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

Lecture – 80
Generator Mode of Operation Rotor Field, Stator Field & Resultant Field

Welcome. So, we are discussing very important topics on synchronous machine. That is if the parameter values are known how to calculate how to do the performance analysis of the machine.

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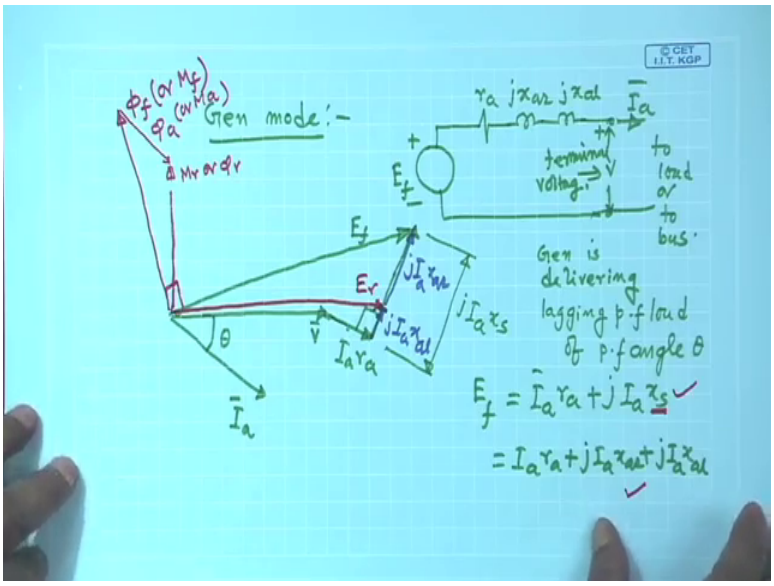

So, unfortunate and very good news is that the per phase equivalent circuit is very simple, it is only series thing no magnetizing branch; this is excitation voltage, this is terminal voltage. So, these are the basic equation, these equation and these x s you can break it up into x ar plus x al. So, what I was telling?

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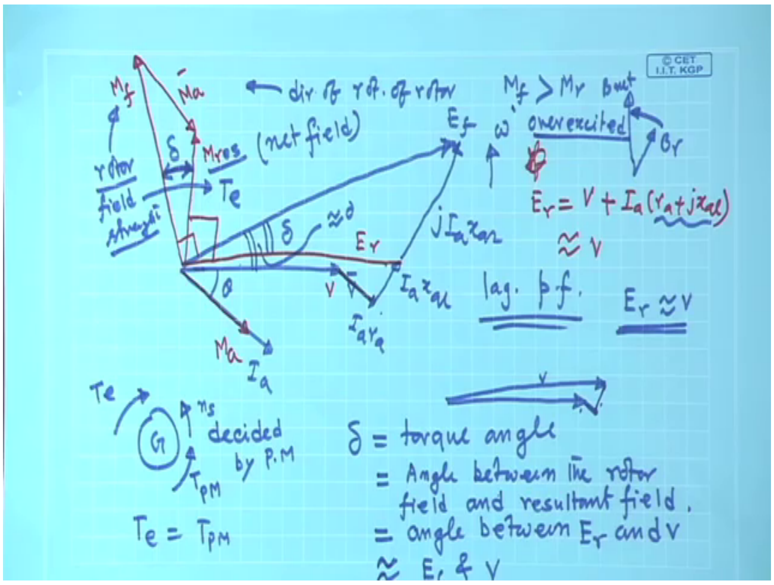

I will better draw it once more so that you become really conversant with this particular way of drawing. Take the terminal voltage v ok, assume the power factor suppose the machine is operating at a certain power factor I a you draw that. This is the power factor angle of the load or at this power factor the machine is operating terminal, voltage terminal current angle between them and it is lagging.

Then to this v we have to add the drops, one is I ra drop and then another is I a x a r drop x al drop, leakage impedance which is with this and these are very small and then the most of the drop takes in that armature reaction reactance x ar, you get and then you will get E f. Once you get E f I know phi f must be here M f or phi f MM f it terms of I am writing and this angle is 90 degree.

What is M r? M r is M f plus M a; M a has to be in phase with I a. So, M f plus ma you do and you will get M r to be here resultant field and if it is M r and you know this is E r I r a plus I a x al is E r, everything is consistent this angle is also 90 degree. In fact, if since you note that E r is equal to v plus I a r a plus j x al this will be very closely equal to terminal voltage itself. Because this drops are small, I mean if I draw to try to draw somewhat realistic thing; it should be like this v suppose this length is v this will be I r this will be I a x al are you getting and this is your E r.

So, this two are very small; sometimes they are neglected do not bother. Anyway so this is the complete phasor diagram. Mind you this is the resultant field do not consider this to be rotor field ok. Resultant field rotor field is which one? This is the thing. Rotor is the DC winding, it carries DC current that is how we have assumed, this is the rotor field and this is the resultant field or which I called earlier as net field while discussing in general about the machine, net field. And all feathers are moving and also rotor is moving with the synchronous speed ns or 2 pi ns.

What will be the electromagnetic field? Electromagnetic field is you know in case of synchronous machine I told this is B net like that I draw this is B r, torque will be from B r to B net and direction of rotation is decided by that. But in case of generator the torque has to produce in the opposite direction and it is very consistent, M f always try to catch up with the resultant field in that direction. And therefore, direction of rotation is here; direction of rotation of rotor is in this direction, but direction of electromagnetic torque will be in the opposite direction that is what in generator happens.

Direction of rotation is decided by prime mover, you apply some torque externally to the rotor will pick up speed, but the moment you want to draw power out of the generator there will appear an electromagnetic torque in the opposite direction. And therefore, prime mover has to draw more power so that it will ultimately convert that mechanical power into electrical and supply it to the load that is the whole idea.

So, in case of generator operation recall once again the direction of rotation ns decided by prime mover; decided by prime mover diesel engine steam engine whatever it is and electromagnetic torque will appear this. Therefore, there will be two torques acting on the shaft of the motor; one is the torque of the prime mover trying to run it in the anticlockwise direction and once again if Te is equal to T PM, it will run at constant speed if T bits T PM machine will slow down if T PM is greater than T machine will accelerate during the transient process. Otherwise synchronous machine will operate always at constant speed, no question of telling speed is changing in steady state operation.

If it is a four-pole machine, the rotor speed of the synchronous machine will be always 1500 rpm; if it is fade from a 50 Hertz supply. So, this is the steady state thing and this will be the complete phasor diagram. We will draw the phasor diagram for synchronous motor operation also, but before that let me draw the phasor diagram. So, this is for lagging power factor.

So, it may and also note that the angle between these and this is very important it is called delta you know, and this angle will be same as this angle. So, delta is the angle between the rotor field and the resultant field because that angle decides how much torque it is produced. If this angle happens to be 0, then no torque no electromagnetic torque at least will be produced by the machine.

Suppose there is no friction nothing, then prime mover also do not have to provide any torque to overcome the friction. So, prime mover for torque will be 0 and synchronous generator suppose operating under no load I a is 0. So, therefore, no power is delivered. So, torque developed has to be 0, in that case M a will not be present at all only M f is there. So, no question of so this is the torque angle delta.

So, delta is called torque angle, very important in a synchronous machine. And this torque angle is angle between whom? Angle between the rotor field and resultant field. We have consistent with what we did in case of induction machine as well to define delta.

So, this is the torque angle which is also equal to angle between E r and V E r and V that is this angle E r and V and which is also approximately equal to this you must understand whenever you do approximations this can be done in the sense that this since E r is approximately equal to V because of the fact this leakage impedance drop is small sometimes this delta will be very nearly equal to this angle as well. This angle is also very close to delta only this small part, are you getting?

So, whenever so angle strictly speaking it should be angle between E r and v, but since I a ra and I a x al are small therefore, it may be considered to be the angle between E f in terms of voltage phasors and V also approximately equal to. So, sometimes people also take that to be the angle delta because delta is going to play a very crucial role in deciding how much power the generator is delivering and what is the torque developed by the machine.

Only one point I will tell, in synchronous machine all the electrical quantity phasors as well as this phase phasors M a, M r ma M f these are fields, armature field, stator field, rotor field, resultant field all of them are rotating at synchronous speed.

Therefore, there can be nicely put on the same phasor diagram because all phasors are also running moving at synchronous speed; that is, another good thing. That is why I could represent all the electrical quantities as well as this space vector quantities on the same phasor diagram. These you just remember.

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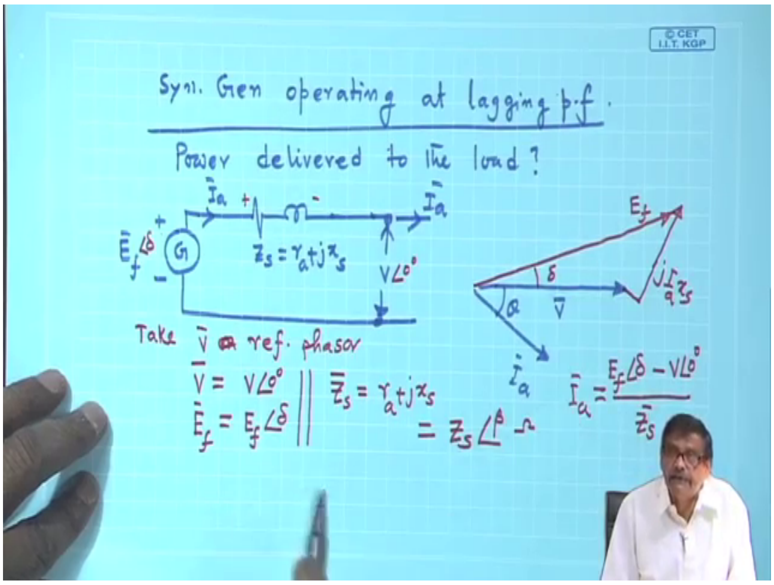

Now, we come now to this. Now, therefore, so next step I will calculate suppose a synchronous generator operating at lagging power factor lagging power factor. This is the thing we want to know what is the power deliver to the load how to calculate how much?

So, I will see it is not always necessary you also draw this M r, M a M f, only thing only one comment I forgot to mention. You see the resultant field is less than the rotor field, rotor field is this much resultant field is this much when such a thing happens if rotor field is greater I mean this is one can look at the phasor diagram and conclude that M f, magnitude of M f is bigger than M r that is rotor field strength M f is rotor field strength.

There is another terminology I am telling. If rotor field strength is greater than the resultant field we say the machine is over excited because a rotor field is decided by I f. So, over excited machine we will see by controlling the excitation the power factor at which the machine is operating if it is connected to infinite bus can be changed.

Therefore, over excited synchronous generator which is connected to the infinite bus and delivering lagging power factor load it must be over excited we will see that, but just one passing remarks from this phasor diagram. If M f is greater than M r this length is greater than M r it is over excited, what will be under excited case if M f is less than M r? Normal excitation may be M f equal to M r things like that ok.

So, this is the thing. So, synchronous generator operating at lagging power factor I want to find out power delivered to the load. While calculating the power we will calculate the total complex power in one go I mean nothing like calculating how much real power it is delivering and then separately calculate how much reactive power it is delivering. And for that this knowledge is only necessary that I will first tell, then I can go very fast to calculate the power delivered.

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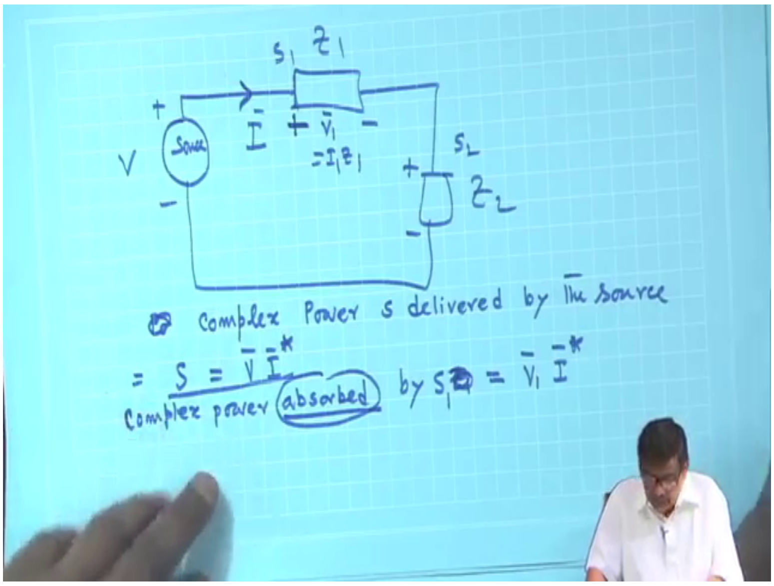

You recall that from circuit point of view if you have a source here, if suppose you have two impedances like this one is Z 1 another is Z 2. Suppose this voltage is V and it is delivering some current I. So, when you draw when current comes out from the positive terminal of a particular element, we say that this particular element is delivering power to be other components present in the circuit.

For example, the V and I the way I have assumed their directions which of course, I am free to choose their directions and polarity, but once this is selected this is plus minus and it is like this I am telling I have assumed that this source is operating as a source of generator. It is delivering power from the positive terminal power comes out, then I will write that power I mean means complex power which complex power s delivered by the source; delivered by the source this is suppose source I will write S as V I star.

Similarly, if I say what this element is doing Z 1 is it delivering power or it is observing power I will say through this element the voltage polarity because of this assumption I Z1. So, this voltage is suppose V 1 voltage drop which is equal to I 1 Z 1 is that. So, the I will write complex power absorbed mind you. Why absorbed I have written? Because of my assumptions of the polarities of current direction of current and polarities of the voltages I am saying that this element absorbs current through the positive terminal; that means, it is absorbing power.

So, complex power absorbed by Z 1 will be this V 1 and this I star ok, if after calculation you find both the real and imaginary part of this quantity oh sorry this is S 1. If you find this real part and imaginary part real part gives you the real power and imaginary part gives you the reactive power, if both of them become positive I will say both kilowatt is absorbed as well as it is absorbing reactive power understood.

Similarly, the complex power delivered by the source if both of its part a real and imaginary part both of them are positive numbers I will say this source is delivering so much of positive reactive power to the load and so much of kilowatt to the load. Anyway this is similarly for Z 2 it can be done.

At anytime you can easily show that the S will be equal to S 1 plus S 2, delivered must be equal to source. So, this is the thing I will be using to calculate the power. So, how to calculate the expression for power for the synchronous machine? So, first what you do? You draw the equivalent circuit this is your E bar f, here is your synchronous impedance Z s which is equal to r a plus j x s and here is your terminal of the machine per phase equivalent circuit V and it is delivering a current I a bar and it is operating as a generator that is the thing.

In case of generator mode the phasor diagram will be like this V and this is I a, this is theta. So, V plus I r a plus jia x s; I will now not break up I will straight away write this one x s and I will get E f ok. So, this will be the thing and this angle will be approximately equal to delta ok, I just assume this to be delta.

Now, what I do is this I say take V one reference terminal voltage V take V as reference phasor; reference phasor. So, that I will say V is equal to its magnitude and angle 0 degree, that is what I am telling you if this is the case then you can easily see E f this phasor will be nothing, but its magnitude and with angle delta it is leading V.

In case of generator another way of looking at it that in case of synchronous generator operation you will always find this excitation voltage or no-load voltage will be above V and delta will be positive. So, this two things are there and then also I assume this impedance Z s which is a complex number that is ra plus j x s I will write it as its magnitude which is equal to under root r a square plus x square with angle beta, I have expressed this in and these are in volts.

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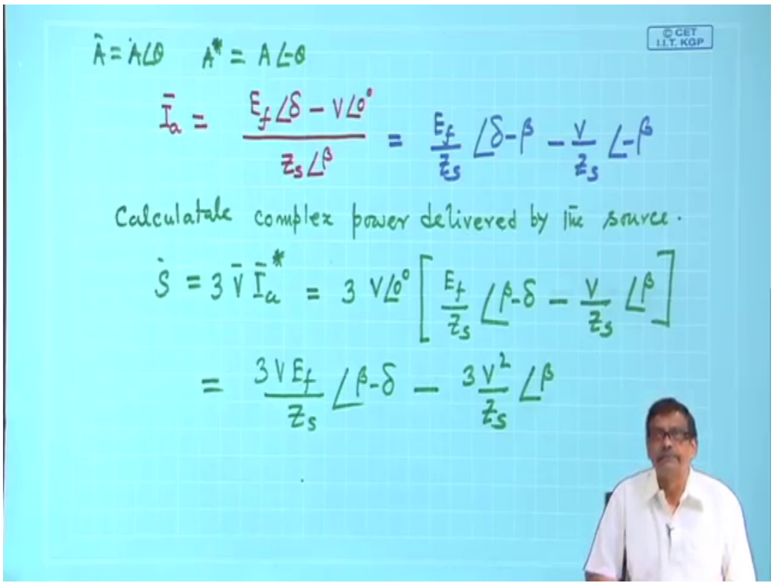

If this is the thing then I want to calculate the armature current; armature current will be this voltage minus this voltage which is 0 degree and this is this angle is delta. So, this voltage minus this voltage is the voltage across this and divided by Z s. So, I can write I a to be voltage across Z s this is the common point with respect to this point the potential of this point is E f delta minus potential of this point with respect to the same point is V 0. So, this is the this one is the voltage across Z s with this side plus this side minus and this divided by Z s will give me the current.

So current I a is equal to E f delta minus V 0 degree divided by Z s which is nothing, but Z s angle beta; got the point? This the next steps mathematical steps are very routine time, what you simply do is this you separate these two terminals at two terms I am sorry E f by Z s it will become angle delta minus beta polar form and minus V by Z s angle of minus beta is not this will be the thing.

Now, what is my goal? My goal is to calculate complex power delivered by the source and which will be equal to S complex is equal to V I a star into of course, total power delivered is to be multiplied by 3 per phase equivalent circuit we are doing so, it will be like this.

Now, this one I will now substitute the values 3 V angle 0 degree this is the voltage, I a star. So, I a is known into I a star it will be E f by Z s. If you have a phasor I mean something like A theta some vector or phase complex number this what is A star? A star will be simply A minus theta angle you have to neglect with respect to the previous thing.

So, it will be equal to beta minus delta I a star I am putting minus V by Z s and angle beta and this you just push it inside. So, it will be 3 V E f by Z s 0 plus beta minus delta remains beta minus delta minus 3 V square by Z s angle beta. Anyway we will continue with this in the next class.

Thank you.