can be broken up into a forward and backward field. Therefore, two induction motor those things can be used individually as if positive sequence and negative sequence components are two individual machines find out from them the torque and take the difference.

Then of course I took of synchronous machines where I told you about how to we discussed about how a synchronous motor operates. There is a DC current to be(Refer Time: 31:02) , there is a balanced three phase winding on the stator DC field winding and then based on that we find out how to analyse synchronous motors. I hope you have enjoyed. Let us see I will take only one lecture if possible next time to solve some problems; numerical problems.

Thank you very much.