Electrical Machine – II
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Lecture - 83
Effect of Variation of Field Current in Generator

So, welcome to synchronous machine lecture.

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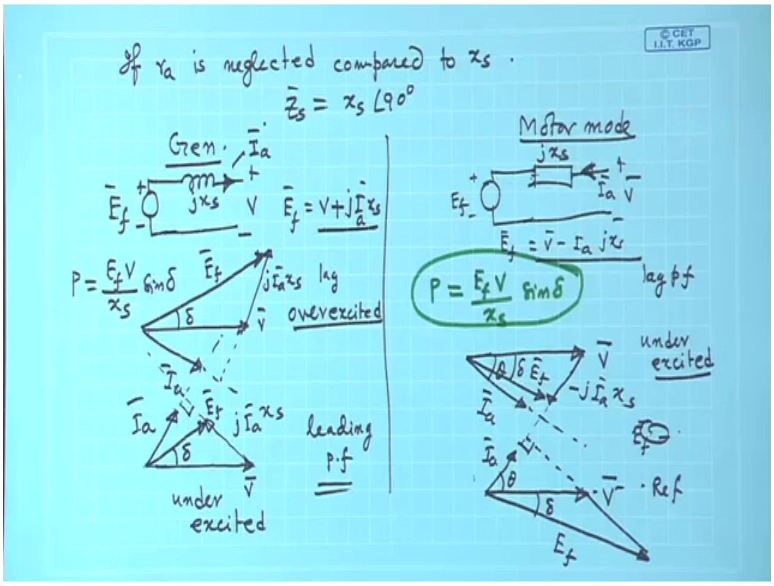

So, in my last lecture. I was telling you that how to draw phasor diagram is an important thing for synchronous machine and computation will be very simple, if you have a scientific calculator. What all you have to connect for a given operating point, if delta is given delta is not given? If r a is neglected straight away go there. In fact, from the phasor diagram also using properties of triangle under this condition this angle 90 degree several problems can be very quickly solved.

I will try to devote one or two sessions for problem solving later, but we have a now fare idea. Once again I am telling in case of generator E f will be always above V; no matter whether it is lagging and leading power factor, what will change is either over excitation or under excitation. Similarly, for motor mode and the expression of power with this condition that r a is neglected becomes your excitation voltage very easy to remember product of these and this divided by the reactants and sin delta that, that is all ok.

So, we have done. Now, in this lecture after knowing these things, I will introduce to you the what will be the effect of variation of excitation of a synchronous machine. What I mean to say is this; see first try to understand the operation what I will do that suppose.

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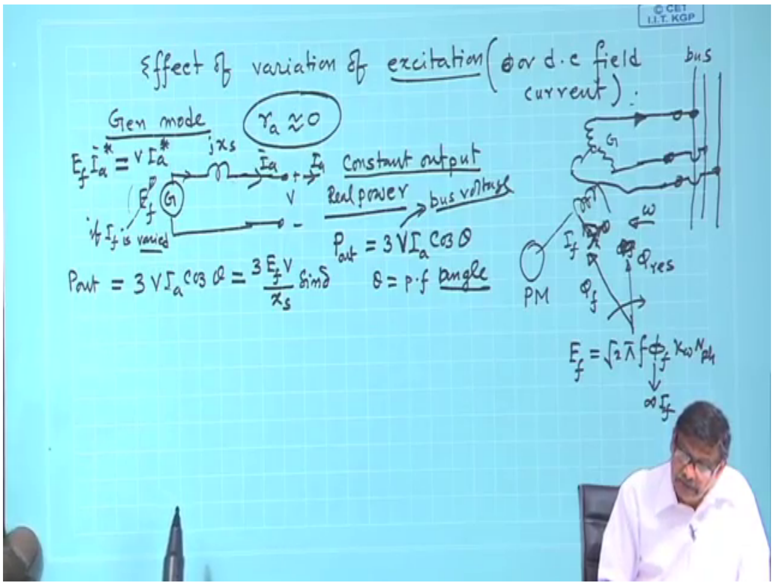

So, effect of this is very important topic effect of variation of excitation. That means, excitation means what? dc field current variation of variation of excitation or dc field current that we will investigate. So, first we will do for generator motor, then I will do for motor mode. Suppose generator motor generator motor and in this explanation what I will assume r a is pretty small. So, that I will come to know very quickly what will be the effect of course, with r a also it can be taken into account that I have included in my note at this stage you need not go to that ok. First, let us see this can be very nicely explained.

Now, effect of variation of excitation in generator mode what does this mean? This is the generator; let me first draw this is the thing and here is the field winding. What I am trying to tell here is some if dc current and here is some voltage and it is connected to the bus a phase, b phase and c phase; how to synchronize those things we have discussed. So, the synchronous and it is operating as a generator. How it will operate as a generator, because it this rotator is driven by a prime mover prime mover ok.

And what is a prime mover? Prime mover could be a steam engine, a water turbine, a steam turbine or a diesel engine this sort of thing. Now, that it will operate as a generator; see after you have synchronized a let me a spend few sentences. After you have synchronized the machine this synchronous machine is said to be floating on the bus, it is neither operating as a generator nor as a motor. If you want to operate it as a generator means that this generator will fit power or current into the bus, this is bus.

What you have to do is, you have to increase the steam input if it is a steam turbine, then only real power the rotor will then become in advance with the resultant field that is this diagram. In steady state everything will be rotating so, that this rotor field will be behind the resultant field rotor field should be in advance so resultant field. So, if this is rotor field B f or I f; you are in case of generator mode of operation, your rotor field that is phi f will be phi resultant that we have seen and in case of generator everything is rotating in this direction omega torque will be in the opposite direction.

Anyway, so input increase the steam input to the bus then it will feed power you have to burn more coal then and it is generator mode r a equal to 0. So, suppose for a given steam input the real power input from the mechanical side is constant or I will assume that in that case the output power delivered to the bus will be also constant. So, per phase circuit diagram is this and I will assume only j x s is present and it delivers a current I a. One may wonder where is the load if it is supplying lagging power factor you do not own the, in the infinite bus all nodes are connected all big generators are feeding, the bus a common bus nodes are already connected nothing that it is not there.

So, eod this small generator in the laboratory if you have synchronized and increase the prime mover input it will also contribute to this total demand of the load which is connected to the bus by a small amount, some kilowatt say if it is a kilowatt rating machine. So, load is already connected there in the bus and this voltage is V is that clear now suppose for a constant output power for constant generator mode output power output real power constant output real power. I can say this output of the generator will be 3 V I a cos theta.

Where theta is the power factor angle of the motor because angle between V and I a this is I a it is delivering. So, this will be the thing if the output power remains constant. I look at this expression P out V V is the bus voltage, it cannot be changed in any case bus voltage is bus voltage fixed it is. So, many generators are connected infinite sort of bus.

So, V remains constant also I will say that this P output it is equal to 3 V I a cos theta no doubt from the terminal condition and also I know this power is 3 E f V by X s sin delta and this two will be same is not. There is no real power drop here that is, if you calculate E f I a star; it will give you what is the total power output from looking from the excitation I mean excitation I mean emf induced in the generator side do you think this power E f I a star in this case E f I a star must be equal to V I a star. Why not, because there is no power loss it is a good exercise you can easily show this.

But, none the less this is true. Now, what I am telling this E f you recall this E f is equal to root 2 pi f flux per pole K w into N phase of the stator phase. Now, what I am telling that I will vary this field current I f by connecting at rheostat here, I will simply play with this without changing the prime mover input or output power. How much will be the prime mover input needed power delivered same as this whatever you are delivering here that must come from the mechanical side it is doing like that.

But, the one thing is very clear if vary I f pi f is directly proportional to I f therefore, as you vary a field current of the alternator induced emf in the alternator will change E f is bound to change, that is the magnitude of these will change if I f is varied why not. But, what I am saying is this by doing this you cannot change the magnitude of V terminal voltage is fixed [laughter]. So, something else then has to change we are trying to investigate what is that thing how things will now look like. Therefore, if I am not changing this team input to this prime mover output power delivered in kilowatt will remain same and for s an excitation present these two must be same. So, let me draw the phasor diagram this is quite interesting you just we will see ok.

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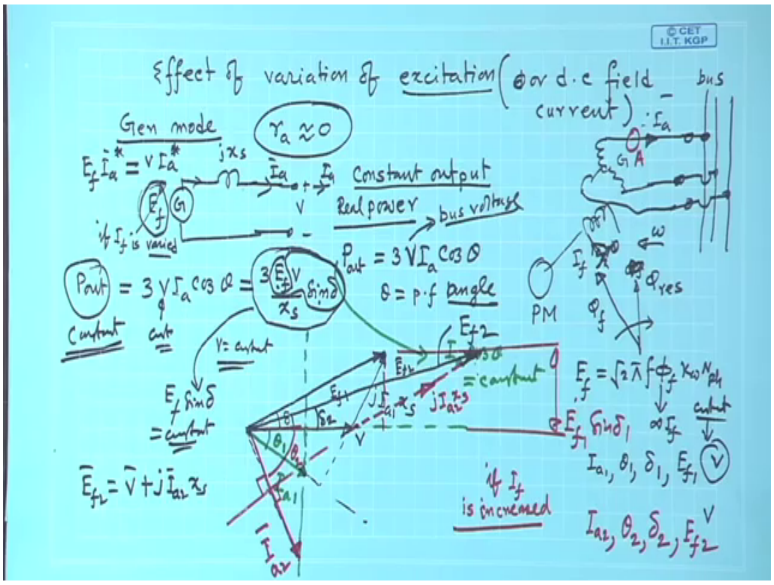

Suppose this is your V. I will once again re draw let me spoil this pen see this is V a. Suppose at some excitation this is your I a 1 and machine is delivering lagging power factor load theta 1 this is general operating point I have told I a theta. Suppose, it is doing like this. Then, if you are not from this equation I come to the conclusion that I a cos theta has to remain constant, because of the fact V is said constant ok. Therefore, as I play with the field current perhaps magnitude of I a will change perhaps theta will change I am not sure that this stage. But, what I will demand is that since output power is constant no matter how you are playing with your field current. I a cos theta this product has to remain constant that is the important point.

In other words, what is the I a cos theta? The projection of this on this V axis I do not know how I a and theta is going to change, but I will say that the tip of the current phasor I a must lie on this vertical line. So, that I a cos theta is constant; I will come to this so, this is one thing second thing is at this operating point with some field current I f 1. I now complete the phasor diagram. So, where is your E f suppose I want to find out E f will be I a 1 plus j I a x 1 is not. Synchronous reactors and this voltage excitation voltage I say this is E f 1 at some field current I f 1.

I found that the machine is operating as a generator, and supplying a lagging power factor load, delivering a current of I a 1 at a power factor angle of theta 1 at that time this is the thing V plus I a j x s is this one and this angle is the delta 1 at this load angle sometimes delta is called at this load angle the synchronous machine is operating as a generator why generator E f is about V and it is delivering current I a dash understood.

Now, this power I am selling this is this remains constant this cannot change. If it cannot change V is constant I told I a cos theta has to remain constant that is why the tip of current phasor armature current phasor must lie on this vertical line then come to this equation. This power constant, what it implies there in this equation it implies that V is already constant bus voltage, x s is constant.

So, I will say under this condition power is constant E f sin delta also as to be constant now what is E f sin delta E f sin delta is this length this vertical length. This is your E f sin delta in general E f 1 sin delta 1 in this case and I am telling you play with your field current this thing must remain constant understood. Now, suppose I say now the most important point.

So, this is for a general operating point generator is delivering a certain armature current I a 1 at a power factor angle theta 1 at that time this is E f 1 and I am demanding that this power remains constant then I will conclude that E f sin delta will remain constant that is this vertical length will remain constant, and I a another way of calculating power V I a cos theta this to must be same V constant so I a cos theta is constant means this projection of the tip of the current this will be cost and. So, draw a vertical line here [FL]. Now, see suppose I have increased the field current it is operating nicely at this operating point one.

What is the operating point one armature current I 1 power factor angle theta 1 load angle delta 1 excitation voltage E f 1 terminal voltage V in other operating point this is constant V is constant bus voltage. Now, suppose I have increased the excitation what will be the consequence of that, if you change the excitation; E f has to change. If you increase the field current; E f will become bigger because E f depends on root 2 pi f phi f K w N phase. Phi f is directly proportional to I f therefore, excitation voltage E f must be increased.

So, this length must be increased it will bigger, it will become bigger now the interesting point is it will be bigger no doubt, but since the power is constant the tip of this current phasor cannot, but lie here suppose the field a current you have increased excitation voltage has become more then take that length cut this line because E f 2 sin delta 2 has to be equal to E f 1 sin delta 1, because E f sin delta this thing has to remain constant E f into sin delta.

So, what do you do you have increased the excitation. So, take this to E f 2 and then I know this is by delta 2 because the angle between V and E f 2 is there and on the top of this E f 2 will be equal to V plus j I a 2 x s V plus I a j x s is your E f. So, E f 2 will be here, then I must say V this length follow me carefully this length must be your j I a 2 x s it has to be V plus j I a 2 x s is your E f 2 x s is constant j I a 2 x s I know. Therefore, I will be able to fix up where is my I a 2 where it will be this is j I a 2 x 2. Therefore, I a 2 must be perpendicular to this must be the direction of I a 2, but the tip of I a 2 must lie on this green line. So, this will be your I a 2 and this will be your new power factor angle theta 2.

So, if you have increased the excitation of a synchronous generator at under constant power condition earlier it was operating with E f 1 delta 1 etcetera your new current will now become if I f is increased your new operating point will be I a 2, power factor angle theta 2, new load angle delta 2, and new induced voltage E f 2. So, how did I get the new operating point, we have increase the field excitation. So, E f is bound to rise.

If E f is bound to rise I know E f sin delta has to remain constant no matter what is the excitation. So, E f sin delta tip of E f must lie on this horizontal red line. So, depending upon by what percentage you have increase the field current this length will increase that cut it, it will be E f 2 and this is E f 2 V is constant. So, this must be this length dotted line red must be your j I 2 x 2 if the j I 2 x s is known then I a 2 must be lagging this a voltage across that x s is this length therefore, the current must lag this length by ninety degree I a 2 and tip of I a 2 must lie on this green line.

So, this will be the new thing therefore, what you will see this if you have connected an ammeter here as you increase the excitation armature current will rise. It will become more understood ok. So, I will now neatly I will draw this once again. So, that you do not miss any point.

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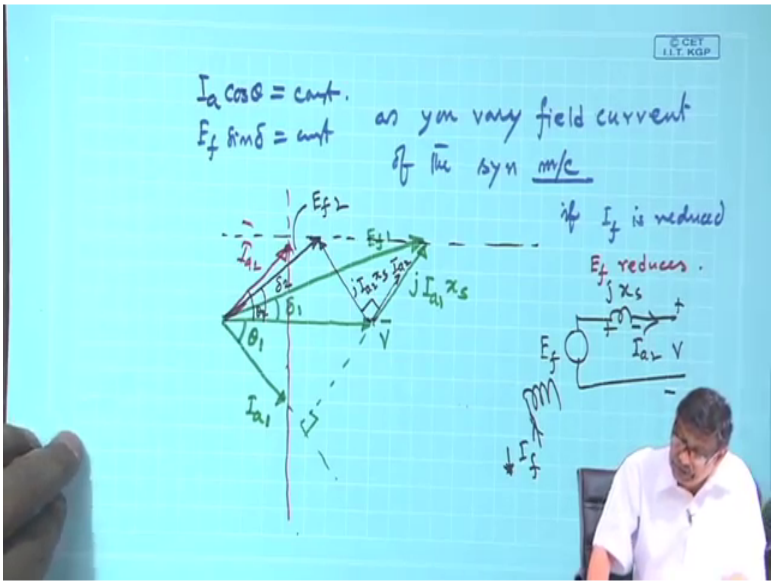

The point is I a cos theta has to remain constant. E f sin delta has to remain constant as you vary field current of the synchronous machine synchronous machine. I have taken generator case so, in the generator case it will be then like this suppose initial operating point is V and it is delivering a current of I a 1 at a loading power factor of theta 1 then E f 1 will be V plus j I a x.

So, this angle is 90 degree j I a 1 xs and you get your E f 1 and this angle is delta 1 initial operating point. Suppose, I say I have reduced the excitation what is going to happen. If I f is reduced E f reduces E f reduces that is length of E f will reduce, but I know E f sin delta is constant. So, draw a line like this. So, T of E f must lie on this line. So, if you have reduced I f your E f 2 will be suppose here and your new delta will be this. Now, if this is your E f 2 then V plus E f 2 j I a 2 x s this will be j this point is crucial this will be your j I a 2 x s that is the this is the thing you should always j x s and this is V V and this is this is the direction of I a 2.

So, I know the voltage across the inductance that gets fixed and I will claim then I a 2 should be here 90 degree lagging I a 2. This is the voltage across the inductance 90 degree lagging I a 2 now the thing is deduction of I a 2 I have got it is like this is not. So, I a 2 must be here I mean parallel to this I a 2. I mean something like this, but tip of I a 2 has to be on this line. So, calculate j I 2 x 2, then and decide what is the deduction of I a 2 draw it and this is I a cos theta constant line. So, it will be here.

Therefore if you have reduced the field current of this generator this is suppose the field current I f and I have reduced it. So, new excitation voltage will be E f 2 new armature current will be I a 2 new power factor angle will be this and it will be leading and when you go leading you see the length of E f has become less than length of V indicating that it is under excitation.

So, if you have under excite the machine for a synchronous generator operation power factor may become a leading. In fact, you can find out an excitation such that the generator will deliver the same amount of power at unity power factor even if you can find out such a excitation got the point. So, I will just draw that case and then I will stop here I will do this for motor as well.

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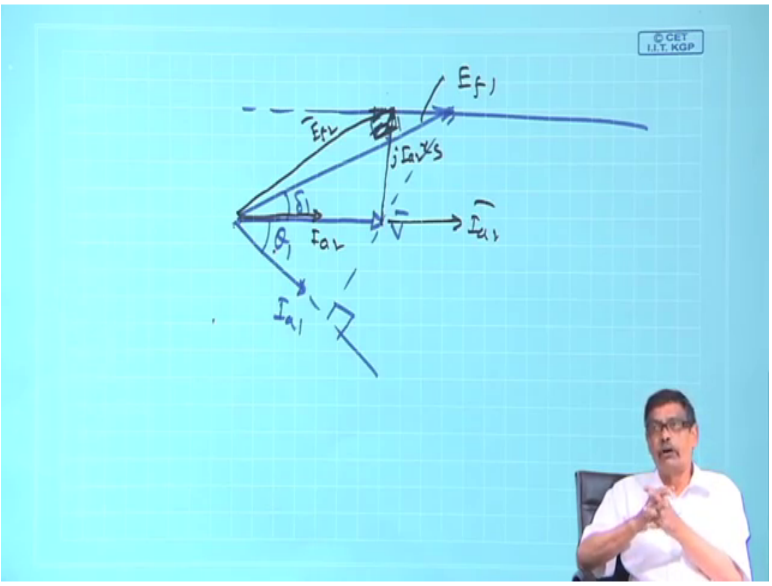

Therefore this is the thing suppose this is V very quickly V and this is the initial operating point I a 1 theta 1 and V plus I a 1 x 1 is your E f 1 this angle is 90 degree. This is E f 1 and I want to see that the and this is E f sin delta business this is delta 1 and this is theta 1 it is doing fine.

Now, if I can select if you it is lagging power factor reduce the excitation is V such that here is your E f 2 I reduce the excitation sorry this is E f 1 deduce the excitation such that it becomes perpendicular V to this one then where is your I a I this becomes j I a 2 x s and this will be the direction of I 2 in phase with V and this will be I a 2. So, by simply by concluding the field current I will be able to operate the generator either at lagging power factor or leading or at unity power factor we will continue with this.