**Electrical Machines – II**
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**Lecture - 84**
**Effect of Variation of Field Current in Synchronous Motor, Induction to Salient Pole Machine**

Welcome to this Synchronous Machine lecture and we were discussing one of the most important features of synchronous machines. For example, in case of an induction motor if it is operating you will the power factor of the machine is essentially decided by the load and it will be always lagging power factor.

In case of induction motor of course I have not told yet what happens in synchronous motor, but it will be similar thing that is in a synchronous machine apart from the fact that it does not draw any magnetizing current from the bus, but at the same time you can operate the synchronous machine at a desirable power factor. Simply by varying the excitation of the machine under what condition? Under constant power operation; constant real power operation of the machine.

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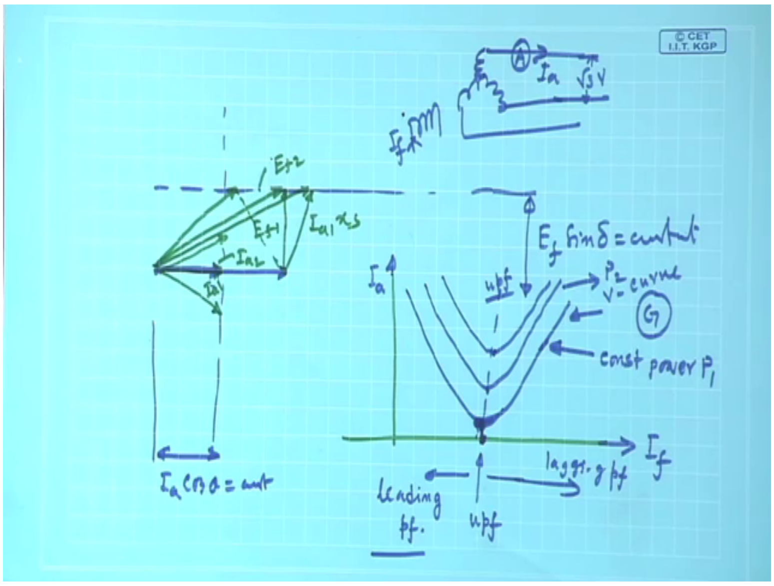


And we have seen that in case of generator if this is your V and the if this is your V here and you draw a vertical line I a cos theta and you draw a horizontal line here such that this length is E f sin delta constant and this length is I a cos theta constant, then at any excitation if it is doing like this, this is I f 1, this is I a 1, this is E f 1, then your this current will be here I a 1 at some excitation, increase the excitation such that this becomes your new E f 2. If you lower the value of excitation, this becomes E f2 and this is j I a2 x2, your I a2 will be here new delta and further reduce the excitation. It will be operating at leading power factor such that I a2 x 2 and I a2 x 2 and so on.

I can I have some idea therefore I can draw a car. So, the observation will be in the experiment. If you do some experiment, this is connected to bus here. This voltage is root 3 V line to line and this is your generator mode I a, this is your excitation I f, then and you connect an ammeter here. You will find that the as you vary the field current I f, the armature current magnitude of armature current will become minimum at this one and this curve will be somewhat like this here.

V because you see the minimum current will be drawn when the machine is operating at unity power factor. This length of armature current phaser is minimum. So, it is unity power factor for generator mode I am drawing and this is the armature current. And armature current will become more when its excitation is increased from the unity power factor point of view. So, any deviation of field current which makes the motor to operate at unity power factor, then the armature current drawn will be minimum. And if you exceed the field current from this to this overexcited machines means, lagging power factor. So, this side will be lagging power factor and this side also once again armature current will increase its leading power factor.

So, you see overexcited synchronous motor operates at lagging power factor under excited synchronous motor operates at leading power factor. Of course, if you draw this curve, you must attach another parameter to this. What is that? At some constant power constant power say P 1. If the level of constant power is made more, then it will be another V curves. These are called V curves it looks like V curve.

And here for another level of power P 2 constant and so on and this points minimum armature current points if you sketch these are UPF point. I hope you have understood this that is a synchronous generator connected to bus delivering a constant power say P 1. As you vary the field current how armature current varies at unity power factor operation minimum armature current, and people like this point of operation is not very close to unity power factor operation because current handled by the machines will be minimum.

This I could not do in case of induction machine because there was no control of field current it was not there at all. So, a synchronous machine operating power factor of the synchronous generator, at least we have talked about generator can be easily understood. Let us see what happens in a synchronous motor.

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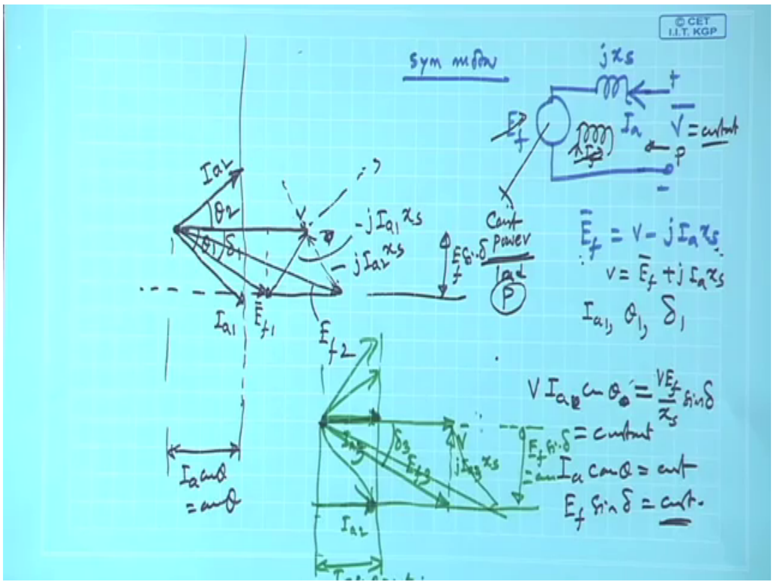


Synchronous motors similar things synchronous motor, once again draw this curve as circuit, so that and I will only assume j xs to avoid any complexity to understand the basics of this excitation variation. This is bus voltage and this is the armature current I a and as you know this E f is equal to V minus j I a xs in the same way I will do. So, suppose this is the terminal voltage and load on the shaft of the machine is constant power load ok, speed is constant that is torque is constant. So, anyway this is v.

Suppose the machine at some excitation it and I will vary the field current of the machine; field current of the machine, I am planning to vary under a constant power p. So, suppose the one of the operating point is that a machine is operating with armature current I 1, P is the power, theta 1 is the power factor angle and delta 1 is the load angle V is constant bus. So, if you vary excitation field current, if you vary this your E f is going to vary that is the idea.

So, suppose the initial operating point is such that it is drawing a lagging current I a1 at a power factor angle of theta 1, but only thing is for to get E f here you see E f is V minus j

I a xs, this is I a 1, j I a x 1 will be here negative of that. So, minus of j I a 1 xs you do you will get E f1 and this is the initial load angle between V; V is this, V and E f 1.

Once again the expression of the power is same power drawn. This power drawn must be equal to this power, real power. So, the power drawn is V I a 1 cos theta 1 and also the power drawn from using this expression is this sin delta. So, as a general I a theta thing, it will be the thing. So, once again if this is constant, so I will say I a cos theta is constant has to be and E f sin delta is also constant has to be E f sin delta means this length. So, the E f phasor must lie on this line now.

I a cos theta is constant means tip of the current phasor must lie on this vertical line and this is E f sin delta in general E f sin delta. Now suppose the machine is operating under this condition like this. Now suppose I increase the field current of the machine, if I increase the field current E f is bound to change 4.44 f phi f kw n phase. Therefore, direct effect will be on E f; E f will change, E f will become more. So, maybe E f will become this much new E f2 you have increased the field current of this machine.

Then V and E f2 are fixed, then this difference must be your drop j I a xs is not and where is your E f? E f plus j I a xs is equal to, so V is equal to E f in whichever way you interpret I am just writing like this. This is the thing. So, this is E f2 so, your j I a2 x 2 must be this one j I 2 x s, E f2 plus j I a2 x s is your V. Therefore, your I a 2 must be lagging this voltage by 90 degree that is I a 2 will be somewhere here and maybe I a 2 will be here and this is your theta 2.

So, you have increased the excitation and you find the power factor has become now leading. Of course, you can increase the excitation such that the power factor will become unity. So, I once again redraw these with different color V, so that you get a practice how it is really done. Suppose this is V, and this is the length Ef sin delta constant and suppose this is the length I a cos theta constant oh sorry I will move it I a cos theta constant ok,

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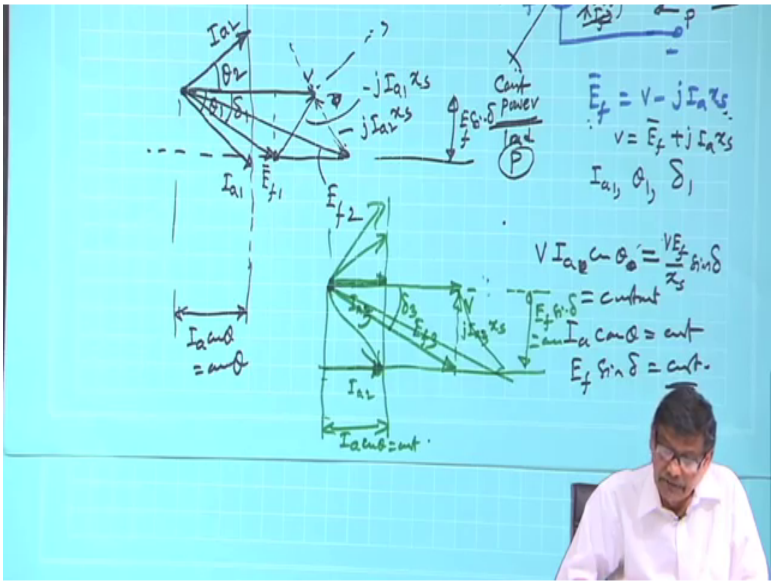


Then you can find out the excitation at which operating point will be unity power factor. Yes I can do that because in that case this is j I a2; I a3 xs will be like this, then your I a2 will be like this and oh sorry I a2 will be here correctly drawn, but anyway it is even the power factor V a2 and your excitation voltage will be E f3 plus j I 3 x s is I a3 and this is delta 3.

Increase the excitation further, it will be like this, this and your I a2 will be this. So, once again you see as you vary the excitation of the synchronous motor, you can operate it at any power factor you like it may be unity it may be lagging it, may be leading, but you should know that when it becomes leading power factor, the synchronous machine becomes overexcited because length of E f will become more than length of V under excited V length will be less than E f.

So, once again one can draw a sort of, so armature current will be minimum at unity power factor operation and it will be of course higher whether it is under excited or overexcited. So, once again for a motor I can draw a V curve. So, please make a practice of this one because this phasor diagram new operating point how to calculate as you vary the excitation for a constant amount of power. And I am it can be done with also r a included that I have and I will not pursue right now, although I will include that in my node. You first get conversant with that this simple case when only xs is there array is much smaller than xs.

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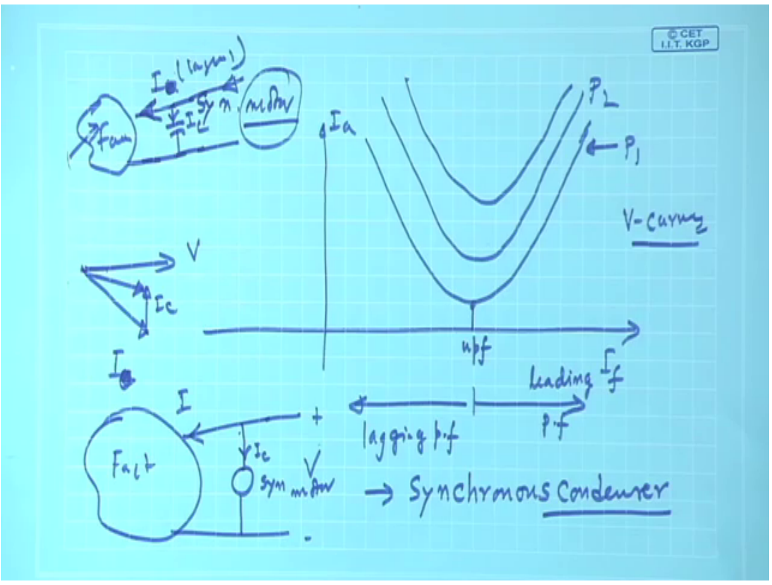


Therefore in case of synchronous motor the V curves will look like once again armature current versus field current. Magnitude of armature current versus magnitude of field current once again it will be like this at a certain amount of power P 1 and this point where the armature current is minimum is the unity power factor point, over excitation in this case means leading. So, this side is leading power factor just opposite to generated and this side is lagging power factor.

And similarly for several level of powers one can draw several V curves do, these are the V curves of the motor. So, what is V curve? V curves is nothing, but it shows that when the motor operates at constant power that is shaft power I will not touch, then V it in case of generator steam input I will keep maintain same. Then output power has to be also same because I have assumed machine is as if lossless there is no array. So, that thing is also confirmed under that condition if you vary the field current that is the resistance controlling the dc current of the field winding, you will see that armature currents will change. It will be minimum at unity power factor, otherwise it will be (Refer Time: 19:24).

All things considered you should never forget that at overexcited synchronous machine operates at leading power factor, under excited synchronous motor, motor overexcited synchronous motor leading power factor, under excited synchronous motor lagging power factor. Of course, you have the option also at unity power factor. In case of generator, it will be the same similar nature, but this leading will come here, lagging will go there that is overexcited synchronous generator will operate at leading power factor, under excited synchronous generator operator lagging power factor. In fact, it is this nice property of this synchronous motor that you can operate the motor that is the motor can be used to draw leading power factor current as well.

So, in earlier days synchronous overexcited synchronous motor was thought; was considered to be like a capacitor that is a motor operating under over excited condition will always leading current. Therefore, this type of motor if you connect across the line will draw leading current suppose in that mode you operate, then whatever load you have actual load its power factor can be improved upon. In other words what I am telling to improve the power factor of a factory suppose you are the owner of the factory. All motors are induction motor loads are generally lagging and you know it is always better to operate at some close to unity power factor.

Then what you use to do, you connect some capacitor at the supply terminals. So, capacitor will draw some say your this is your factory, it takes power lagging current, it takes I lagging and if power factor is very poor, you will be charged heavily by the supply authority. So, what people used to try connect where the supply is entering in your factory, you connect a capacitor is not. So that this was suppose the your factory poor power factor, the supply voltage and this will be a poor power factor less than 0.8.

Then what you do? You connect a capacitor, your this lagging current it takes whatever your factory load is there, but now the current drawn from the supply authority it will be I a plus I c and your overall power factor of the factory will be improved. So, earlier people used to connect capacitor, but you know in fact you can choose your capacitor such that it may operate at a unity power factor as well. But the point here is if your load changes in this factory, the capacitance needed to attain a certain power factor the capacitance value will also change. You have to connect another capacitor things like that.

But now I know what I will do is, this a factory is there, this is the supply without condenser or capacitor it is a poor lagging power factor current your factories drawing, then one solution earlier was connect a suitable capacitor, but instead of doing that you now connect a synchronous motor, you have to invest of course a synchronous motor and adjust it fields current such that it draws leading current. In fact, you can adjust this, so that it draws close to 90 degree leading current. So, it will substitute the capacitance and in that case when a synchronous motor is used to supply a leading current, to draw a leading current, it is called synchronous condensers.

Synchronous condenser is nothing but a synchronous overexcited synchronous motor. This was one of the use and this synchronous it is after all a synchronous motor. This synchronous motor can supply both your mechanical load as well as provide leading current that was the idea ok understood this point. Therefore, overexcited synchronous motor draws leading current, this property was used to replace capacitance to improve the power factor of a factory. In that case, it is to be called a synchronous condenser. Of course, it is not that synchronous motors are only used for synchronous condenser. It is only one aspect.

If in your factory you have a synchronous motor also needed, then is that synchronous motor also to improve the power factor of the machine, so that it will supply both mechanical load as well as improve the power factor of the machine. Anyway there are lot of interesting problems that centers around the operation of synchronous generator or synchronous motor under variable excitation. We will try to solve some problems later. I hope you have; so we have understood the effect of variation of excitation of synchronous generator and synchronous motor.

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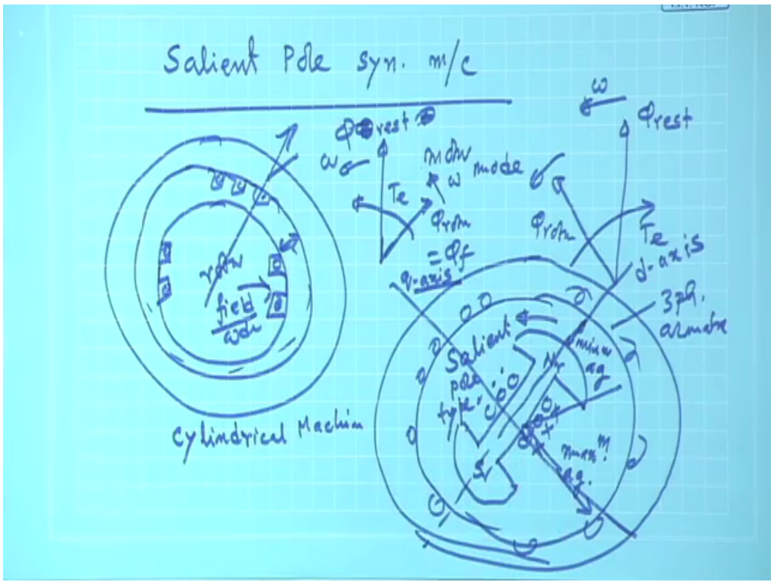

Now, today whatever time is left, I will now tell you something about salient pole synchronous machine. So far we have talked about uniform air gap or cylindrical rotor type synchronous machine. What was that? That was there was a stator; a stator slots are there three phase winding on the stator and rotor was also cylindrical. Please forgive me for this somewhat bad diagram.

Air gap is uniform, in the field winding is on the rotor diagram dc field current this is the rotor which houses field winding. And stator houses a balanced three phase winding and machine operates and this stator field rotates at synchronous speed, rotor has to rotate at synchronous speed whether it is operating as a motor or generator, it does not matter. Only thing is in case of generator mode of operation, rotor field will behind the net field.

In case of motor operation rotor field that is phi rotor which I was calling it as phi f or V f whatever it is and this will be phi resultant which I was phi resultant field, and if this is the situation that the torque is always the rotor field tries to catch up with the resultant field. So, it is motor mode of operation motor mode and in case of generator mode operation, phi resultant and phi rotor will be like this, so that this is the electromagnetic torque, electromagnetic torque is here, but everything is rotating in the anti-clockwise direction. This we have discussed earlier, anyway this is the thing.

So, this is the cylindrical machine, there is another variety possible that is the stator winding, there is no difference in the stator winding in these two kinds balanced three phase stator windings three phase which is often called armature. But on the rotor what you do, you have a salient pole structure and here is your coils field coils which will carry cross current, dot current here to give you NRSR understood and it is also rotated synchronous speed. So, this is the rotor rotating field, stator rotating field of course will be there balanced three phase winding, they will interact gives you torque it is also possible like this.

But the air gap of these machines are not uniform. It is minimum here minimum air gap and maximum air gap is along this line. In between there will be variable air gap. Now the question is can I apply the same theory to analyze this kind of synchronous machine which is salient pole. It looks like it is very difficult apparently I mean what to do because armature mmf you recall can be placed anywhere depending upon the degree of loading. Sometimes armature in this case there was no problem late armature mmf it be here, then the flux produced will be also maximum along the same line air gap is minimum, that is armature mmf c is constant reluctance and therefore, we could very easily say that armature flux will be also constant. No matter where armature mmf is placed, it depends upon the power factor etcetera at which the machine is operating.

But in this case armature mmf can be anywhere because of power factor of the operating power factor may change it may be here, it may be there. But the reluctance seen by the armature mmf which will which in turn will create the armature flux looks like a stupendous task because of the fact when armature mmf will be there, it will see a minimum reluctance path, maximum flux will be produced and when armature mmf will be along this line, maximum air gap I have to divide this reluctance to get the flux or if it is in between, some other air gap will come. Therefore, this is in a salient pole machine is essentially a non-uniform air gap machine.

And therefore, the reluctance changes it looks like the analysis of the machine. At least we are certain the same principle I cannot apply here to analyze the machine. But only one thing I will tell that this is your d-axis and where the reluctance will be minimum and this one where the air gap is maximum is called q-axis; quadrature axis and direct axis. [FL] So, therefore, with this basic difference in construction in my next class I will tell you how to analyze a salient pole machine

It was actually called a two reaction theory first proposed by Bundles two reactants it was suggested by Bundle. And you will see that what he proposes is this, this armature mmf the idea is like. This idea is very simple. He first told that let armature mmf be anything; armature mmf is sinusoidally distributed. If armature mmf is here in this direction, I have to take this reluctance. If armature mmf is here, I have to take this air gap that changes and that is causing trouble what you told ok. Armature mmf is sinusoidally distributed and the air gap of this minimum path along the D axis and reluctance along the quadrature axis their constant, and armature mmf has nothing to do with reluctance.

Therefore, why not to break up the armature mmf which is sinusoidally distributed along this two lines. Then you can well define the flux here, flux there and for each of the flux there will be induced voltage in the armature coil and by following the same principle of induced voltage, we will be able to find out another model XD XQ model. We will consider this in the next class.

Thank you.