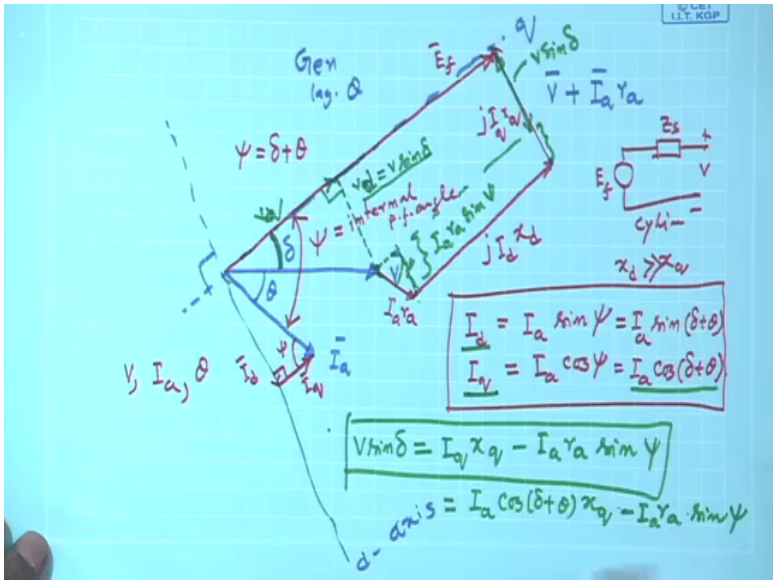
**Electrical Machines - II**
**Prof. Tapas Kumar Bhattacharya**
**Department of Electrical Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 86**
**Phasar Diagrams of Salient Pole Synchronous for Generator & Motor Mode**

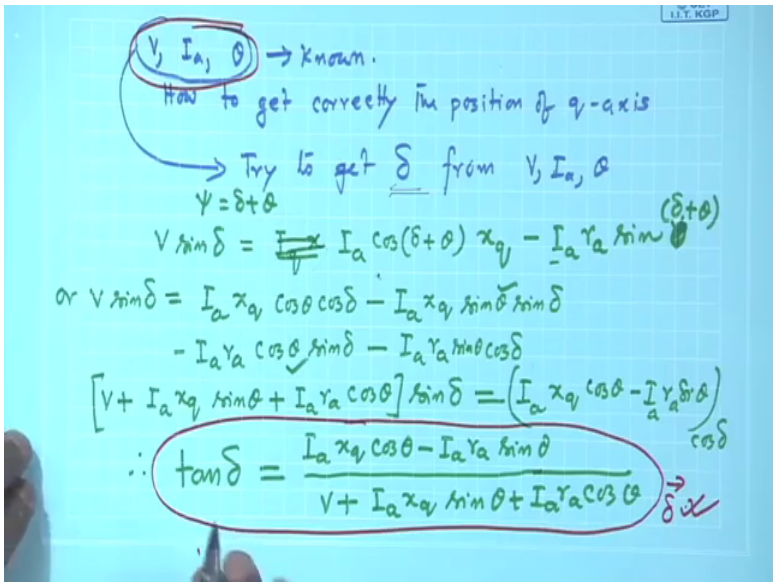
Welcome. So, we were discussing about Salient Pole Synchronous Machine.

(Refer Slide Time: 00:21)




And I have taken Generator mode of operation and it is supplying lagging power factor angle theta and I told you how to do it.

(Refer Slide Time: 00:40)




So, the point is that I am once again stretching these terminal voltage will be known, armature current will be known, power factor angle these are known. The question is how to get correctly, the correctly the position of say q axis. Once you get the position of q axis d axis position is fixed, it is that right angles to q axis. So, in this last class, this is the diagram with r a included I told you that I did not know the exact position of this one, but I knew this much that it is generated therefore, E f must be above E f V.

So, somewhere I draw this line and told this must be your delta and then V I r a plus j I d a x d then you I drew the d axis line, I broke up currents I d I q, then at this voltages you will arrive at E f. But, still the point was that exactly where it will be, what is the value of delta? Is it possible from is it possible from this information's try to get try to get delta from the knowledge of V I a and theta. Unfortunately, in a synchronous machine you cannot connected an ammeter to record I d and I q, it is totally conceptual in our mind it exists.

What is there, which current is flowing in the line? It is I a and that can be measured, I can measure the terminal voltage, I can measure the power it is delivering. Therefore, it will be necessary to know delta first from this knowledge that is what I am going to do now. Listen carefully, I will not redraw because it is already fairly it is drawn correctly it is like this [FL]. Now, you see I have to calculate this delta, what is this delta in terms of those quantities and machine parameters is not. So, that is what we will do and we have

got I d and I q.

Now, you see that from the steep of this voltage phasor you drop a perpendicular there, then I will say this is V d and this length is V q. And, V q will be V sin delta V q will be V sin delta, I am sorry this is V d this is V d and this is V q. So, V d is V into sin delta is not from this right angle triangles and this V sin delta, if you drop a line is this length; this length is V sin delta is that clear. So, V sin delta is this length and this whole length is I q x q this whole length is I q into x q. So, from I q x q if I subtract this length; I will get V sin delta. So, V sin delta must be equal to I q x q minus this length.

What will be this length? See angle between I a and this line is psi. So, angle between I a r a, r a is a number it is parallel to this I a. So, so this angle is also psi this is parallel to this I a r a parallel to I a. So, this is psi therefore, if you drop a perpendicular there this length will be nothing, but I a r a sin psi from this right angle triangle ok. Therefore, you take this projection I a r a sin psi and this length is nothing, but this length therefore, I will say V sin delta is I q x q minus I a r a into sin psi, this must be true.

Then the whole idea is this I would like to get rid of the terms involving I q I d from this expression and form a equation from which I will be able to calculate delta, that is the idea. Now therefore, I will write this in this page only I am writing although it is becoming somewhat clumsy, but not that clumsy so, that we do not understand. So, what I will do is this for I q I will put this value in terms of I a. So, this I will write it as I a into cosine delta plus theta into x q x q x d will be known to me minus I a r a into sin psi this is.

So, we come to a fresh page and tell that V sin delta I rewrite that V sin delta is equal to I q I sorry I a cosine delta plus theta into x q minus I a r a into sin psi and we know that psi is equal to delta plus theta. So, we expand this term so, for psi here I also I write sin delta plus theta. Now, what all you have to do a little bit of algebra here that is you expand those terms. So, b sin delta will be equal to I a; this is I a not I q I a into x q that is good. And, this you break up into two terms cos a cos b then minus I a into x q sin a sin b sin a sin b. This will two terms and this term also give you two terms, what is that minus I a r a sin a cos b.

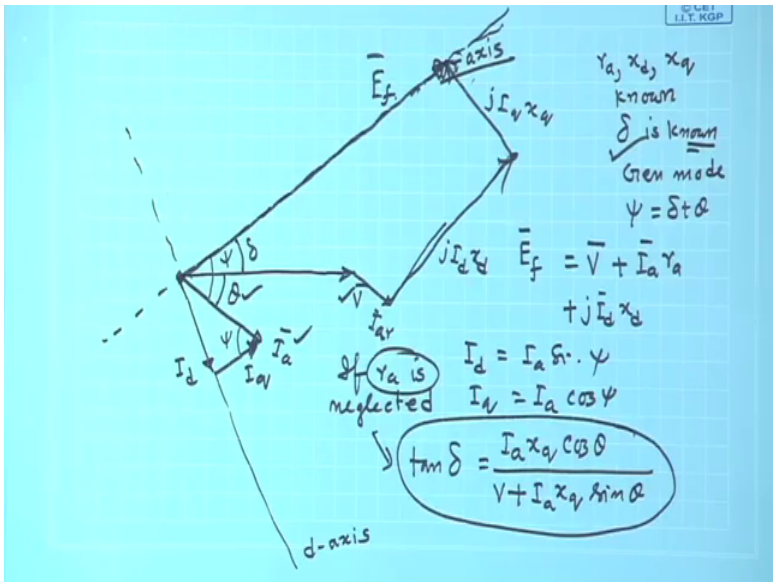
So, cos b sin a cos b plus; that means, this minus once again minus I a r a oh sin a cos b minus cos a sin b. So, this will be the thing. Now, what I do I bring all the sin delta terms

that is this and this to the left hand side and I will be getting here V plus I a x q sin theta plus I a r a cos theta whole into sin delta is equal to this two terms will be there on the right hand side I rewrite them. So, I a x q cos theta minus I a r a sin theta and whole into cos delta. So, that tan delta will be equal to I a x q cos theta minus I a r a sin theta divided by this whole thing that is V plus I a x q sin theta plus I a r a cos theta, this is the thing..

This will be the expression of tan delta, on the right hand side you see I a there is no I d I q fine. There is only terminal voltage V and there is power factor angle knowledge of theta is necessary to compute this. Therefore, if I say a salient pole synchronous generator is delivering 10 ampere current at a power factor angle of lagging 30 degree and x d x q and r a values are these, then I can calculate before starting drawing this phasor diagram tan delta hence delta.

So, tan delta tan inverse of that so, delta will be known from the knowledge of V I a and theta. And, once delta is known now I will come back to this drawing the phasar diagram; I will know what is the value of delta may be 10 degree, 8 degree whatever it is.

(Refer Slide Time: 12:53)




So, after from the operating point I will calculate delta then I will between the phasor diagram much more confidently now it is like this. I will sketch V I a also I can sketch I a theta power these are the known things and then r a x d x q known. So, calculate tan

delta from this expression delta is known and then it is generator mode E f which is the q axis must be above V. So, delta known so, draw a line now delta known I will write delta here of course, I do not know where the E f is, but q axis is now known precisely, I know this is q axis. E f must lie along this line then what I am going to do, I will draw a line perpendicular to this here and I will say this is d axis, where that field poles will be there.

Now, theta is known delta is known so, psi is also known delta plus theta then you get this two components and this values are now known in numbers I q, this is psi, this is also psi. Then what I am going to do? To this V I will say E f will be equal to V instead of trying to write and V plus I a r a of course, will be I can take into account; I a into r a there is no idea I q I a into r a plus plus this drops. I a you now forget there is difficulty because, the m a will be along this we do not know what is the reluctance it will go on changing. So, I have broken that I a into I d I q it is I u I a from your memory to complete this equation I will write instead of I a there are two currents two current exist.

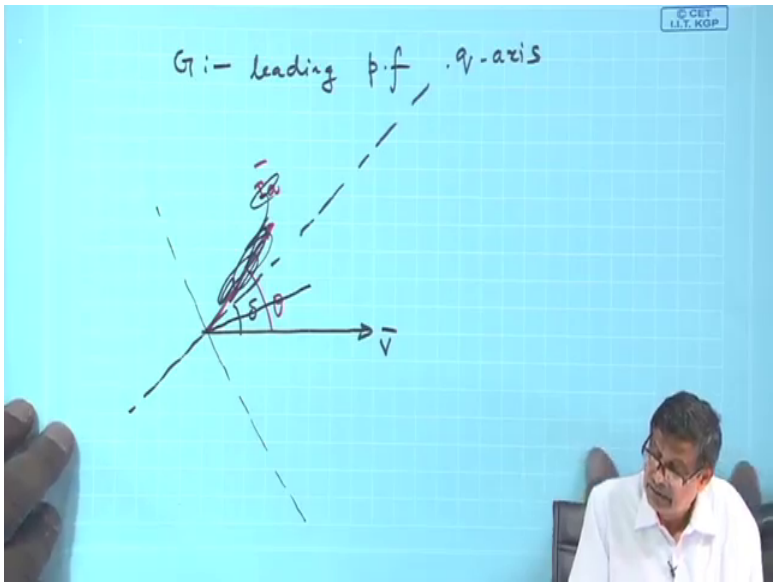
So, j plus j I d x d where it will be, it will be perpendicular I a r a first I will add I a r a I will add I a r a this is I a r a, then I will add to these oh sorry this will be parallel to q axis because I d is here. So, j I d x d and once I get there then everything is in place I mean see I q x q will be j I q x q; it brings down this point there j I q x q and this is j I d x d and then I will say this is E f E f.

So, in this phasor diagram everything is numbers now, why I started with V I a and theta then I calculated delta, then I drew the q axis line. Still I did not know where the E f will be this much that much this that I did not know, but q axis was drawn properly. So, delta was known E f d axis so, this is I a psi is known. So, I d is I a sin psi I a cos psi like that will be doing and note that that in this phasor diagram everything is in place x d is higher than x q. So, this length will be higher than this length and you get it. If r a is neglected you can separately find out the expression of tan delta, but in this case put this term will not be then present.

If r a is neglected then tan delta tan delta will be equal to I a x q cos theta that I a r a minus I a r a cos theta sin theta will vanish divided by plus V plus I a x q sin theta. This will be the simple expression, if you neglect r a which sometimes people neglect and then this is the thing. So, this is the phasor diagram of a synchronous generator operating at lagging power factor. I think this synchronous generator operation, operating at

leading power factor you will be also able to do and find out the expression of delta you see yourself. But, to first what I will do if time permit generator leading power factor also we can do, but I will give you hints.

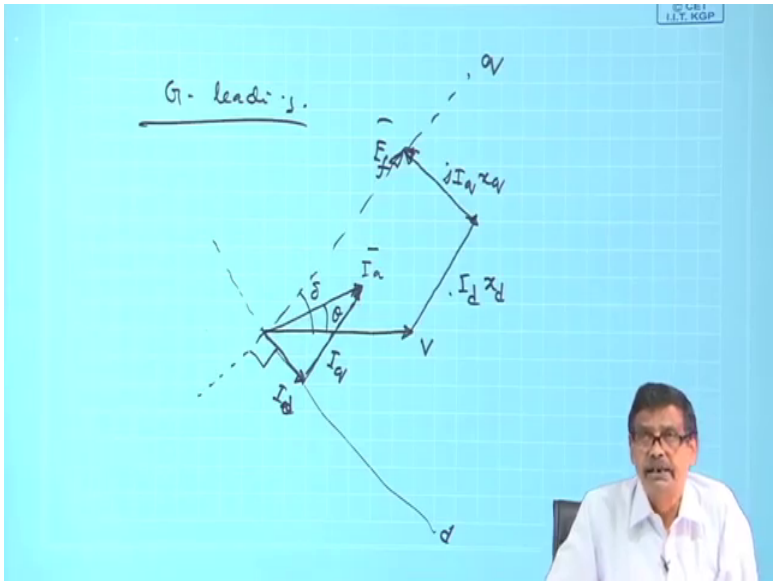
(Refer Slide Time: 19:12)




For example in case of generator leading power factor generator leading power factor I should do them like this. This is V I will draw, I am just sketching I will not do any mathematics on this phasor diagram that is left to you to do then I know it is generator. So, E f will be above it suppose, this is the q axis where your E f will ultimately reside. So, this angle is delta and suppose, I say that it is leading power factor.

So, suppose the armature current is like this I a and this is the power factor angle theta I have just drawn leading. But, the moment I got q axis your d axis will be like, this is not your d axis will be like this. Oh I just it has become greater than I will sketch it this I a for this thing it is leading power factor I will use this one.

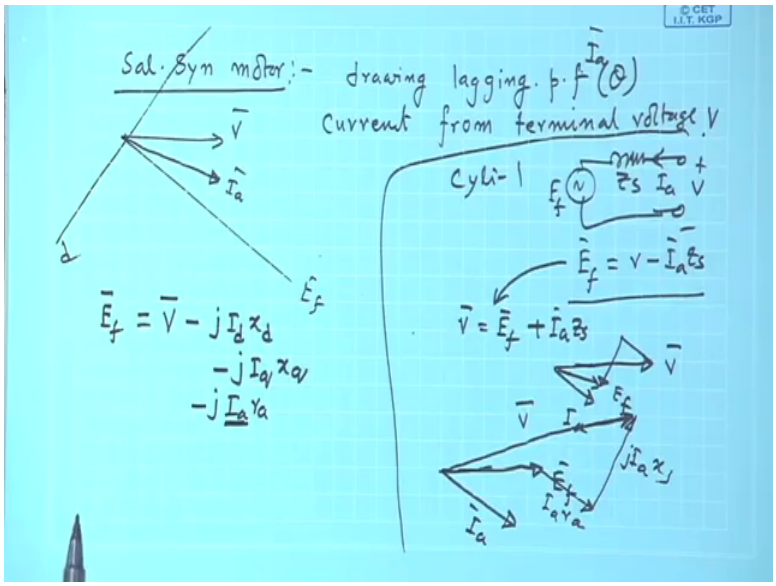
(Refer Slide Time: 20:54)




So, leading generator leading: so, a typical thing will be this is V your E f will be above it ok. So, suppose this will be E f q axis, this will be your d axis and this is 90 degree and then this is suppose your I a. Then what I have to do? Then you know this angle is delta, this angle is theta. Then I a I have to break it up into two components d axis that is I d and this is I q.

So, V plus I d x q I will do this is d I d x d and then you add V I q x q V j I q x q to get this value of E f and I r a drop I have neglected in this diagram that can be taken into account. So, there are several cases I hope you will be able to tackle this, but above the motor mode I must do it synchronous.

(Refer Slide Time: 22:40)




Suppose, now I say it is synchronous motor salient pole salient synchronous motor and suppose it is doing drawing lagging power factor current from terminal voltage V power factor angle suppose theta. Now, in case of generator you know in case of cylindrical machine I drew it like this, but in this case we cannot draw. So, this is the Z s, but the convention I am trying to reminding you this is V this is I a and this is E f and we wrote like this E f is equal to V minus I a Z s is not this is the way.

Now, see that is fine, but you know human nature at least for me addition is much more simpler is not, things are added subtraction also easy, but anyway certainly not easier than additions. So, also see that this in case of motor mode you if you start with terminal voltage in case of cylindrical machine; what I was doing V? I was drawing current I a then minus I a r a minus I a j axis we were doing getting E f is not you recall that. But, you could also draw the phasor diagram saying that this is the voltage equations which is nothing, but this same equation I a z s you bring there and say that V is equal to E f plus I a Z s.

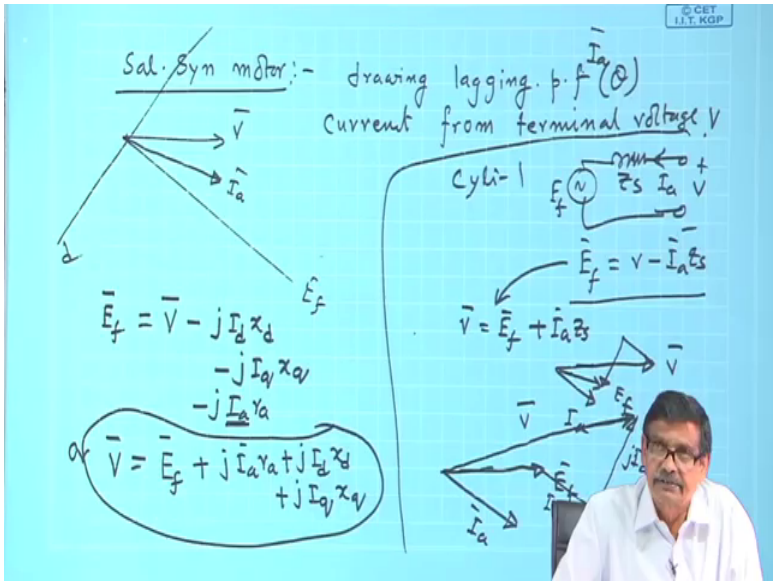
Try to get this point same equation I am doing then I am arguing that ok, this to draw this phasor diagram what you do you start with E f; getting the point cylindrical machine this discussion cylindrical. So, I could also draw this phasor diagram in this way first draw E f. Then say lagging power factor I a is there ok, then two E f and I a r a plus I a Z s adding I a r a and you will get terminal voltage ok. So, the same phasor diagram. It is

now just rotated in space how does it matter? Without any loss of generality so, that you can quickly draw the phasor diagram, better draw E f first in motor mode and go on adding drops addition is much more you have to think little to add the vectors.

The moment one vector is to be subtracted where, was that vector opposite to that we have to do that is the advantage anyway it is not essential, but I will do like this. So, a salient pole synchronous motor drawing a lagging power factor I a at a terminal voltage V what will be the thing.

So, I know this much only that in case of motor I know if this is your terminal voltage E f must lie below it that is certain motor mode with this convention. So, E f will be below your voltage, what else are given? You are given I a, but it is a salient pole machine therefore, if this is q axis I will find out d axis here like this. And, then I will find out the components of I a in d and q axis add to E f those drops and get the terminal voltage V.

(Refer Slide Time: 28:23)




So, in this case I will say that E f must be equal to this thing that is fine V minus j I d x d minus j I q x q and minus j I r a if r a is also present, this is I a reminding I i a r a. Or, I will say V translating this equation in terms of additions; I will say if you first draw E f then to E f you just go on adding these j I a r a plus j I d x d plus ji q x q this is the thing. And, at this addition thing I will use to relate between V and V E f in the next class.

Thank you.