Electrical Machines - II
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Lecture - 89
Phasor Diagrams of Salient Pole Synchronous Motor Under Various Conditions (Contd.)

So, we have been discussing about drawing of Phasor Diagrams of Salient Pole Synchronous Machines Under Different Conditions. Why it is important? It is important, because in case of salient pole machines, it is because I a is to be decomposed into two components; I d, I q. Machine may operate either as a generator or as a motor, or it may be a also operating either at leading power factor or lagging power factor. And students often make mistake in drawing the correct phasor diagram.

Unless you draw the correct phasor diagram, because phasor diagram drawing will help you to solve the problems very quickly. We will give you some examples, typical examples not all. But, you go through books, where worked out examples are also there on salient pole machines, but do it independently on your own. So, last time I told you how to draw phasor diagram of a synchronous generator at leading, lagging power factor, how to draw a phasor diagram of a synchronous motor at leading lagging power factor.

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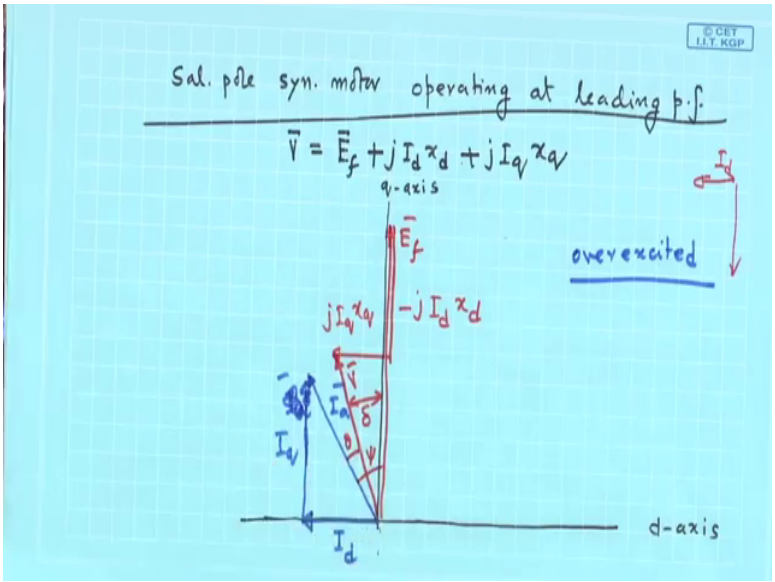

There are several things after drawing the phasor diagram you can verify that everything is in

correctly drawn. For example, synchronous motor, leading power factor somebody has drawn like this. Is it correct? I find it is correct, because V is ahead of E f that is the first thing motor mode, V cannot be here out of question.

Then you have been asked to draw at leading power factor. Is it at leading power factor? Yes, it is, because I a leads V as well as E f ok, and everything is in place. And also I know that when a synchronous motor operates at leading power factor, it is over excited; over excited. Does this phasor diagram confounds this? Yes, it confounds that because length of E f is greater than V that is all, and so this is the thing.

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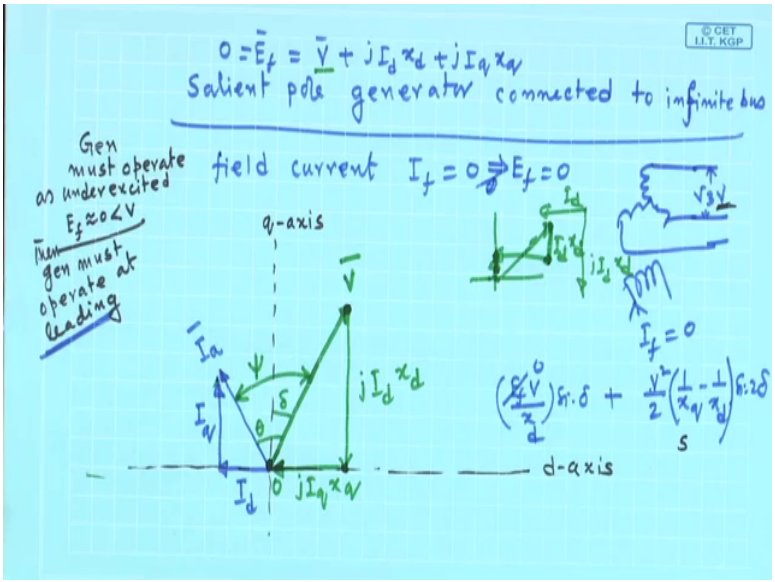

Now, I will draw another two interesting cases of drawing phasor diagram. For example, I say that a salient pole machine; salient pole generator mode generator connected to bus. All phasor diagrams, I am generally referring to connecting connected to bus. Although, it does not mean that if it is been isolated operation this phasor diagram is wrong, it is not like that because, if it is connected to bus, this length of V in this phasor diagram gets fixed. Other length of the phasors may change, but length of V will remain same that is what it is. Otherwise, it is also true for isolated operation of generator, this phasor diagram is true ok, this you must understand.

Now, suppose salient pole generator connected to infinite bus; infinite bus or also isolated, it may operate. I hope so, let us see what happens. And suppose, but the condition I put that the field current of the generator field current I f is 0, no excitation. First of all with no excitation

that is a synchronous machine is there, it is connected to bus here root 3 V line to line voltage it is there. And the alternator field current, I have made it 0 I f, you recall I f is 0 that is no excitation.

First of all will it still operate steadily, yes it can operate, if it is a salient pole machine. Because, in salient pole machine, the power term you recall there is one term of power which was equal to this. What is V? V is the terminal voltage. There is no E f here, so that the other term sin delta term that coefficient has become 0 that was E f V by x d, if you recall. But, I since I f is 0 means, E f is 0 that is all, so this term is 0 in this case.

However, this term will be there, therefore a salient pole, synchronous machine is capable of delivering or observing power depending upon whether it is operating as a generator or motor mode. So, generator connected to infinite bus with field current 0, which implies that E f is 0 can still operate can still deliver some power to the bus that is very important thing. Now, in this case how to draw the phasor diagram, listen carefully. So, it is generator mode, so I will use this one the relation, I will use is E f, I will start with perhaps V plus j I d x d plus j I q x q. And this E f is 0 is not E f is 0, so this must add up to 0 that is the thing.

Now, how to draw the phasor diagram of this? The first step as usual is assume that this is your q-axis I assume that ok. And this is of course will be at right angles, this will be your d-axis, this I can do no problem. So, q-axis, d-axis is defined. We know E f has to lie on the q-axis, but E f is now 0 or for that matter, what I am telling. Suppose, I f is very close to 0, then E f will lie with a small length or vanishingly small length that is how you try to convince yourself E f 0 means, E f is vanishingly small, but its direction will be along q-axis is not that is the thing.

So, although E f is 0 means this point ok, you imagine absolutely very very small I f exist ok, E f will be along this line nothing doing. So, E f is 0, but V is finite, it is connected to bus. Terminal voltage is there, you have synchronised the machine, then perhaps brought the field current gradually to 0 of this machine, so that only salient power due to saliency term is present, V is finite having large voltage like that, however E f is 0.

So, the next thing, I ask is that is the machine and no power factors given in this case, what I am telling field current 0, terminal voltage is finite. Then I have to apply my knowledge about the synchronous motor in this way that oh this E f is 0, I f is 0, V is finite. Therefore, the machine must be this generator must be operating under excited condition, because E f is

vanishingly small, V is finite.

So, this conclusion I have to draw, after knowing this it is a generator mode. So, generator, this generator must operate under excited as under excited, why under excited, because E f which is 0 is less than V length of V that is the reason. And I know if a generator is under excited, then it must be delivering leading power factor current, then generator must operate at leading power factor nothing doing under excited synchronous generator leading power factor.

How do I know, it is the under excited? I know because, E f is 0, and V is finite connected to bus, so this thing must happen ok. So, this is the thing, so I now know that armature current will be leading power factor. So, let me draw the armature current, suppose the armature current is here I a. E f is not there but vanishingly small along this line that is that zero collapse, then I know where is my I d and I q that is this one is your I d, and this one is your I q, this I know.

Second property, I will utilise that it is a salient pole generator. In salient pole in generator operation on synchronous machine E f will be ahead of V, E f is which direction; zero small along these, so V must be behind that V; V must be in this quadrant, it cannot be here in any case. Because, then V will be ahead of E f, E f equal to 0 may disturb you, but what I am telling? Imagine that E f ok, it is field current is vanishingly small 0 very close to 0, so E f is there along q there.

Therefore, the question is the V must lie here, this must be your V nothing doing. So, it satisfies everything, it is generator mode V is behind E f, where is E f; very small 0, here along q-axis. At this angle, I will still call delta (Refer Time: 13:14). I f equal to 0 is a special case of excitation, so this will be your V a. Then in generator, I will add to the moment I get V a, and I got I a. This must be your power factor angle at which the machine must operate. And this is I d, so V plus j I d x d, this is the I d direction is like this as you can see I d. So, j I d x d is this way is not, so it will be j I d x d. Then j I q x q, I q is this way, so j I q x q is to the left, therefore this is j I q x q.

So, V plus j I d x d plus j I q x q must end up at this point O, because E f has to be 0 that is I have not drawn like this, you know this was V; I have not, I cannot stop I d x d drawing up to this point, because then these and these j I q x q will give you some finite E f, but that E f has to be made 0. It can do so, only when if it comes up to the d-axis, then j I q x q add up

everything is in place theta, delta. And this angle is psi, the internal power factor angle psi.

Therefore, a salient pole generator, even with its field current 0 connected to the bus can pump power into the bus at some specified angle delta, but at leading power factor, it cannot be this salient pole generator cannot operate under lagging power factor, why because E f is 0, which is much less than the length of V, therefore it is under excited machine. So, this is the phasor diagram of a synchronous generator connected to infinite bus over ok.

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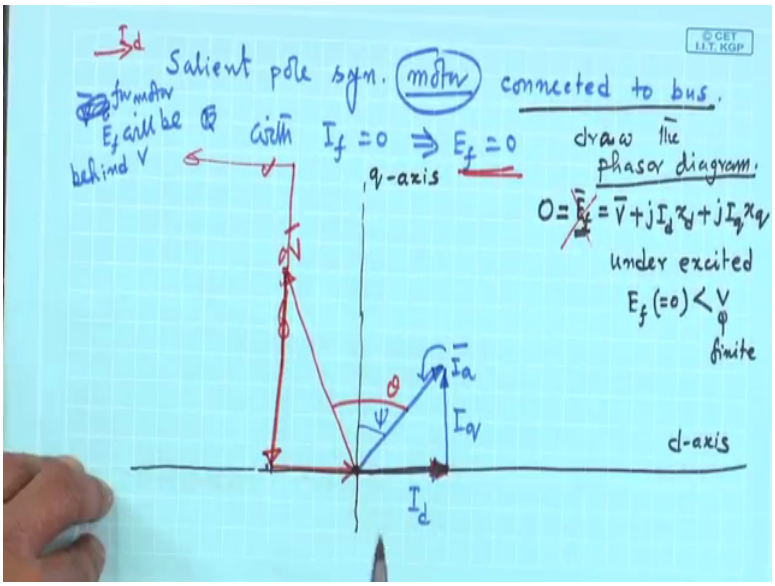

Now, similarly let us draw the phasor diagram of a salient pole synchronous motor connected to bus, and field current brought to 0 ok. So, salient pole synchronous motor, now it is operating in motor mode connected to bus with I f equal to 0, which implies that E f is equal to 0 is not, so this is the situation.

Now, in this case salient pole synchronous motor connected to bus with field current equal to 0, I have to draw the phasor diagram. So, what is the thing, draw the phasor diagram. So, once again I go by that rule, I first draw the q-axis that is I marked it as q-axis that is all. Then your d-axis will be at right angles draw it.

In case of motor, I told you it is always better to use this formula, because then you have additions V plus j I d x d plus j I q x q ok. This is the thing we will be using, because then addition rules will be applied. But, in this case E f equal to 0, because I f equal to 0. So, V plus I d x d plus I q x q must add up to 0; I q x q, so where to start? V is finite, because

machine is connected to the bus, V is the terminal voltage per phase. And that is finite E f is 0, therefore a synchronous motor connected to bus with E f equal to 0.

At what power factor, it will operate. Under excited synchronous motor, so the machine must be under excited why, because E f which is equal to 0 is less than V, V is finite connected to bus, it has got a definite voltage. So, it must be under excited. If it is under excited, then armature current must lag the voltage. So, E f is vanishingly small, but along q-axis, so it is here a small length vanishingly small length like this E f.

Therefore, your armature current may be somewhere here. So, E f is this is the line along which E f lies, so armature current lags that, and also it is a motor mode. In motor mode V E f will be for motor E f will be behind V, so E f is here, so V cannot be here; no, nothing doing it cannot be, because in a motor mode V will be always behind E f. E f is along this line, which in this case is vanishingly small, but nonetheless it is along q, and V cannot be here, then it would have been generator.

So, V must be in this axis, so a your V will be in this coordinate. And before that of course, the moment I got I a, I will say this is my I d, and this is my I q, this is I a, this length is I a, I q. This is the internal power factor angle psi, because in this thing. And your V will be in this line. So, let us draw the suppose V is here, then this is the power factor angle theta, angle between terminal voltage and armature current is theta.

Then I have to add to this is 0, E f is not there, so 0 is equal to this, so V plus j I d x d, so I d is along these I d if it is like this I d, then j I d x d will be like that like this, this is I d. So, j I d x d, so this is q-axis this is E f, this is armature current here armature current here, and under excited; under excited means lagging power factor. So, q I d I q you get, then in case of motor V should be ahead of E f, the same arguments I am repeating, because I am facing some problem, so this is the thing I d x d.

Now, to this V you have to add j I d x d why, it is giving like this. I d j I d x d will be like this, I d is this way V, it will be E f is 0 now lagging. So, j I d x d [FL] let me draw whatever it is giving, then we will conclude j I d x d is like this, V plus j I d x d, j I q x q is like that. And then this will be your E f, now it cannot be, so it must be O j I d x d and j I q x q is not, this will be the thing.

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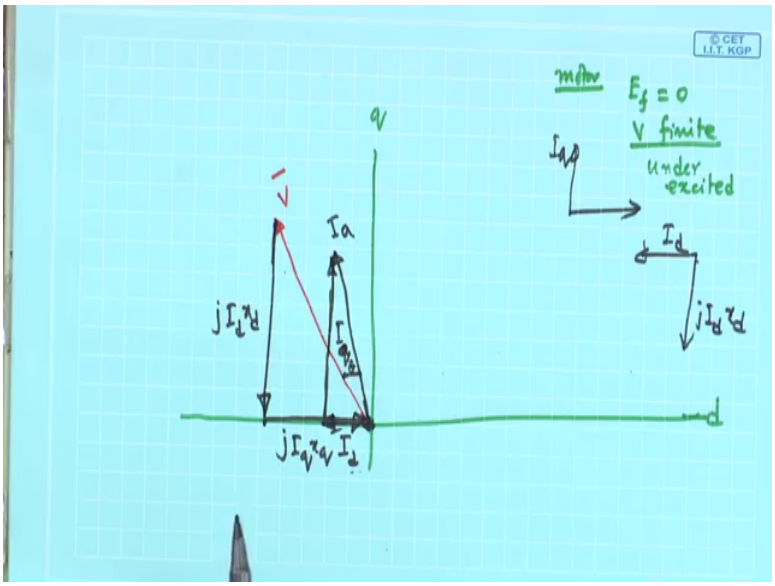

I will edit drawing nicely. See the it is motor mode, so what you do with excitation 0 ok. So, I draw q-axis, please let me be with me, so this is d-axis. And your field current will be 0, it will be somewhere and it is definitely E f equal to 0, and V finite; V finite and it is motor mode. These are the informations you need motor mode. So, the machine is under excited under excited, under excited synchronous motor always draws lagging current ok, it will draw lagging current.

So, this E f is here, so we will be here along this line, this will be your V. And it is lagging current, so suppose let me draw this lagging current as like this here I a. So, this will be your I d, this will be your I q. So, V plus j I d x d, I d is this way, it will be it was wrong earlier, it will be like this j I d x q I d. And this one this vertical line I q, so j I q x q, so this will be the thing j I d x d plus j I q x q that is in other words what I am telling, it is better to learn from mistake.

The when I drew like this, I a I drew here same argument leading power factor, I thought it may be here, it may be there with respect to V, it may be here also I do not know, but I drew like this leading power factor theta. If you draw like that, then your I d and I q becomes this way. And your V has to be ahead of here, so V you draw.

But, then you note that j if it is to be like this, then to V j I d x d will go like this, and j I q x q will be go going like this. And they this point must be at the origin so that your E f is 0, and it is violated situation cannot be like this ok. Lagging power factor that is this is theta I a has to

be in this quadrant so that I d is this way, I q is this way, then V plus j I d x d, so I d was here like this j I d x d is like this. And I q of course was vertical I q, so j I q x q will be like that. And you will get the phasor diagram of many types of machine in this way.

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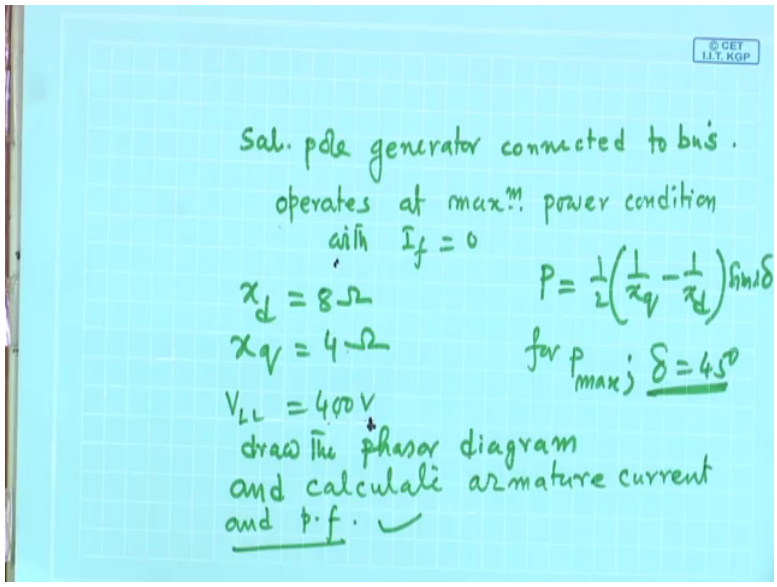

So, with this I so salient pole synchronous machines can operate with exciting current I f equal to 0. Suppose, I say that this is the last thing, one example I am giving. Suppose, I say a salient pole generator connected to bus operates at maximum power condition with I f equal to 0, then what do I do?

Expression for power in such case is half 1 by x q minus 1 by x d sin 2 delta. So, in this case for P max delta must be 45 degree understood. And I can draw the phasor diagram of the machine, and if I say x d equal to 8 Ohm, x q is equal to 4 Ohm, V line to line is 400 Volt; draw the phasor diagram and calculate armature current and power factor; this you try to solve drawing the phasor diagram on your own, giving proper argument that is the important issue.

The things I have used is synchronous motor or generator I must see whether it is under excited, over excited, then I will draw the armature current. First I fixed up of course q and d-axis, then I d, I q you find out, and then complete the phasor diagram. And once and in case of with excitation 0, it will be a single triangle of this kind in case of generator mode, it will be a single triangle of which this side is given, this side, this side I will be able to calculate. I d, I q if you know, armature current will be under root I q square plus I d square.

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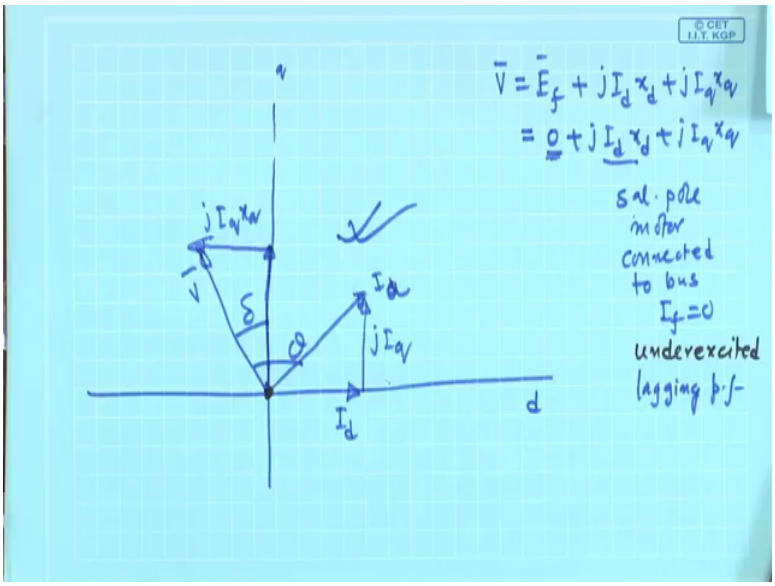

So, this synchronous motor with field current 0, we were discussing. And the interesting, thing I would like to tell about the drawing of the phasor diagram which very quickly let me do it, so that we can see this is q, this is d. But, in case of motor I was telling that I will start with E f, this was the thing you must be very careful about I a plus j I d x d plus j I q x q most probably, while adding I started with E f, and that is the confusion.

So, this E f is 0 plus j I d x d plus j I q x q must be, so this is salient pole motor connected to bus, and with I f equal to 0. So, field current is 0, it is here and it is under excited, therefore your it must be lagging power factor.

These are the logic you put properly lagging power factor, so your I a will be here, this is correct I a. And then I a, and this is your I d, and this is your j I q it is like this. And E f is 0, so 0 plus you know to this 0, you have to add I d x d. So, E f plus j I d x d, and j I q x q everything is consistent I d j I q x q. And this is your V, and this will be your theta, and this will be your delta, this is the most correct one, and x d x q. So, give proper argument and right correct equation, so E f 0 plus I d x d plus j I q x q gives you V, lagging power factor under excited ok.

Thank you.