Electrical Machines - II
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Lecture – 78
Loded Synchronous Generator Resultant Field

Welcome to this synchronous machine lecture. And so, in the conclusions we made from the earlier lectures is this in a synchronous machine which is whose armature 3 phase winding is on the stator.

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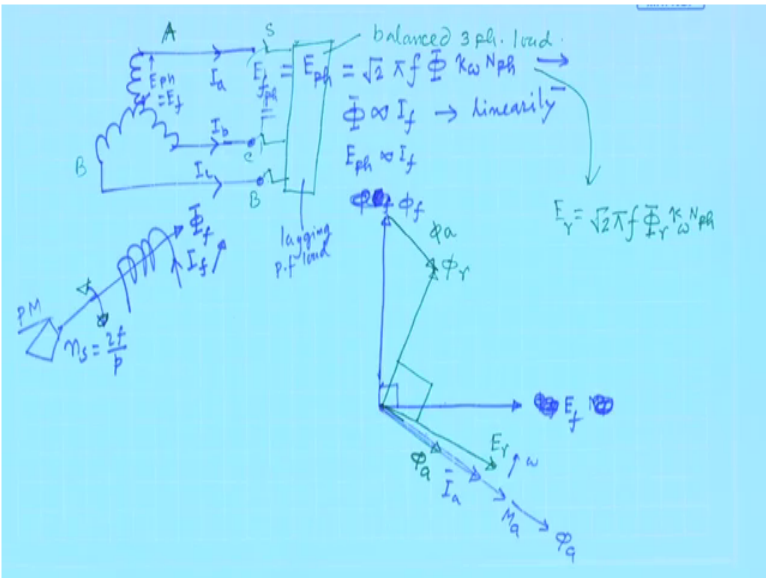

This is field winding and I am not showing this if which can be varied by some controlling resistance here and what we did the conclusion of the last lecture is that, there is as if some flux per pole is present which is directly proportional to I f and then the per phase induced voltage E phase it is here E phase, will be was shown to be equal to root 2 pi f phi k w into N phase. And I told that this phi is proportional to I f linearity on the basis of the assumption of the linearity field current mode flux per pole will be more. And that is if somebody and this machine is running at a speed ns equal to 2 f by p what is f? f is the frequency which you want to generate in our case it will be 50 hertz I mean in India.

So, it is like that. So, phi and I f is proportional. And this lecture is very important. See what we are trying to do and therefore, it looks like that E phase will be also proportional to I f. All these things means. Now and we have got this phasor diagram. That is if this is your e induced which is often called ef. And is called the voltage due to excitation of the alternator. It directly depends upon I f. So, e f I will write. That is per phase e f per phase that is. And then this is the flux per pole phi f. Or m f also you can write armature mm is along this direction [FL].

Now it is open circuit phasor diagram, nothing else happens. Because there is no scope for any armature current to flow. That is all air density matter, but what I will do now what happens we want to study that, if there are also stator currents. This is suppose a phase oh this direction if you show it here. Then based on this direction it should be numbered at AB and c. Now suppose you have a 3 phase load no bus. This box is a balanced 3 phase load balanced 3 phase load.

So, in the terminal of the machine, with this switch s open this voltage would be this induced voltage root 3 times that line to line voltage phase voltage I am plotting. Now if I close this switch if I close this switch. So, we see that there is induced voltage and you have connected a load balance load. And therefore, I expect some currents should be flowing. I have done a mistake here this this is phi f is not it was shown like phi f and this is Ef I am sorry this is e f.

So, this is phi f ok. 90 degree lagging the induced voltages. Now this induced voltage therefore, we will drive some current here. Balanced 3 phase current is expected to be delivered generator mode here is a prime mover no problem. Now the question is there will be now currents delivered to the loads which at least about one thing I am sure it will be also balanced 3 phase current, why not? Now the question is where should I draw the if phasor. Let us assume I have connected a lagging power factor load. Suppose I have connected. And such that this Ef which is also Ef I have denoted here the armature current will be like this suppose. Of course, you must understand this angle is not the power factor angle of the load with respect to Ef I because everything is rl type.

So, it is the internal power factor of the machine with respect to Ef I f will be there some, but it will be lagging because I have connected a lagging power factor load. So, this will be the armature current. Now, therefore, the moment you close this switch, drama starts in the sense that now. So, long when the switch was open air gap flux was decided by I f alone. Now you are closing this switch forcing the armature to deliver currents to your load, that is there, but the moment this balance 3 phase current flows. Armature 2 will produce a rotating mmf or rotating field. That is stator coils 2 will now produce a field. Therefore, the resultant field will no longer be your phi f the moment you close the switch I f was there because of this, but it is now closed this fellow will also produce a field. This one and this phi f together will decide the field in the machine resultant field. Very logical I mean nothing this way that way. That is earlier it was phi f alone, close this switch let balanced 3 phase current be delivered. The moment it delivers that you know this stator coils too produce a field phi f was there already because of I f. So,.

So, the air gap field should be now this phi a plus field produced because of Ia Ib Ic resultant field is not that is good. Therefore, what will be the induced voltage now. In this scenario when the switch is closed will it still remains phi f no 2 phi f I have to add the field produced by the stator coils. Now tell me where should I draw that armature field. We have already seen in case of 3 phase induction motor, that the armature field at a given time is will be along this is Ia phasor means rms value of a phase current; that means, peak value of a phase current is also along this line.

And it is very easy to identify if you can identify one coil which is carrying maximum current you will be sure he field is along that line produced by that 3 phase coil. Therefore, it is expected your armature mmf or armature field must be along this. Because all are rotating at synchronous speed. One good thing about synchronous machine is that everything is rotating at synchronous speed.

So, this rotating at this current switch will be off frequency of the generated emf and therefore, this will be your armature mmf ok. Then your resultant field should be this is phi a along this line, there will be phi a phi a. I am drawing it here once again. Therefore, phi f plus phi a phi f plus phi a this is parallel to this we will decide what will be the resultant flux linkage thing that is phi r. Or phi net whatever you call. It this will be the thing is that clear. So, this will be your phi r. If this is your phi r net resultant field, then I will say oh now the induced voltage (Refer Slide Time: 12:00) in this expression the induced voltage is no longer e f the induced voltage must be decided by phi r because both phi f and phi a exist. Therefore, I have been able to find out locate where is the phi r and because of that phi r.

Now, the induced voltage that is the induced voltage should be Er should be from the same expression I will say oh induced voltage is now root 2 pi a flux per pole because of this resultant thing into kw into N phase that is what logic says that. The induced voltage in the coil now changes it is like this. If that be the case then where is Er er then should be 90 degree behind phi r as Ef was 90 degree behind phi f it should be here such that this angle is 90 degree, it must be like this this this must be your resultant induced voltage.

Now, therefore, the point I want to make is in a synchronous machine the flux per pole changes. From no load to full load operation. In case of induction motor it is not like that. In case of induction motor flux per pole approximately remains same from no load to full load operation. This must be understood. Because of what? Because of separate excitation of the field flux. Therefore, this is the picture we must understand. Then the most important concept I have to introduce in the next paper it is like this now.

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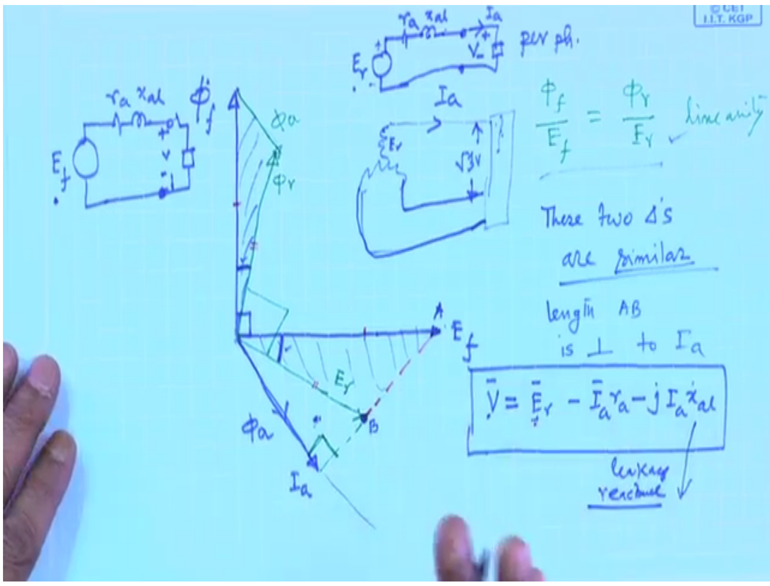

Therefore, we say that this is your phi f under no load condition open circuit condition, this is your Ef fine. And this is 90 degree. Now you load the machine suppose this is your I a.

So, that your phi a would be also along this line phi a. And then your resultant field phi I is this. So, phi f and you add phi a and you get phi r. And your Er will be here 90 degree. This is your Er. And we also note that phi f by Ef must be equal to phi r by Er why not, because linearity. I have assumed machine does not know whether induced voltage is being caused by phi f or some phi r somebody else, but whatever is length it will maintain this 90 degree relationship and this ratio will be same. In other words what I am telling you look at these 2 triangles. This triangle and this triangle look at it. We find that ratio of this 2 sides is same as the ratio of these 2 sides. These are not equal they phi r by Er is equal to phi f by Ef. Because of this thing this is one thing. Second thing is this angle this angle is same as this angle. These 2 angles are same. Why? Because angle between these 2 sides is 90 degree, it has shifted this line is shifted from this by say angle delta it is this one.

This fellow should also shift, that is angle between 2 straight lines is equal to angle between their perpendiculars. So, angle between these and these is this and angle between this and this this is perpendicular to phi f and Er is perpendicular to phi r. So, angle between these 2 green, I mean this and this must be also delta angle between 2 straight lines is equal to angle between their perpendiculars. So, this is what I get. Therefore, this condition, that is this this is to this is equal to this is to this that is this one. And angle between these are same.

These 2 combined we can say these 2 triangles these 2 triangles which triangle this triangle and this triangle. These 2 triangles are similar. These 2 triangles has to be similar is not that is the thing. If these 2 triangles are similar, then another conclusion I can make. As if this triangle has the this triangle has been rotated by 90 degree and proportionately their lengths have been changed. It means that this whole triangle has been bodily moved by 90 degree.

So, this side has moved 90 degree. This side has moved 90 degree. And this side must have also moved by 90 degree, that is the angle between this and this must be 90 degree it has to be. That is in other words what I am telling this line look at this line this must be perpendicular to this phi a has to be. Understood? This angle is also negative. Therefore, this is one of the most important conclusions we draw that a synchronous machine under no load condition that is this switch opened phasor diagram had only Ef and phi f, but when this switch is closed suppose assume lagging power factor something you have connected.

So, the armature current will be lagging, but mind you once again I am telling this is not the load power factor, but effectively lagging some angle. So, the armature current comes. The moment armature current comes argument is flux per pole is bound to change. Because the flux per pole is the resultant of this phi f and the resultant field of Ia Ib Ic. And I know the position of the resultant field will be along the direction of the maximum current a particular winding is carrying, in this case if this is I a rms value means maximum is also along this. Therefore, that rotating field produced by abc phases must be along this line it has to be if that is there then our arguments are fine.

Now, phi f in any case was there now phi a appears. So, I a get phi r, but machine is operating in the linear zone. Therefore, ratio of the induced voltage and the field current or field flux they must be maintained. Therefore, phi r Er should be also satisfy this one. If that is the case, then we argue that consider these 2 shaded triangle and conclusion is they are similar triangles if they are similar then this length has to be perpendicular to this length. Because all the sides has undergone a rotation of 90 degree in the clockwise direction. Therefore, this length is 90 degree.

Now we are at a very important stage now. One can therefore, say that to analyze I mean to obtain the equivalent circuit or performance analysis of a synchronous machine perhaps the load changes it may be leading power factor load lagging power factor load varying load whatever it is steady operation then demands that Er goes on changing. Therefore, one point could be that each time you find out this here, then try to establish what will be the thing etcetera.

But there is a nice way of handling this situation. That is this one did this length this length let me give some name. So, that I emphasize this point. This length is suppose AB and AB length AB is perpendicular to I a. Therefore, to explain this change from Ef to Er, I can also imagine since this line is perpendicular to I a, I will consider this to be a drop due to an inductance. That is the most crucial point. Are you getting? That see the point is your machine is here machine is here, here is your load here is your load (Refer Time: 24:41) here is your load here current is delivered.

Now, induced voltage is here. What is the voltage across the load, it should be Er minus the resistance and leakage reactance drop of this winding please follow me? This Er I have got it is Er now. What should be the model of this one there is Er. And then in between the load and this one it should be some armature resistance per phase. And some small leakage reactance xal and then this voltage will be your terminal voltage say b and here is per phase equivalent circuit, per phase equivalent circuit here is your per phase load try to understand this point in open circuit condition, it was like this there was the Ef ra xl was there, but nothing was connected. And wherever this switch and your per phase load. The moment you close the switch there is no ef.

Now, what is there Er induced voltage per phase. And then remaining thing remains as it is Ia. Got the point? Hopefully, therefore, you see if you call this is terminal voltage minus this is plus minus this current is Ia. What is the relationship of this current and this? I will write terminal voltage V should be Er phasor Er minus this drop minus Ia ra minus j Ia xal this is leakage reactance mind you and this will be the thing this is fine. That is if I wish if somebody tells me where is the terminal voltage V appearing across the load then from this Er, I should subtract minus Ia ra like this then minus I a j xal.

And then I will fix up this V. I am not spoiling this diagram, but only telling what should I do now, to get the terminal voltage across the load here the terminal voltage root 3 V. Suppose star connected load you understand this so, Er is there the relationship of terminal voltage and this resultant induced voltage is this Er minus this drop minus this drop will give me terminal voltage. So, I would have then Er I know, then minus Ia ra Ia j xal is this way minus of j Ia xal. And you will perhaps land up terminal voltage V here.

Student: (Refer Time: 28:43).

Which one?

Student: (Refer Time: 28:45).

Which equation here?

Student: (Refer Time: 28:48).

No I am talking about the loaded condition. It is loaded induced voltage Ef is no longer there.

Student: Ef mins j xal (Refer Time: 28:59).

No.

Student: (Refer Time: 29:01).

What I am telling that is the important thing. See the moment you load the machine, flux per pole is no longer phi f it is phi r. Machine does not know winding will respond to you are rotating that coil at some synchronous speed all things are fine. Induced voltage will be now root 2 pi f phi r. Because that phi f is not, only inducing voltage along with phi a. Phi a will also have it say in determining the induced voltage. That is why better you then add the phi f and phi j get phi r that is the induced voltage. What I am telling is that one can live with this ok. Every time calculate Er I ra minus ji xal these xal is leakage reactance leakage. I hope you have understood, but give some time to understand this and we will continue with that.

Thank you.