Electrical Machines - II
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Lecture - 88
Phasor Diagrams of Salient Pole Synchronous Generator Under Various Conditions

Welcome to this salient pole synchronous machine lectures.

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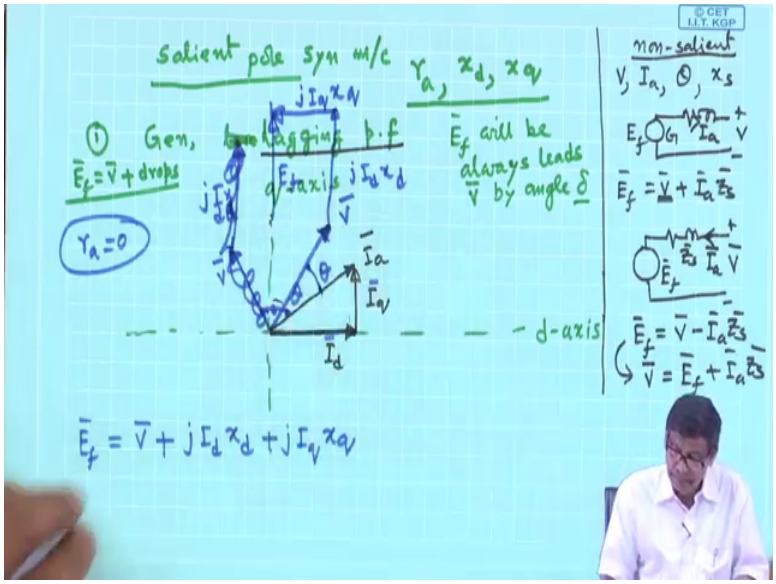

And we have seen that in a salient pole machine, the we generally do not draw try to draw an equivalent circuit, where you can show terminal voltage, armature current and induced emf em in a single equivalent circuit. Because of the fact that the armature mmf can be anywhere in space depending upon at what power factor the machine is operating. And therefore, it is necessary to break up those currents in I d and I q found.

And then, you know in case of synchronous machine two reactance are of importance one is x d, x q and r a. Unlike a cylindrical or non-salient pole synchronous machine, where only one reactance is sufficient that is called synchronous reactance.

Now, today first what I will do I will; we found out the power expression of a salient pole synchronous machine, considering it to be a generator mode; one can extend that to a motor mode, all these things. But today first thing is after learning all these things, let us try to recapitulate and advise you how to draw the phasor diagram correctly, because

that is at the heart of problem solving of salient pole synchronous machine. You must draw the phasor diagram correctly.

In case of cylindrical rotor machines, the drawing of phasor diagram, what you only need to know is that, what is the terminal voltage. Generally, terminal voltage will be known; armature current will be known, and the power sector angle will be known. So, in case of cylindrical machine, there was only one reactance x s and we told you that if this synchronous machine, which is non-salient pole type, non-salient pole type, then if it is a operating as a generator mode, you draw the circuit diagram like this E f, then show the r a, x s and here is your v terminal voltage and since it is operating as generator draw the current like this.

And then, we found that E f is equal to V plus I a z s that is the synchronous impedance. So, it is better you start with V and this one. So, this is generator. In case of motor mode a non-salient pole machine, I told you it is like this that is r a, this is z s no doubt, and here is your v terminal voltage, and here is your E f. But this time you show the current it is motor, so it is drawing power from the bus like this. And then we find that E f will be equal to V minus I a into z s. What is z s? Z s is r a plus j xs.

Now, it is often you know last time also perhaps I told you that addition of vectors is much more easier I mean human being love to add than to subtract. So, therefore, this equation also can be same equation can be written as V is equal to E f plus I a z s. So, in case of motor mode, it is better you first draw E f, then add to it the I a z s drop to get the terminal voltage. So, this you must remember, I mean this is no additional information's about machines, but this way if you do you will be making least mistake I mean no mistake perhaps.

Now, suppose salient pole synchronous machine, I will apply the same rule. And I will now show you today that giving different condition, how to draw quickly the correct phasor diagram. Suppose, I say case 1, this I have drawn in some way, but let us see and follow me try to follow me how this phasor diagram can be drawn rather quickly.

Suppose I say it is generator, generator mode. And it is leading power factor or lagging power factor it is operating. Let us first take lagging power factor and connected to the bus v. So, how to draw it? Generator mode remember E f will be, will be always above always leads v or above V by angle delta, by angle delta, no matter whether it is lagging

or leading power factor; E f will be above V. [F L]

Now, what you do first is that you just assume that let this be your q-axis this particle line, then the next step is then d-axis is fixed, this is d-axis, this is q-axis. These two axis gets fixed. Now in case of generator, E f addition wise if you go it will be V plus the drops, drops is not it, this will be the thing.

Now, what I will do is this therefore, E f must lie on this line I do not know where it is now, but I am sure E f is always along q-axis this much I know. And I am considering lagging power factor. Therefore, the internal power factor angle psi will be also lagging. And I draw the armature current I a suppose, this is my I a. Lagging E f, E f also of course, I do not know right now how much it is, but I know E f lies on q-axis. And it is lagging power factor you want to draw phasor diagram. So, draw I a lagging, but I will not show this to be theta. This must be psi, psi, anyway that I will write later.

And once I get these, I can draw I d and I q which will be like this is not it. So, forget about I a now; leave with I d and I q. Now, since it is lagging power factor where V a is suppose to be V a must be somewhere here, this is V suppose; and this is your theta; understand this is V; this is theta. Then you know E f is equal to V plus suppose r a is 0, I am drawing that case it is possible to draw r a non-zero also, but let us first understand this V plus j I d x d plus j I q x q, this will be my E f.

Therefore if this is V, this is lagging angle, then v plus j I d x d, I d is this way j I d x d that way. So, it will be j I d x d plus j I q x q. So, did I made a mistake? So, this is q-axis E f lagging power factor I a ok. So, you get I d and I q like this, then terminal voltage will be also lagging power factor. So, b I made a mistake it, it has become some 90 degree that is why the mistake is. So, V will be here, this is V is it not, because it cannot go 90 degree, and this is theta; this is theta.

Therefore, armature current lagging power factor I have taken by whatever angle it lags, I drop v here. Then 2 V, I will add j I d, x d, it is here j I d, x d and then, but I know E f will lie here and you see I q is such that this is j I q, x q and this will be your E f. So, quickly I will once again redraw it, because it has become slightly clumsy.

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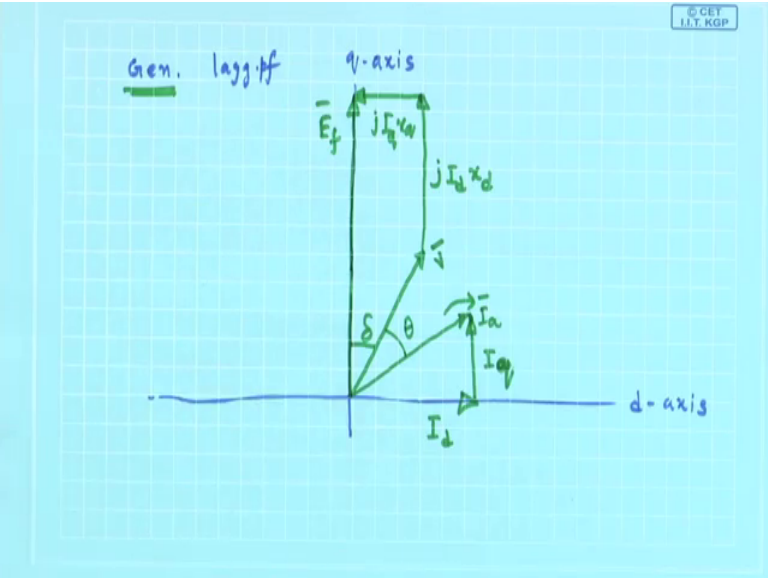

So, the argument is generator lagging power factor it is operating at lagging power factor. So, what you do? First draw q-axis, q-axis. Once q-axis is drawn, d-axis gets fixed at 90 degree draw that. Then I am saying it is lagging power factor, so I a will be here ok. And I know E f will lie here, then V must be, because E f always leads V in case of generator mode, it E f will be always ahead of V. Therefore, drawing of v this side which I did for the first time it is better you also understand V cannot be here, because generator mode tells me that v will be behind E f. understood.

So, so V must be here terminal voltage that is the thing, and this will be your delta then this I a will have two components that is I d and I q, I q I q mind you, this is not I a, this is I a, this is Ia. And then V plus j Id x d you draw and this length will be higher, because x d is higher. So, this is j id x d. And then j I q x q fine, j I q x q, and I will tell this is my E f. And you know a lagging power factor at lagging power factor a generator is over excited, because E f is greater than the magnitude of V everything is consistent. If you want to theta, theta will be this angle, got the point. This is how generator lagging power factor I have drawn.

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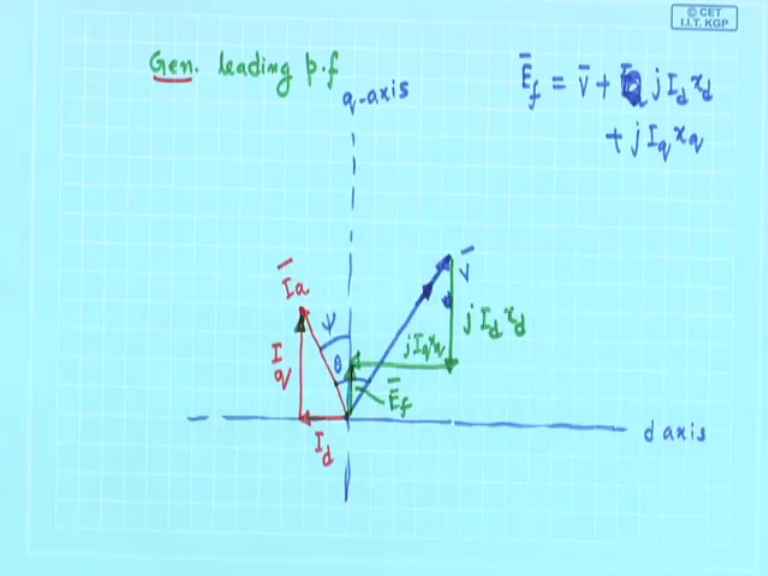

Suppose, once again I am telling, suppose I want to draw leading power factor generator salient pole generator leading power factor. So, once again what you do you first draw q-axis, suppose this is q-axis and this is suppose d-axis. q-axis means finally, your E f has to lie here. Now, I have been asked to draw phasor diagram for leading power factor. So, with respect to V current must lead and also with respect E f suppose current leads that is the internal voltage.

So, I first draw the I a here I a I a since it is generator, your E f will lie along this V must be behind. So, I draw next V. This is your V, suppose this is V. And this angle is theta power factor angle theta got. Since I a is this, so I will draw I d like this I d plus I q at the two currents.

And you know this angle is your psi internal power factor angle, angle between E f and I a, of course, the position exact point, where E f will be here, I, I am yet to get that that how I will get by using this relation E f is equal to V plus I a r a, I have neglected, but that can also be taken into account I a, sorry I d j I d x d plus j I q x q that that is what I have to add to V addition rule I will apply to get E f.

So, what will be the thing, V plus j I d x d; I d is here j I d is will be there below. So, V plus j I d x d; I q is along these j I q x q will be 90 degree leading I q. So, these plus this j I q x q, and then this will be your E f, got the point. So, everything is in place generator leading power factor, see v is always behind E f power factor angle is angle between V and I a internal power factor angle is angle between E f and I a; E f is along this line and

I a is here. So, this will be psi. And this will be the phasor diagram when generator is supplying leading power factor.

Note that the length of E f is much smaller compared to length of V. So, it is under excited. So, a under excited synchronous generator no matter whether it is salient pole or non-salient pole, we will have we will be operating at leading power factor under excited synchronous generator. Now, let us do the same thing for motor mode.

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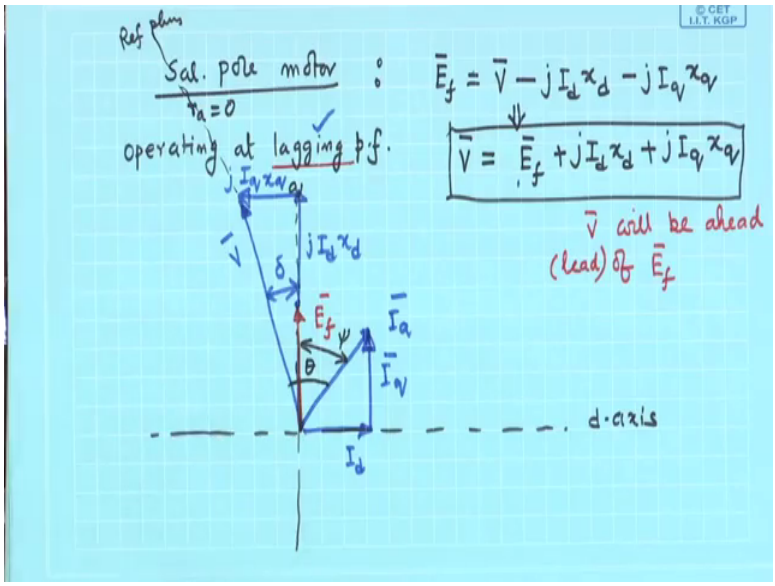

So, let us assume that salient pole motor, I all salient pole motor ok. And in salient pole motor, first of all because of reversal of direction of armature current, we know this is true E f with r a equal to 0; I will be sketching first. E f will be equal to supply voltage minus the drops in case of motor, so minus j I d x d minus j I q x q that is the thing.

Then I will convert it to this form that V is equal to same equation E f, because I feel very much comfortable with this. Hopefully you will also feel comfortable otherwise this will also do anyway. So, j I d x d, because addition comes naturally to human being I mean to us I suppose so.

So, so this is like this V is equal to E f plus j I d x d. Therefore, it is better in case of motor mode, you start with the E f, go on adding the drops to get terminal voltage that is what I want to stress upon ok. Now, how to draw the phasor diagram; in case of motor mode always remember V will be ahead of or will be ahead means will lead, will be

ahead robot lead E f that is the thing we have seen. Therefore, to draw the phasor diagram now under what condition suppose lagging power factor salient pole motor operating at lagging power factor how it will look like.

So, like the previous one first draw the q-axis, let this will be the q-axis then d-axis is fixed draw that d-axis. And I know E f will lie somewhere here. Suppose, E f is this much ok, I will draw it like this E f is suppose this much. And I have told you that lagging power factor. So, lagging power factor means current will be lagging the both the terminal voltage as well as E f by some angle.

So, I will then draw the armature current. This is because of lagging power factor I draw it here. At the end where do I expect V will lie, V will be ahead of E f it must come here. If it has not come, then I have made a mistake that is the idea. So, this is I a. So, first I find out its direct and quadrature axis component I q. I find it out. Then I go to this equation means this equation only I am applying, but in additive mode that is why I have started with E f. Then to E f, we have to add these drops. So, to E f you add j I d x d that is this length will be this one j I d x d plus j I q x q I q is here. So, j I q x q will be like this. So, so j I q x q and then this must be your V; this angle must be delta.

Let us show the angles. This must be the power factor angle, angle between V and I a lagging power factor, theta. And this angle must be internal power factor angle psi like this. And your phasor diagram is over. Now, I told you since V is the bus voltage it is always better to take voltage on reference. Now, this phasor diagram when I have started with we have got this, this is the correct phasor diagram, then you call this is to be your reference phasors, how does it matter the V, call this V to be V angle 0 degree nothing like that. This, this phasor diagram remains same.

But if you follow this rule I personally believe you will very quickly and correctly draw the phasor diagram of a salient pole synchronous machine. First you ask yourself whether you are drawing the phasor diagram for a motor, yes, in this case for a motor if it is for a motor V will be ahead of E f. So, you and always start with E f go on adding the drops that is the idea. So, E f is first drawn q-axis, then where is armature current drawn, oh, it is lagging power factor. So, I a will be placed behind E f that I draw.

And once I have assumed q-axis to lie vertical, d-axis must be along this line then I a is there. So, I d, I q are known. If I d, I q are known, then you assume that suppose, this is

your E f at that time. So, to E f and j I d x d plus j I q x q and get your V, and it is in right phase correct absolutely correct. So, very quickly you can draw the phasor diagram of salient pole machines.

Let you; let me tell you also let me once again draw and you see in case of motor mode E f is and this, this angle is delta, E f is behind V, because direction of torque reverses, E f is behind V and all things are there. So, if some parameters of this you can apply the properties of triangle, this that to solve simple problems apparently complex problem, but very quickly ok. Armature current, power factor angle, these that are given draw the phasor diagram correctly then you are through see, which sides are given things like that. [F L]

Let me draw the phasor diagram when the salient pole machine and you see lagging power factors salient pole machine is under excited, because length of V which decides the resultant field is much higher than the excitation field, which is given by the length of E f we have seen. [FL]

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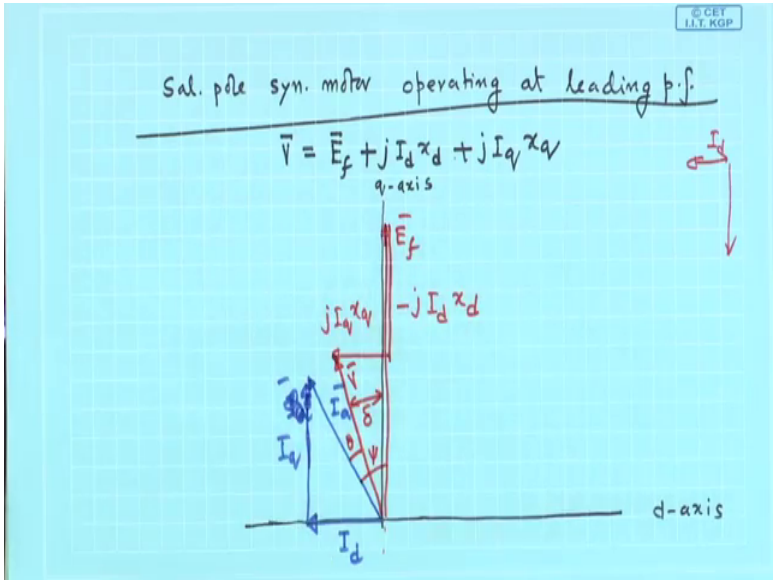

Now, let us try to draw salient pole; salient pole synchronous motor operating at leading power factor, operating at leading power factor. I want to draw correctly the phasor diagram correctly and quickly that is the thing. So, once again I will use this relationship V, I will start with E f, then end up with V by adding these drops j I d x d plus j I q x q that is what we will be doing.

Now, so the steps are same, draw the q-axis first, this is your q-axis ok, then d-axis gets, gets fixed. So, this is the your d-axis ok. E f will lie here that is there. Now, leading power factor, so armature current leads q, so you first draw the where will be V, V will be ahead of E, I know V will be here and currently. So, you draw the current first. Suppose, this is your armature current, if this is my armature current, then I know its d component is this way and q component let me this is I q, and this is your I a. And this is the internal power factor angle psi.

Now, suppose I say this is my E f, E f. So, to E f you add these two drops j I d x d. Now, I d is this way j I d x d will be downwards, is it not, I d is this way. So, j I d x d will be like this. So, minus to this you add and it will be along q-axis j I d x d will be there. Then you have to add plus j I q x q, I q is here and j I q x q will be in this way. So, j I q x q, and this will be your V, this will be your theta, and this will be your power factor angle internal power factor angle psi, where is delta, this is delta. So, this will be the salient pole synchronous motor operating at leading power factor, this will be the phasor diagram, and you can quickly draw it. We will continue with this in the next class.

Thank you.