Electrical Machines - I
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Lecture – 62
Generated Voltage Across the Armature

Welcome to 62nd lecture on Electrical Machines I and we are discussing about DC machines.

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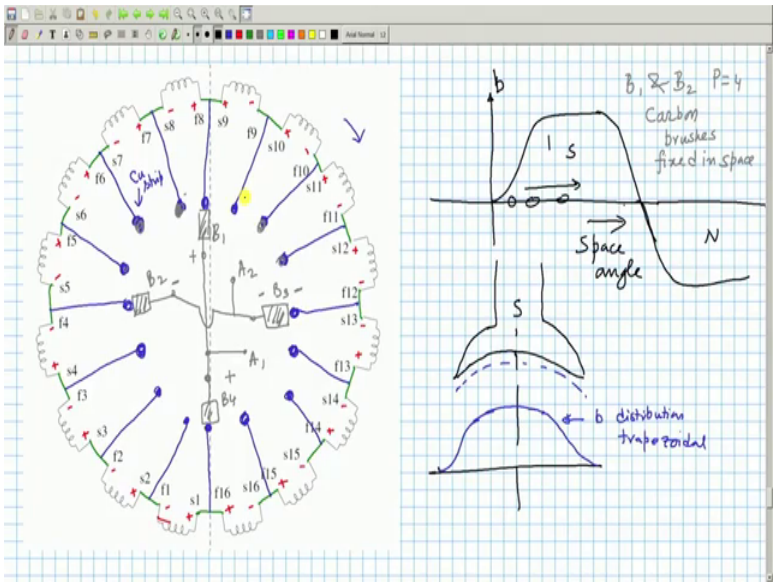

And, in DC machines the armature winding is slightly difficult unlike AC machines windings, but although the basic features of a winding is still present that is each coil will be generally full fixed coil and they will have 2 coil sides and the separation between these 2 coil sides will be 180 degree electrical. So, in the simplified diagram you recall that earlier we for a 4 pole machine, 4 pole machine we had the simplified winding diagram.

I need not go to slot and show the exact winding how it is done provided I know how I am presenting a coil in these slots in this diagram. That is suppose 7 th coil s 7 and it is finishes another coil side f 7 and I if at any point of time this coil side s 7 is under North pole f 7 has to be under South pole. And after assuming some direction of rotation generated voltages were shown and then we found that no matter which coils occupy this particular position which is presently occupied by 7 th coin, whether it is 6 5 whoever

comes here because if things are rotating they cannot, but have this polarity of induced voltage and it is magnitude will be also same.

This prompted us to think that in that case I will take from the junctions with the help of conducting wires terminate on some commentator segment circular and then we will placed fixed brushes in space which will be stationery, but in which position where plus plus will be joined where minus minus will be joined negative plus here plus plus joined positive plus and this one we explained this. So, there will be in case of this lap winding there will be 4 brushes B 1 and B 4 they can be joined together and 4 brushes can be will have to be connected.

Then this is not how exactly this is done last day I forgot to bring this model. So, this portion that is this and this copper strips these are done by what is known as commutator segment. If you look at it very carefully the in the commutator segments there are several commutator segments and the which is mounted on this shaft and 2 commutator segments this and this next commutator they are insulated by it is looking like a gap, but there is a mica insulation ok. So, that each commutator segment has got it is own identity.

Therefore commutator segments number of commutator segments will be just replica of the number of slots here if they are equal in number. So, we will considered the simplest case when the commutator number of commutator segments are equal to this one, because in each commutator segment 2 winds of 2 different coils will be joined therefore, number of commutator segments has to be equal to number of slots present in the machine.

So, this whole thing will rotate and then we will have carbon brushes suppose this strip is a carbon brush placed in space like this and fixed. Therefore, as it rotates this fellow does not rotate this one this brush it will touch whoever whichever coil comes in that position it will connect that particular commutator segment, ensuring that B 1 and B 4 will remain always positive B 3 and B 2 will always remain negative polarity of the voltage their by giving you a DC voltage.

And another thing you note that. So, this 2 terminal so, commutator segment later I showed that it can be like this if you go there will be commutator segments here.

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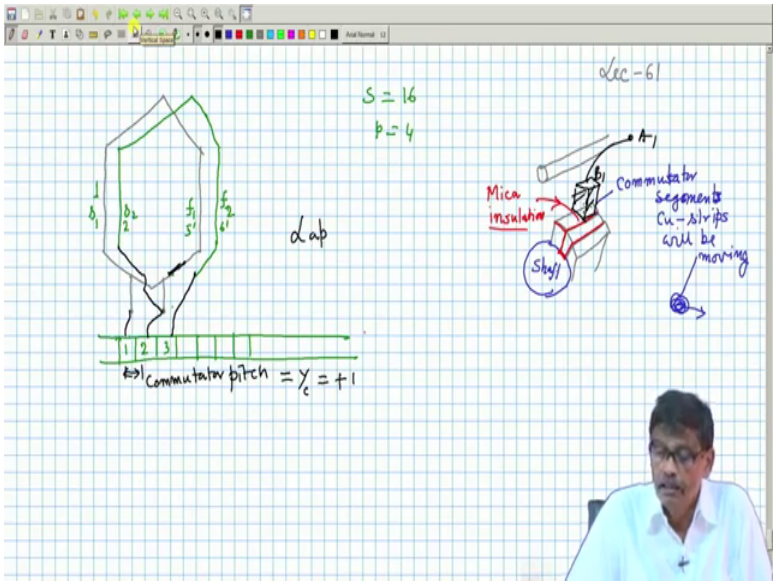

And each coil suppose s 1 and f 1 is a coil it is 2 ends will be terminated here and it will be terminated there. The commutator segments where the coil ends will be terminated of a particular coil the difference this length is called commutator pitch commutator pitch which is denoted by Y c.

In case lap winding it will be equal to plus minus 1 plus 1. So, so this coil number 1 is connected to adjacent commutator segment, similarly coil number 2 will be actually connected between 2 and 3. So, so from 2 you start this junctions and your 2 2 and this side it will be terminated on 3 and like this then s 3 it will continue like this. So, this is called commutator pitch this is what the difference between the commutator segment numbers of a particular coil which happens to be plus 1 in case of lap winding lap pointing ok.

So, and after we complete it then we make the winding table as I have shown simplified winding table and from here I know which at which junctions the brushes are to be placed everything is known B 1 B 2 B 3 B 4 if it is a 4 pole lap winding which 2 are plus which 2 are minus brushes are stationeries I will connect them and ultimately get the armature terminal.

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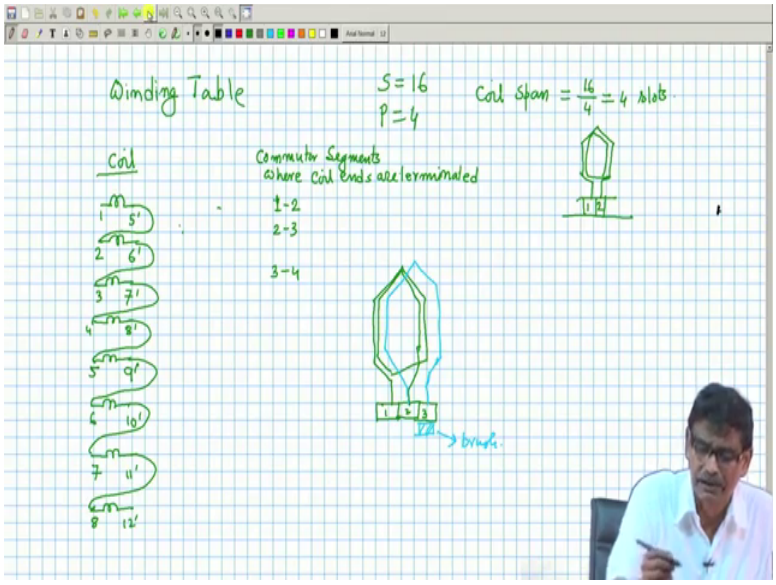

Now, and this one can complete I leave it as an exercise up to 16 coils you complete then put plus minus here they their also and the commutator segment first coil 1 5 dashed in terms of slot number 1 – 2, 2 - 3 like that and then you can determine the position of the brushes much more scientifically if time permits I will further discuss on this, but it is not necessary at this stage.

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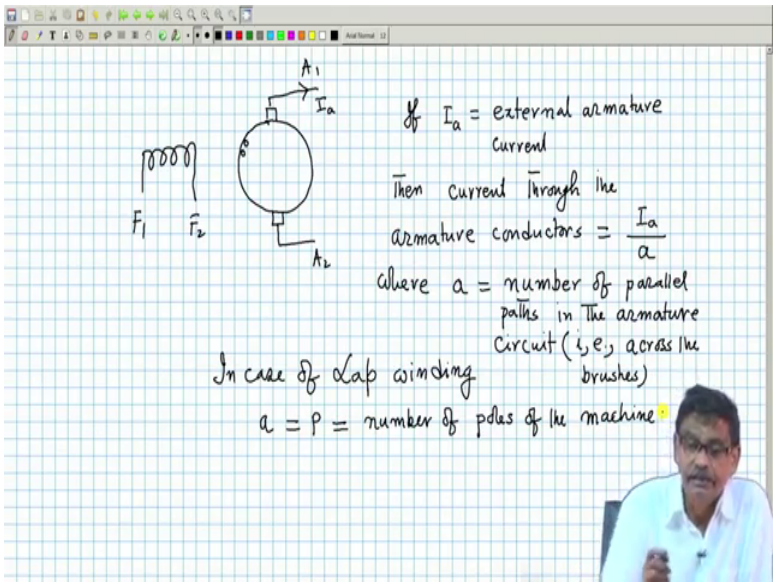

Therefore, I now know that field winding a DC machine I will represent it schematic diagram I will show the field winding like this F 1 F 2 and we you know how these 2 terminals are coming and armature I will show it like this, a circle and 2 brushes.

Even if it is a 4 pole machine only 2 brushes I will show why, because of the reason that it is the equivalent simplified representation ok, whatever is happening under a pair of pole in the armature conductor next under the next pair of pole same thing is bound to happen it is not. North, South whatever is the happening whoever conductor is present under the next pair of pole same thing is going to happen. Therefore, it is the simplified representation which are called the armature terminals A 1 A 2 which are coming from where if it is 4 pole machine B 1 B 4 we have shorted got this and B 2 B 3 you have shorted you have got this.

Now, if you look carefully between this one this diagram I will refer too previous to this, this is a 2 pole machine if you join like that you can easily see if you start from B 1 you traverse 4 coils and you come to minus ok. So, between positive and negative brush this is one parallel path, it could be you could reach the negative terminal because negatives are shorted also. So, B 1 another 4 coils and you reach the negative terminals so, second parallel path ok.

So, here is one parallel path, here is the another parallel path, similarly from this positive terminal if you want to reach the negative you see 4 coils you reach the negative, from this another 4 coils you reach the negative. Therefore, between the positive and negative brushes the armature circuit all the coils will be divided into as many parallel paths as the number of poles of the machine provided it is a lap winding at least, because I have not discussed anything about wave winding that I will do slightly later.

So, for lap winding the conclusion is between the brushes there will be a number of parallel paths a number of parallel paths means if the number of poles of machine is 4, number of parallel paths between positive and negative brush will be 4, if it is a 6 pole DC machine number of parallel paths will be 6. So, this point you please see it can be easily same from plus to minus if I want to reach because it is this plus plus thing what I am telling I will write here A 1 A 1 I have written yeah I already I have written sorry.

This is the brush A 1 plus this is A 2. So, coming back to now the simplified diagram this A 1 is coming from the junctions of B 1 and B 4 which are positive and this is suppose positive and these are called armature terminals and this is minus. Of course this plus minus may interchange depending upon direction of rotations depending upon the direction of flux from left to right, but anyway. So, it is if it is an ideal machine no point

in showing this plus minus, but only a pair of brushes. This is how it will be shown, but what I am telling if suppose at any time the armature carry some current here.

Suppose it is carrying some current here suppose it is generator mode it is delivering a current here connected to the load because it will become a seat of AMF. We will soon find out what will be the expression of the TMF, but the point is if it delivers current what will be current in the conductors flowing. It will not be equal to I a why because there are 4 parallel paths if it is 4 pole machine. So, this current divided by the number of parallel paths all parallel paths are identical so, current will be equally distributed in the parallel paths.

So, if the if number of parallel paths if I say if I a is the external armature current then current through the armature conductors through the armature coil sides or conductors armature conductors will be equal to I a the external armature current divided by a, where a is the number of parallel paths parallel paths in the armature circuit in the armature circuit that is across the brushes mind you it is important to note this external current and the armature conductor current is their not the same.

In case of lap winding we have seen in case of lap winding a number of parallel paths a is equal to p is equal to number of poles of the machine, is that clear. So, this comes naturally, if it is a 2 polar machine lap winding number of parallel paths will be 2 it can be easily seen because we have seen that 2 pole winding we have drawn the physical that winding diagram 2 pole machine you see.

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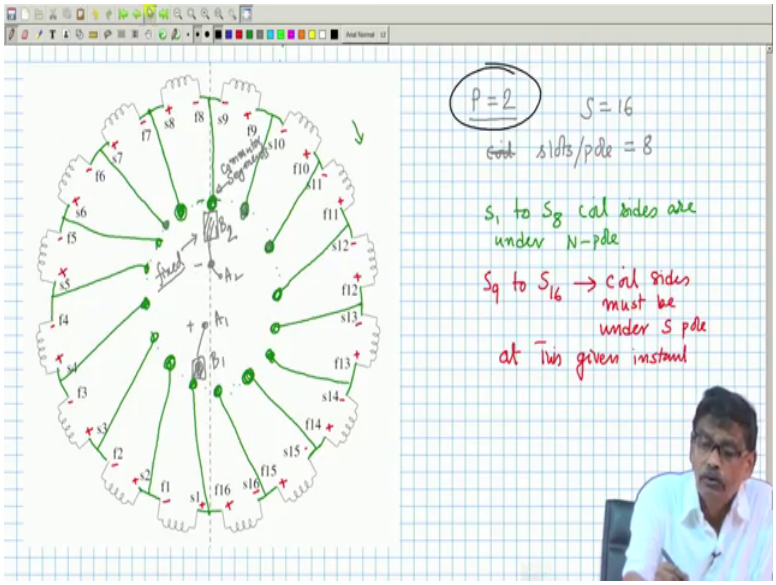

There are only 2 brushes B 1 and B 2 to reach from plus brush to minus brush you traverse either this way 8 coils reach minus and another alternative path is this one 2 parallel paths for a 2 pole machine hopefully you have understood this.

Now, today I will do one very important thing that is suppose I will say I have a DC machine with a field winding and armature winding I will run the DC machine by a prime waver at certain rpm or rps I know will be knowing the field current which will create a flux along this line and I would like to know what will be the EMF available across the brush of the brushes of the machine across the armature terminals on what factors it will depend and how to calculate that. So, let us try to do that first.

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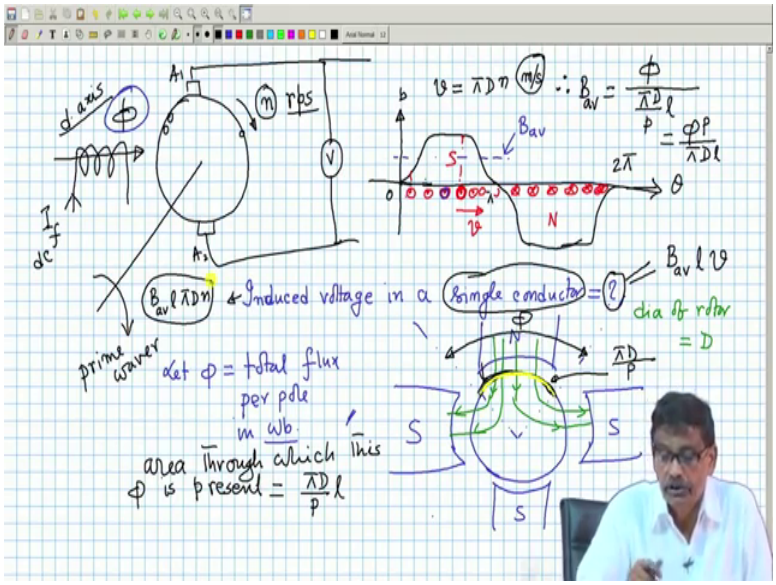

So, consider a DC machine it is the armature terminal calculations are simple in case of DC machine this is the field winding and this is the phi called the flux per pole if you have passed a current I f not South will be created the other side is generally not shown. So, flux is created and this is often called the d axis forget about this name right now it is not necessary, so this is the flux. Incidentally if you look at it why brushes are shown here not here also will be apparent from this diagram ok.

Brushes will be always along the quadrature axis clear. So, so that is why the brushes are shown like this ok. Now I have a flux per pole created and suppose I decide I will run the machine in a particular direction with a speed of n rps rotation per second if it is rpm divided by 60 to get this number and it is across the armature terminal I want to calculate. How it is run, driven? It is driven by a prime waver because generator as a generator I want to run it may be a diesel engine, may be a steam turbine, whatever it is. So, prime waver drives it at n rps.

Then the question is what will be the generated voltage that is the reading of the voltmeter when no load is connected that is our intention is ok. First is how to calculate flux I f is known therefore, and I f is DC ok. So, this emf divided by reluctance of the path will give you some flux per pole ok. Now if flux per pole is known, but I want to calculate the generated emf, I told you that flux density distribution will be somewhat trapezoidal is not that is what I told ok.

This is 0, this is phase angle theta, this is pi, this is 2 pi and lines of force entering into the stator is suppose South pole anyway b b distribution, under which and this field pattern need not be sinusoidal because here my intention is not to get a very nice sign way voltage, whatever will be the nature of this b that will be the nature of the induced voltage in the coil sides or in the coil because 2 opposite coils are under 2 2 2 coil sides are under different poles that direction of rotation are same therefore, this 2 voltages will be additive we know that to be lv will be the voltage across the coil.

And the value of b whichever conductor will be here suppose and this fellow is stationary it is not moving at all. So, armature conductors if I show it like this with a red lines armature conductors are here in this slots is not and armature is moving suppose from left to right and this field is stationary and suppose this is South pole corresponds to this is North pole. Then I will apply right hand voltage to find out the voltage induced in a single conductor, how to do it?

This is the direction of say tangential velocity v of this conductor say I want to find out what is the voltage. This is b, this is b, this is v direction of voltage and this 4 finger this strip will tell you the polarity of the induced voltage coming. In fact, for all the conductors this will be dot dot like that, for all the conductors this is true they are having same velocity. However, the magnitude of the voltage induced in this coil will be I have to take this b length of the conductor is same perpendicular to the paper into v.

The induced voltage in this conductor will be this b length and velocity is same, but nonetheless polarity is same that is what I am telling. So, and similarly you can easily see it will be cross here the polarity of the induced voltage they will be additive. What I will do is, this I will start from this that induced voltage in a single coil I will use a better pen I will first calculate induced in a single conductor single conductor is how much, you pick up a single conductor what is the induced voltage in it.

Now, it may look a bit funny that this conductor will traverse this whole length nah as time passes polarity remains same, but the magnitude of the induced voltage here, here it because this fellow was a little time a time earlier was here, it has now occupied this position induced voltage has become more b is more, then once again it retains that value if it is flat top, then once again it is decreasing. Therefore, magnitude of the induced

voltage induced in a single conductor is not constant when it is under one pole that is fine, but it is polarity remain same.

So, what people do is this conductor is in different value of flux density between 0 to pi. So, why not take the average value of the flux density and multiply with l and v to get that voltage that is will be absolutely accurate nothing wrong in that. So, what you do, you take average value of this b which will be something here B average total flux what is b d theta total flux divided by this length average value of flux density I will calculate and pretend that the conductor she is all the time B average and multiply with that B average with length and velocity.

Now, the big question is how to calculate v average that calculation is also very simple, see if you look at this diagram suppose it is a multi polar machine I will draw it here say 4 pole machine, this is suppose North pole, this is the South pole this is once again North pole windings I am not showing on the stator we know how to create that this is suppose South pole. Suppose air gap is little so, suppose the diameter of the rotor or the air gap whatever you call it is suppose D diameter of rotor is equal to D.

This North pole will create flux which will come out as we have seen it will go like this is not that is how it will be completing through this other portion of ions yox that is called anyway. So, b will be present here, here, here, here, here, here then there will be a if you draw a line dotted line I am showing this portions there will be no flux density perpendicular to the iron because there is it is 0 nothing.

So, whatever total flux comes out from the North Pole which I have denoted by phi, phi is the let phi is equal to total flux per pole total flux per pole in waver suppose. So, this flux what will be this length, if D is the diameter of the coil I mean not that that length this length on the periphery this length how much will be this length, because b I have to calculate I have to divide the total flux per pole divided by area. So, I must know what is the length of this one this portion, I highlight it with different colour got the point, here this length is how much?

This length will be; obviously, this length is pi D is the total periphery divided by number of poles if it is 4 pole pi D by 4 4 pole I have shown if it is 6 pi D by 6. So, flux per pole and what is it is unit, it is unit it is meter and area through which this phi is

acting I mean is present whatever language you write will be equal to pi D by P into length of the machine, because this is perpendicular is not. That will be the area curved area we assume this is sort of rectangle pi D by P into length of the machine that will be the area.

Therefore, B average in the air gap I can say flux per pole divided by the area through which this flux per pole this is phi total flux all the lines of force coming out phi distributed over this length pi D by P into l. So, so this is pi D by P into l which will be equal to phi P by pi D l, what is D? Diameter of the rotor. What is l? Length of the machine or the length of the conductor because rotor length is the coil side length you should remember these are over hand portions.

In this portions there will be no induced voltage I should not bother I will be bothering about the effective length of the machine, here the voltage you will be induced this fellow is rotating seeing different values of flux density under a pole. Although polarity of the voltage remain same when it is under South pole, but magnitude may change because strength of b is changing. That is why it will see some times low value of b sometimes higher values of b once again back to low value therefore, why not calculate the v average and pretend that v average remains constant multiply with l and v and you will get absolutely correct result nothing wrong in that.

So, so, so induced voltage this question mark I can now write it as is equal to it will be in a single conductor mind you in a single conductor will be B average B length of the conductor and v the velocity and I can if N is the rpm rps this mind you is the linear velocity metre per second. So, if it is n then conductors residing here and the rotor diameter is N then velocity in metre per second is nothing, but pi D n, in one second conductor will travel how much distance, pi D is the perimeter in one rotation pi D in one second it makes n rotation. So, in one second it will move by so much meter per second is not and that is I think.

So, I will say that induced voltage let it be a bit clumsy I do not mind, but let me on this page only. So, it will be then is equal to B average l and for v I will write pi D n this is the expression for induced voltage in a single conductor. We will continue in with this in the next lecture.

Thank you.