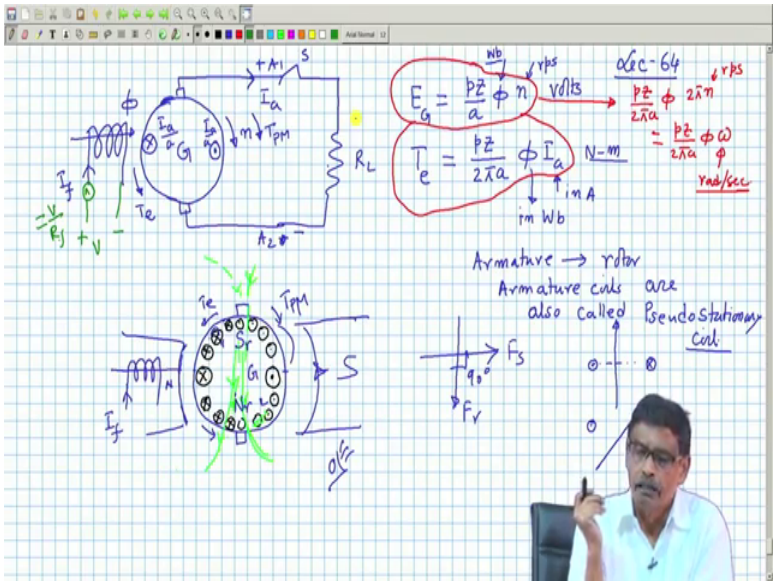
Electrical Machines - I
Prof. Tapas Kumar Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 64
Generator & Motor Operation – Basics

Welcome to lecture 64. The previous lectures were very important, because of the fact that we derived a two relationships; one is when a DC machine will be operating, then it will have generated EMF, no matter whether it is acting as a motor or generator, a conductor moving in a magnetic field will have generated EMF. Although, we considered generator mode of operation and we found that a DC machine, which is represented like this here and this is the flux per pole created by the machine.

(Refer Slide Time: 00:57)



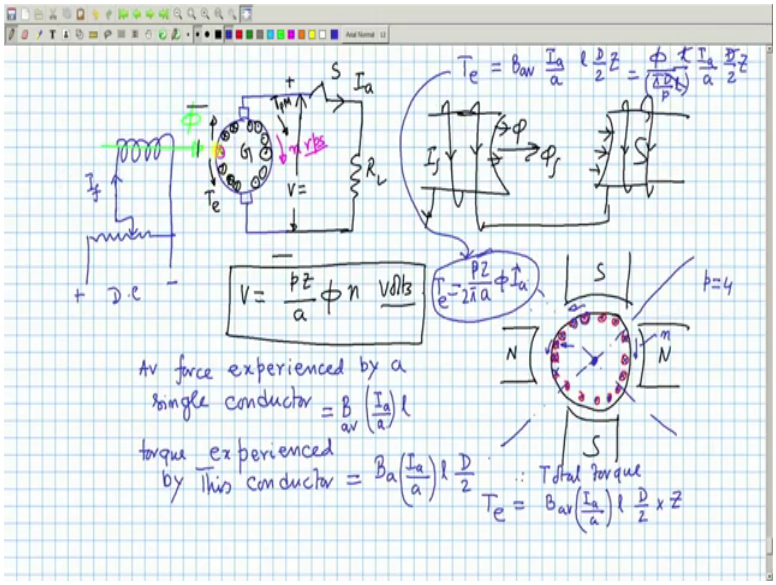
When you pass some current, if here and we considered generator mode of operation and suppose, it was running in this direction with a speed n, then this side is North Pole, this side is South Pole. So, what I am trying to tell in the schematic diagram, we must try to understand that the whatever is happening in the armature conductors under a pair pole, same thing is going to happen to other armature conductors under the next pair of pole.

So, people represent the this simplified diagram pretending it is a two pole machine, if you know what is happening under a pair of pole, same thing will happen. So, that is

why it is done like a two pole machine North Pole, South Pole, a pair of pole. This degree is 180 degree electrical and so on.

Anyway, we found out that if this is rotated in this case, the voltage across the armature terminals A 1 A 2, under open circuit condition if I say generated emf EG it is given p z by a phi into n. So, much volts if phi is in Weber and n is in rps, n in rps do not forget that proceed can be changed to rpm and another thing is the polarity of this voltages can be found out, instead of drawing all the conductors here in this slots, I will just draw two conductors, because this side DC machine one good thing is under a particular pole, the direction of currents will remain same in all the conductors or generated emf polarity will remain same.

(Refer Slide Time: 03:45)



So, if you apply right hand rule we found that a it will be equal to cross under a North Pole. So, applying right hand rule this side will be cross and this will be dot. This is the thing; this is the polarity of the induced emf in each conductor. Suppose, the brush becomes plus from this, I am unable to tell which brush will become plus minus ok. Unless, I go through the actual machine and I will be able to tell, but for my mathematical analysis it does not matter whether this is plus this is minus or this is plus this is minus. Anyway, let us assume A 1 becomes plus when this is generated emf cross dot here this becomes plus.

And then you have a load RL where you want to consume power. Now, several things comes out; if this switch is opened, then there is no external current supplied by the armature and therefore, no current in the conductors as well, but if it is closed, then it will deliver power to the load. If it delivers power to the load, this current and current in the conductors will not be same, it will be Ia by a.

What is a this, small a is the number of parallel paths that will be the current in each conductor and if they carry current in this direction, then by applying left hand rule we observed that the electromagnetic torque will be in this direction. Direction of rotation is decided by the prime mover torque T prime mover and if these two are equal then only generator will run continuously at a constant rpm delivering power. Any disbalance between T and T PM will either accelerate or decelerate the generator and this will happen, when the machine will be under transient conditions and finally, machine will always seek to reach a state where Te u will be equal to T PM [FL].

Now, therefore, a DC machine in case of generator, I am telling it will be like this. Then when it delivers a current, we would like to know how much electromagnetic torque the generator is producing. We also find out that and these two expressions are most vital in understanding the operations of DC machines whether generator or motor it does not matter and we will do that, but here it will be like this. So much of Newton metre provided Ia is in ampere, Ia in ampere and phi in Weber.

Similarly here, phi is in Weber then only it will be in volts. These are the two most important equations and DC machine anything you want to explain about DC machines, you cannot do without these two equations that is why they are so vital. Remember this things pz by a is a constant of a machine. Now, the constant appearing in generated voltage and constant appearing in the torque expression differs by a factor of 2 pi you should be very careful about it ok.

Sometimes what people do is this expression can be also written as pz by 2 pi a into phi into 2 pi n I can do like this, n is in rps I told you and this is nothing, but pz by 2 pi a into phi into omega, radian per second if you express this speed then these two constants will be equal it is important to point it out that. If you express the speed in radian per second mechanical radian per second mind you nothing electrical here then these two constants

will be same anyway you should be careful if it is in rps then these two constant of proportionality are not same.

In any rotating machines, I have been telling to you a through my machine two course that to produce torque in a DC machine number of stator poles and number of rotor poles must be same. And another thing, I told you that the field produced by stator and field produced by the rotor the angle between them should be time in variant should be constant, then only it can produce sustain the electromagnetic torque.

Now, in case of DC machine also this is true, why? Let us see that. Suppose, I redraw the same thing, this is the thing, this is the armature rotor and this is the stator field. Suppose, when you pass current, it produces field lines like this, that is a this side is north, this is north is not, that is what we have been telling and this side there is a South Pole here, all this means like this and physically it is like this north south ok.

Now, if there is no armature current that is if this switch is open then of course, there is no armature rotor field stator field is present no rotor field. Mind you armature is the rotor, the armature winding is housed in rotor not on stator. Stator is this field winding. So, anyway this is the defined case. Now, for example; if armature carries current under what condition it will carry current, when you want to draw power out of the generator this Ia then this is the thing oh sorry, these are the lines of force we understand this is north, this is south, I am not drawing.

So, armature conductors will be here bigger, I am drawing and if the armature current is Ia, armature conductors will carry has to carry current cross dot applying right hand rule I get and all the conductors here under North Pole will carry cross current and they will carry same current. Mind you Ia by a whichever conductor is under South Pole and whichever conductor is on this line, they will not carry induced voltage will be 0 ok, current will be there.

Now, let us see what will be the poles of this machine. Rotor, the these are the conductors which are cross this side this side dot therefore, the direction of the field produced by the armature current will be like this, right hand rule right hand rule, this side cross, this side dot. So, lines of force created by the armature will be going like this

going like this top to bottom, that is lines of force produced by the armature will be somewhat like this is not this will be the line of force green lines are the lines of force.

Now, look at the rotor iron, rotor iron then this phase of the rotor iron will it become North Pole or South Pole? North Pole, because lines of force this is a iron mind you iron slotted iron in which conductors you have placed, but I iron it is rotor cylindrical iron. So, lines of force if they come out from this, this portion of this it will become Nr, let me.

So, rotor this portion will become North Pole Nr rotor and this will become South Pole lines of force are entering and you see interaction of these two poles produces electromagnetic torque. This North Pole will be repaired by the stator North Pole that is what the electromagnetic torque is in this direction. This South Pole will be attracted by this. So, this is the direction of electromagnetic force.

It is for a two pole thing for four pole same thing will happen Nr Sr Nr Sr therefore, those things are valid. Now, the question is a stationary observer, if he is looking to this things, you will say there is stator poles NS NS, this N, this S and they are stationary in space. He will also conclude there is rotor field Nr Sr although, conductors are moving, but Nr Sr if fixed in space that is the stator field is like this and rotor field is like this.

This is the rotor field Fr, this is the stator field Fs and angle between them is 90 degree always, no matter. Unlike, a induction machine or synchronous machines with respect to a stationary observer, they may move, but they must move with same velocity. So, that a stationary observer must conclude these two fields are angle between them. These two are fixed, then only a constant torque will be produced.

In case of induction or synchronous machine as we changed, if the load power factor is an important issue there that also decides where the rotor position of the field will be, where the stator field will be, we discussed at length in our machine two courses and this angle changes with change of load on the machine shaft. If it is a motor or your electrical load, if it is a generator, position of this two fields might change, but in steady state condition they must have some sin delta etcetera matters.

But in this case this angle, 90 degree is always ensured. No matter what is the degree of loading increase load, load current increases this strength of this two field will increase rotor field there by more electromagnetic torque in the opposite direction. Mind you prime mover torque is here, in this direction getting therefore, it is like this. This is slightly, I mean not surprising, it is interesting to note that armature conductors are moving they are carrying current, but the direction in which the armature field is present that is Fr, that is always fixed. What do I mean by this?

Suppose, you have a coil a coil it is carrying a current cross and dot it will produce a field here is not a rectangular a coil is there, it will produce a field here. Suppose, you say that I will move this coil by certain angle carrying same current then the field it will create will also move by that same angle is not, the field produced by a single coil let us understand, it is like this perpendicular to the plane of the coil. If you move the field created, once again will move in space, but here something surprising is happening.

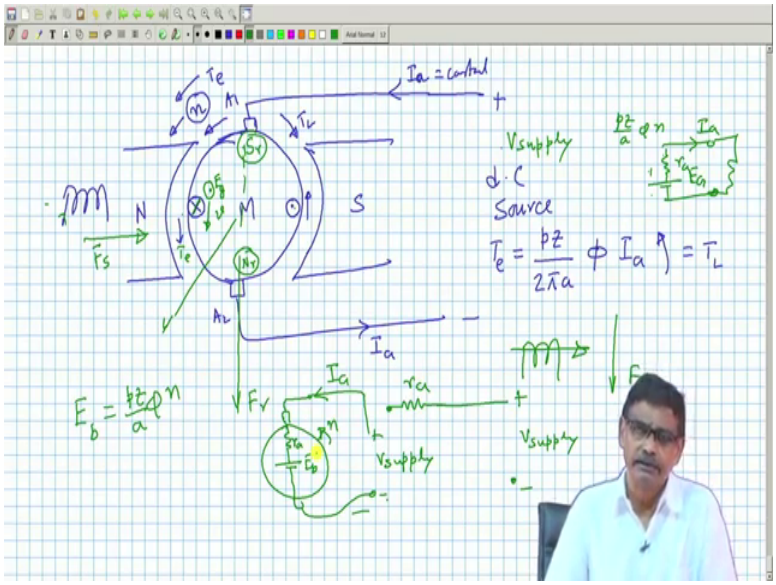
Coils are physically moving, but the direction of the field is always remaining fixed, that is why the armature winding, armature coils are also called are also called stationary Pseudo coil, Pseudo I am not mass spelling Pseudo stationary coil. What is this Pseudo stationary coil? Coil is really moving, but so far as the magnetic field is concerned, it is as if stationary and who is behind all this things. Why this is happening? It is the commutator segment and brush arrangement, because any conductor coming under the influence from the North Pole is distinct to carry a current in the same direction.

Now, it is conductor want to hear after sometime this 1 will come this side and 2 will come this side, but the moment they crosses this side they cannot, but carry dot current cross to dot, that is the most interesting part of the DC machine, that is the coils are moving physically, but it is the commutator segment and brush arrangement which makes any conductor whoever, comes under the influence of north pole will always carry north current. That is this armature is moving, it is not that same conductor is just resting in piece here no everything is moving, but it will be replaced by this fellow after some time, this fellow, this will cross over and so on.

So, mind you, it is like this and therefore, in case of DC machine number of poles of stator and rotor must be same and not only that the we can draw knowing the whether it is operating as a generator or motor, the current distribution by applying right hand rule

and it is all DC therefore, direction of emf decides the direction of the current no question of any power factor coming in between therefore, the distribution of current, I mean polarity of the currents under north and South Pole is fixed once it is you know it is generator or motor. Similarly, let us see what will happen in case of generator.

(Refer Slide Time: 23:03)



Suppose, this is your armature, this is your field which creates North Pole here and South Pole there and there are brushes. Suppose, I say it is operating as a motor what do I do I will connect a this armature terminals A 1 A 2 to some supply, DC supply now, DC source, voltage source and it will carry some current, Ia armature current to the outside world. Mind you, this is not the conductor currents and this goes like this, then this current will be divided into various parallel paths Ia by a will be the currents. Anyway, that will be the current. Now, I will draw just a one conductors to avoid clumsiness in the figure.

Now, this current whether this will be cross or this will be dot I am not pretty sure is not outside, how can I say, but if this current gets divided into parallel paths and if it so happens that this is cross this is dot this armature current divides like this then I will apply left hand rule to say in which direction it is moving that is now, I have to apply left hand rule.

So, this is north this is the direction of the current provided by external source current is fixed first and it will experience force in this direction and this fellow will experience force in this direction and all the conductors will experience force like this it will start running and suppose so, motor will run like this, in the anti clockwise direction, because I applied left hand rule.

Similarly, here you see this is dot same direction of. So, this is the rps at which it is moving in the anticlockwise direction that is fine. How much is the electromagnetic torque? It will be equal to, if it is steadily running suppose at some rps I am then certain that the electromagnetic torque if it is suppose constant it, I find a DC machine is running in the anti clockwise direction, then I will say electromagnetic torque developed by the machine is pz by 2 pi a into phi into Ia, this Ia is the total current a is the number of parallel paths.

So, this is the electromagnetic torque and I will say electric by applying this rule, electromagnetic torque is acting in the counter clockwise direction and if everything is running steadily, then I will say oh there must be an opposing torque present on the shaft of the machine, which is the load torque and this must be equal to the load torque as well, the magnitude.

So, electromagnetic torque in the case of motor decides the direction of rotation. So, in case of motor mode, direction of rotation and electromagnetic torque will be acting in the same direction and the mechanical load torque will be acting in the opposite direction that is what I know and at steady state operation T equal to TL. It is running at a constant rpm therefore, net torque acting on the machine must be 0 and it will do like this.

In this case also, it is acting as a motor, if you wish the armature field rotor field will be always vertical. Once again, here in this case lines of force for rotor field will be like this vertically downwards therefore, this side will become Nr is not this will be this is the armature current, this is Nr and this is Sr.

And this Nr will be repealed by this therefore, electromagnetic torque which we got from left hand side could be also just now, right now tell this Nr will be replaced, but interesting thing is I am repeating the this Nr the position of this Nr and Sr remains same.

No matter whether this conductor is here or it as gone this side, this conductor has come there that is the thing. So, in case of motor mode, it will be like this.

So, in case of motor mode, you connect a DC source pump, current into the armature and this one. Another point, I want to tell, this is the direction of the rotor field, this is the direction of the stator field they are at quadrature fine. Another good thing is in case of DC machines these two are decoupled they call it, I mean armature and field are practically decoupled that shunt field coil.

That is why this armature field whatever will be produced since, it is in quadrature with the field access that is the stator field is like this and armature field will be along this vertical line in may be this direction also depending upon current etcetera, but they are at right angles therefore, this armature field is not going to disturb your field circuit in any case, because component of this flux along this line is 0 is not.

Therefore, the interaction of these two fields is not there, that is why when you are drawing power out of the prime mover in case of out of the DC machine in case of a generator mode. For example here, this field circuit as if it never knows that what happens is this field circuit current is whatever is the voltage applied here V divided by Rf nothing you change the load this that this field current is not going to affect whether the armature is carrying or not, this field current will be V by Rf only, no interaction between field and armature.

In the field circuit whatever power you give that is lost in the field circuit resistance. Field circuit only creates the flux, main power is handled by the armature circuit. It is the prime mover which gives power to this armature and that power is translated here. In no way through the field circuit power comes in the armature circuit, which is not possible because they are at quadrature.

Similarly, in case of motor mode, field circuit current is decided by V by Rf, field circuit game is over, it is you connect a mechanical load on the shaft that is load torque in the opposite direction, its speed will get adjusted such that it can produce enough electromagnetic torque to counterbalance this and make your machine run at constant rpm therefore, to conclude what I am telling today, is that last last, but one thing I must tell that in case of motor mode, this is this thing, this is the supply DC voltage V supply.

Now, if I look at the conductors this direction of the current, current is forced into the armature circuit cross dot ok. Now, you see this conductor is moving and it is placed in a magnetic field therefore, why not there will be induced voltage in the conductor or across the armature terminal, following the rule pz by a phi into n, because what you need across the armature to get generated voltage you need a flux per pole created by If.

You need a rotation which is N in any case the conductor is rotating, because of whatever reason I do not care, but then across the armature there must be some induced emf and what will be the polarity of that voltage apply the right hand rule. Now, in this conductor what will be the polarity of the voltage V direction of rotation is like this like this that is V, V is like this direction of rotation assume to be this way.

So, direction of V is this. So, apply right hand rule and polarity of the induced voltage will be a dot Eg are you getting this. This is very interesting that is the armature circuit equivalent circuit if I draw, this is your I mean for motor mode, it will be like this plus minus V supply there may be some armature resistance ra is there armature coil resistance then or I will draw it like this, this is your armature ok.

There will be an armature resistance here, conductors is having resistance, here is your V supply and between these two points across the armature, there is an emf which is in opposition to the current flow and that emf is back emf Eb and whose value will be your this Eb is nothing, but generated voltage which is pz by a into phi into n.

So, this is the equivalent circuit of the armature as a motor mode. In case of generator the equivalent circuit will be generated voltage ra and then load resistance that is all and armature will deliver current like this, in case of motor it will draw current, but the direction of the armature current and direction of the generated emf are in opposite directions.

In fact, it will Ia V supply will be greater than Eb, then only it is acting as a motor drawing power from the supply and doing things. We will continue with this, but you these two formulas are so simple to remember better memorize them, I do not mind when it is complicated I said do not remember them, but it is. So, you can also apply some physics torque is force.

So, force is vial. So, some phi into I a product and similarly, generated emf is VLV. So, pz by 2 pi a phi into n velocity is taken care of by rps and so on and try to understand this points that armature emf, armature field and actual field produced by the stator coils, they are at quadrature always. No matter at what rpm it is running or things like that and in case of motor mode, always see that there is a supply voltage, but the conductors are in any case moving in a magnetic field.

We have also found out that expression for generated emf, if a conductor is moving in a flux per pole phi then across the armature, there will become another source of emf across the brush, if it is running at some speed n. We will continue with this, but physically try to also understand, it is very simple way you can understand many things of a DC machine.

Thank you.