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

Lecture - 16
Induced Voltage in a Coil in a Rotating Machine

Welcome to the 16th unit lectures of Electrical Machines II. And you recall that we were discussing about B distribution. Last time we calculate the air gap field distribution B which was rectangular in nature and of course if I want to generate AC voltage I must see that may be distribution is sinusoidal in nature because it is ultimately B lvwhat matters. Now before I go into that let us take a little bit of going back and see once again recap in terms of some demonstration how a conductor EMF generates when it moves under a field.

(Refer Slide Time: 01:10)
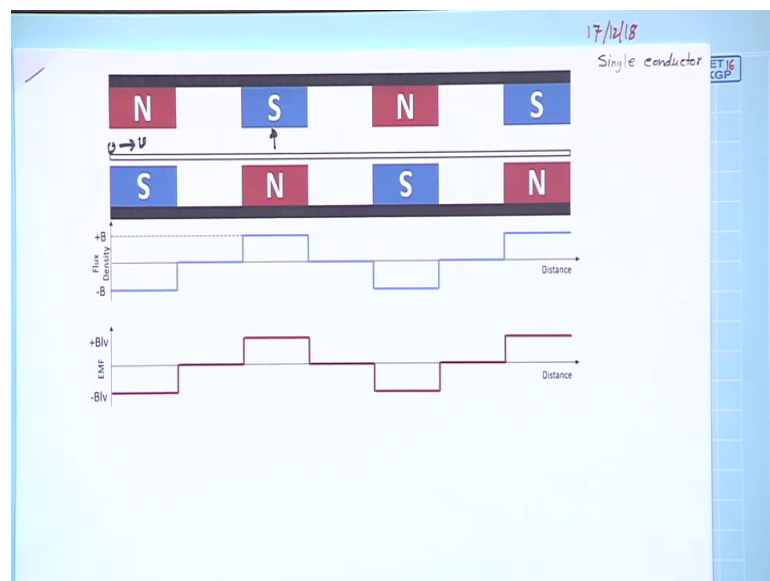
For example the way I will show it in the computer before that let us try to understand, this is suppose your South North South North which alternately comes and the direction of the field here will be vertically upwards and it is just shown a line on which that conductor will move and as it moves then and then after we will get this I can sketch this, because lines of force going up I have shown positive.

So, this is your flux density distribution, but mind you this is in space in terms of distance from any reference point you can measure the distance and this is the flux

density distribution and here is a conductor which if it remain stationary nothing happens and this conductor once again it is perpendicular to the board where I am writing and it is given a velocity.

If it starts moving then voltage will appear and polarity of the voltage will change as it goes to goes under a South Pole looking from the top from a North Pole environment and in between this time this zone if since there is no flux density exist the voltage induced will be 0.

(Refer Slide Time: 02:54)
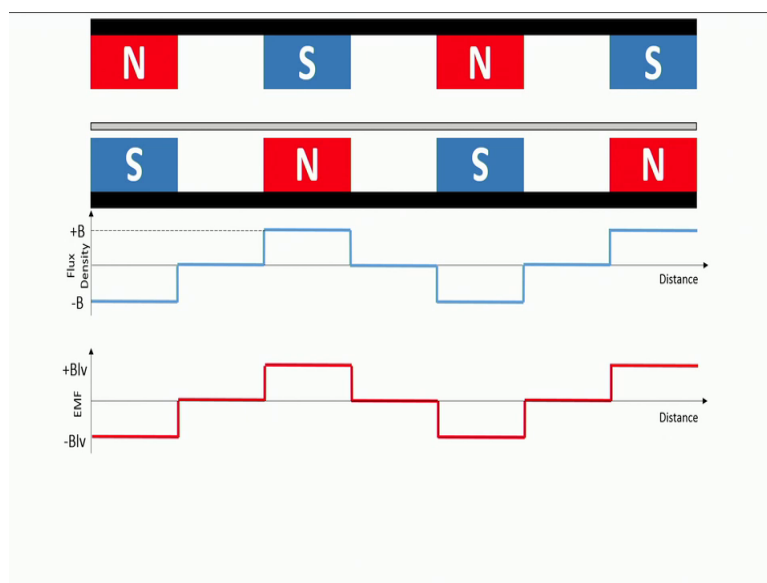
So, let us now go to the computer a demonstration scenario, here you see that the conductor is marked with a yellow sectional view, it is perpendicular to the board and it is stationary ok. Now in the next slide I have shown the b distribution which is rectangular like this not sinusoidal but rectangular and which one is positive I am call calling the lines of force moving vertically up that I have indicated by positive plus b and when the lines of force moves down from north to south, north in the upper south in below, then I am telling it is minus b. So, it is against distance it is sketched and there is a single conductor which is stationary.

Now, if you allow it to move with a velocity v, then what happens is that whenever this conducted is under a south pole a positive voltage is induced positive means the phase of the conductor which is towards me is that is plus and the other end which I cannot see is a negative.

So, once again if I replay it you can easily see it was cross initially by applying right hand rule then dot then once again cross once again dot. The point to be noted is that the EMF generated in a single conductor follows the same pattern as that of b. Of course, the distance in the second curve can be changed to v into t where v is the velocity of the conductor. Suppose I am measuring the distance from the initial origin then the x axis of the red curve can be changed to vt indicating that a time varying voltage will be induced.
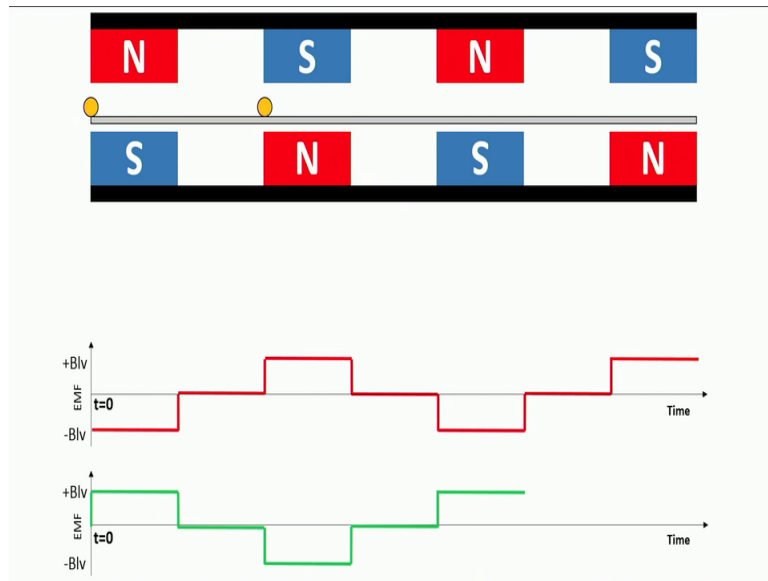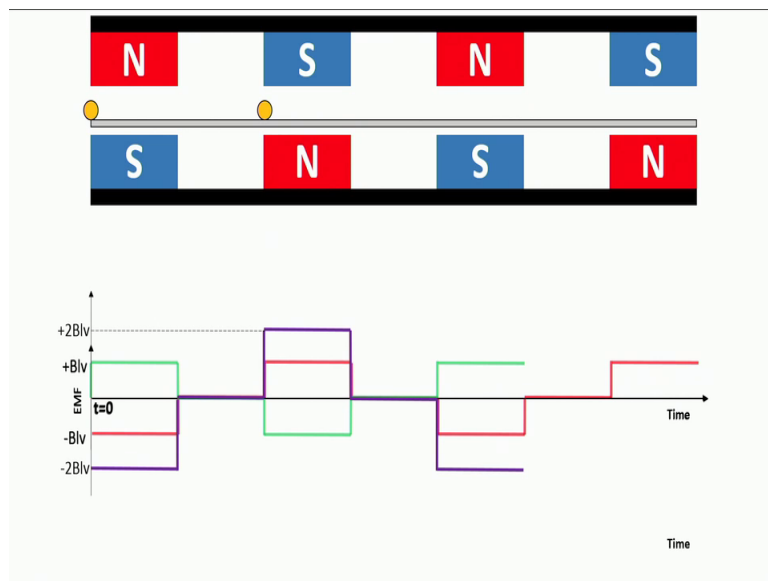
(Refer Slide Time: 05:14)
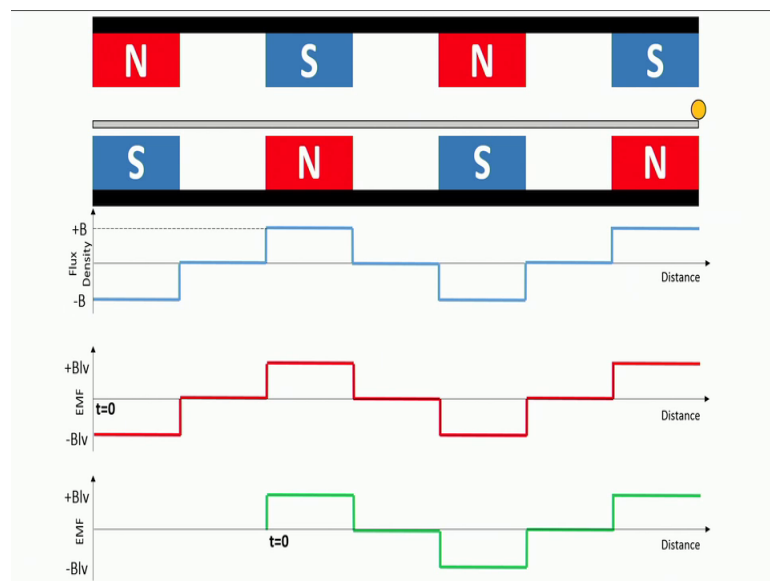
Now, in the next slide if you see I have placed 2 conductors and they are stationary then the first curve B lv curve is the left hand conductor voltage I will sketch and the right conductor, the next conductor on the right it is EMF will be in the last plot down.

Now, here once again if they are stationary nothing happens, but if you make them move with same velocity then the voltage induced in the first conductor will be is indicated by this red curve and in the second conductor it is indicated by green curve. And you see the EMF induced in the second conductor on the right lags the I mean leads the voltage induced in the first conductor. Now if these 2 conductors are connected at the back in series, then you will get the resultant voltage which will be the difference of this 2 and you can see so this is the red voltage is the voltage induced by this red.
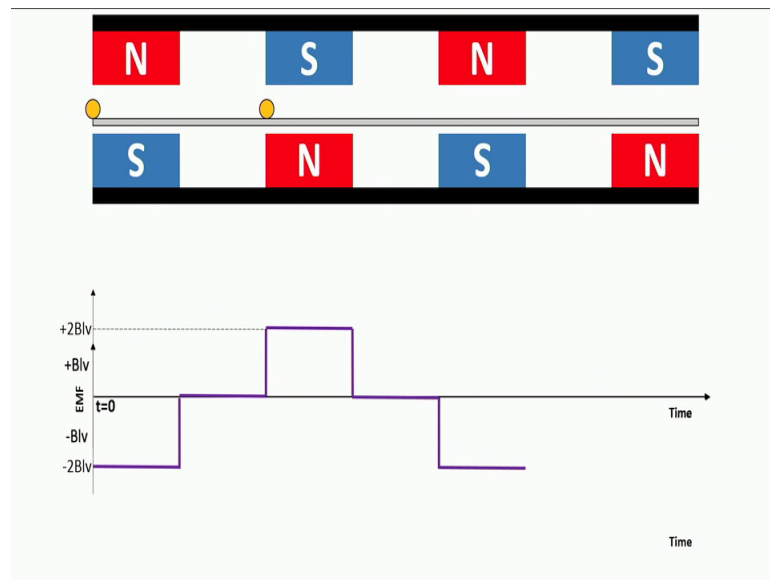
(Refer Slide Time: 06:39)

 (Refer Slide Time: 06:53)

And then take the difference and you will get twice the voltage indicated by the blue curve.

(Refer Slide Time: 06:56)

So, interesting point is that thing starts with a single conductor, now this single conductor and these 2 conductors if connected at the back it forms a coil. Incidentally in any rotating machines if you understand what is happening to a single coil other coils will be identical, only thing is those coils will be placed in different positions in different slots. So, whatever is happening to a particular coil now, same thing is going to happen to the other coils after some delay of time ok. Therefore, it is essential we must know what is happening to a single conductor then a single coil.

After I have come to single coil I will now define in fact what a coil is and we know what is going to happen. So, let me now switch over to our desktop where I will write things and explain to you what do I mean by a coil. So, I am coming back here so that was the demonstration.
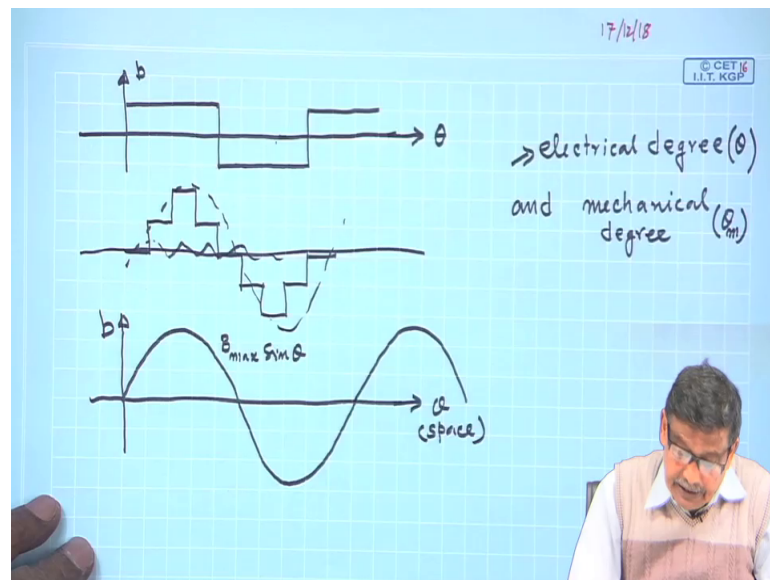
Now, in my last class just quickly review that the b distribution in the air gap was something like this is not, which is this was the b distribution we obtained by a single coil. This is the spatial distribution in b mind you this is distance or if it is a rotating machine better I write theta angular position let me explain to you.
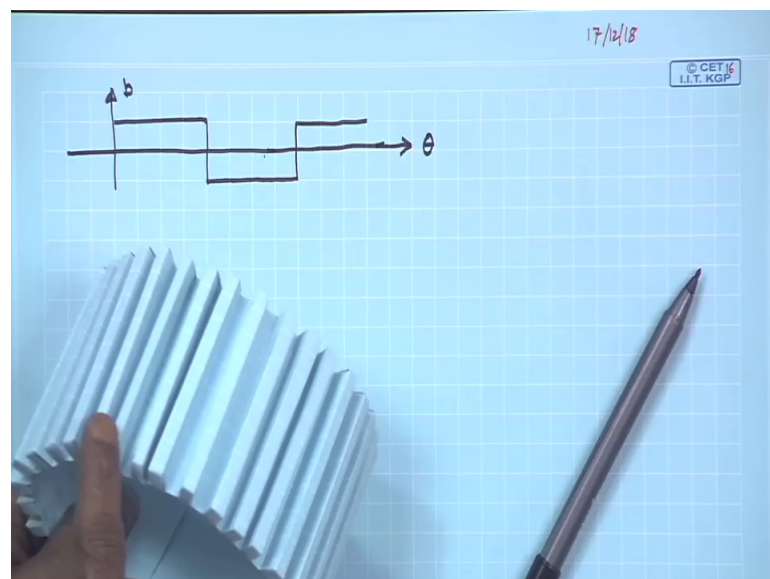
Now suppose you are having a now whatever I am telling can be understood, these are the iron of the rotor suppose and this things that the teeth it is made of iron inside also it is iron. It is the solid block of iron they maybe of course laminated that we will see later,

but the basic structure is it is made of soft iron and with some slots as I told you will cut slots and here in this group or slots I will place conductor and things will be rotating ok.

Therefore, and this can be you know as I told you I will cut it for understanding and display it like this, so it will become a sort of linear way of understanding rotating electrical machine that is called the developed diagram. Now in this rotating machine what happens is this how to place the conductor and what is a turn. So, suppose this is the rotor it has got a diameter.

(Refer Slide Time: 10:20)
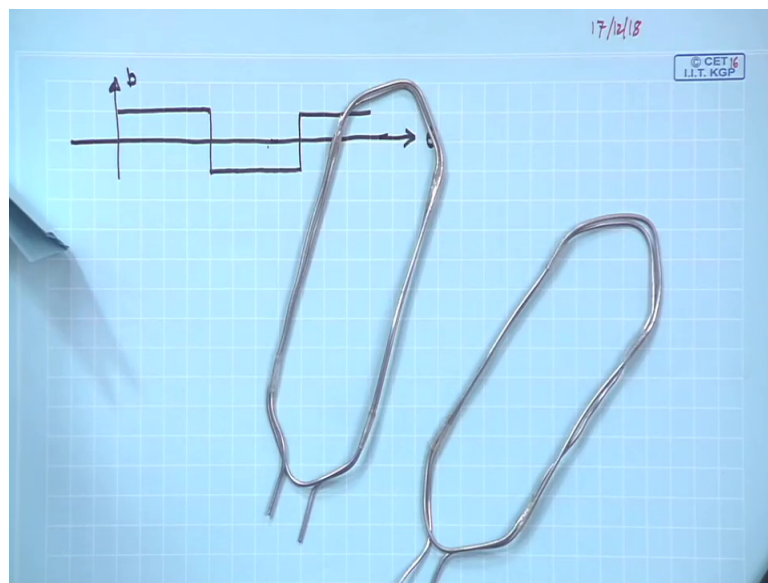
You take a coil it is a multi turned. In fact, it is a 2 turned coil how I have manufactured it I have taken a conductor it goes like this ones comes back then once again goes back to the same slot comes back and ultimately you will have this 2 free terminals, which I was calling x 1 y 1 or 1 1 dash things like that if you one name because, there will be several coils. So, this forms a coil and each coil of course is to be named so as to identify which coil I am talking about. So, numbers are used you know 1 1 dash similarly there may be another coil which we call 2 2 dash got it. As for example, another coil it may be termed as 2 2 dash and this coils I will place in the space reserved for it in a particular sequence and each coil will have it is own free terminals and they can be connected in series or in parallel whatever way it is convenient we will do that.
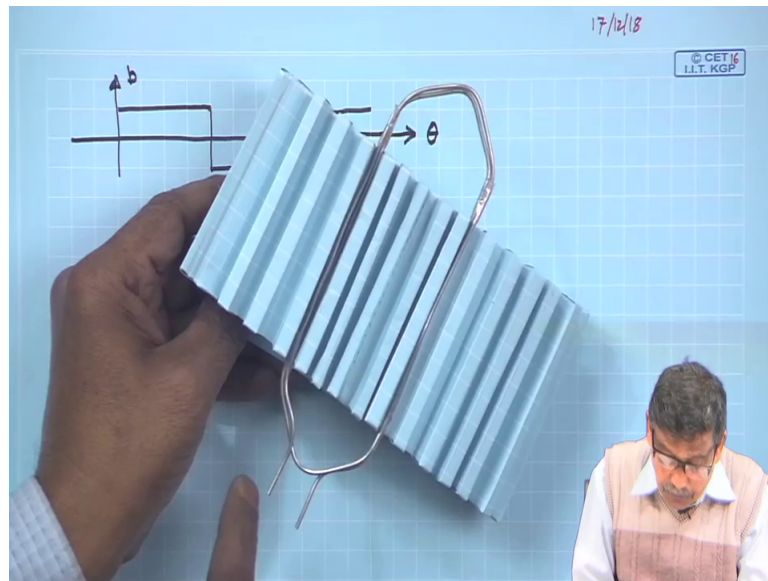
So, how to place the coils? Coils will be placed in this way this is one coil side it will be placed here and another coil side will be placed perhaps in a particular slot. I indicated that if one coil side I must see that this coil span the difference in distance between the 2 coils sides should be such that if 1 coil side at any given time is under the centre of North Pole you must see the other coil side is under the centre of South Pole. Why because then the induced voltage between it is 2 terminals here will be maximum 2 B lv this will be B lv this will be also B lv, but the polarity of this voltage if this is plus this is minus this one will be this is minus and this is plus.

So, that minus 2 plus then once again minus 2 plus B lv B lv 2 B lv and if it is a multi turned coil having n turns you make n loops and then 2 terminals, this total EMF this side will be n B lv and this will be also n B lv with opposite polarity so that they are added up and will give you 2 n B lv voltage.

Now this b if it is varying it is magnitude is varying in space in whichever way it varies the nature of the induced voltage will be of same shape. If it is a rectangular these voltages 2 will be rectangular, if the b distribution is sinusoidal that will be also sinusoidal. Another point I want to tell regarding this arrangement is that this is the this is how different coils will be placed in their designated slots, so these are called slots ok.

Now, this portion of this winding and where will be your North Pole South Pole this is suppose the rotor structure, similarly on this there will be an air gap you will imagine

there is another cylinder with slots and that that stator iron will produce north south poles when stator coils will carry current therefore, this must be seen as this is only rotor I have shown. But it can be made like a stator if you push it like this here stator things will look like these way this stator.

Here also there will be coils like this are you getting me and when they will carry current they will produce their magnetic field 1 quarter if it is 4 pole 1 quarter will become North Pole 1 quarter will be South Pole and so on. Therefore, both this things will be present together suppose b is produced by this stator coil you energize like this there will be coils and then in the rotor there is slots there are coils also and if there is a relative speed between them then we expect there will be some induced voltage in the rotor. So, these are called teeth slot, teeth slot, teeth slot like that sequence it will go.

So, it may look like there will be several coils why there will be several coils because, I shown that if you are using a single coil first of all single coil means you require only 2 slots, then rest of the space of the iron will be underutilized that is one thing. It is better try to utilize this space increase the number of coils because, increasing in number of coils will also ensure that this b distribution will be no longer rectangular, but it will be somewhat stepped like this that is what I have shown if 2 3 coils are used and this will be more like a sine wave ok.

 Therefore people never use a single coil to generate AC voltage, because if you do that then b distribution may not be that sinusoidal. Therefore, a group of coils are connected in series and displaced from each other. So, what you do you place one coin here another coil next slot another coil next slot suppose 2 coils I put and I will connect them in series to get the desired voltage generated which will be more like a sine wave. Now hence forth my discussion in my discussion what I will assume is that the b distribution is sinusoidal, a strong fundamental and I will neglect the effect of harmonics of b distribution. So, this is this maybe denoted as B max sin theta where theta is the space angle.

It will be like this is the b and this is space mind you space angles, I will consider only the fundamental component in the mind I will think that b distribution can be more closer to sine wave. So, only the fundamental component of this different harmonics I will effect neglect the effects of those harmonics to begin with and for this thing what will be

the induced voltage in a particular coil we will try to find out. Now before that I this 2 terms I must tell you one is called electrical degree this is very important and mechanical degree.

Angle can be measured in 2 ways theta electrical and theta mechanical, for electrical I am not writing the suffix I will not carry on, so theta if I write it means electrical degree. Now first let us understand what is electrical and what is mechanical angle, angle is angle. The angle we know of geometrical angle that is the mechanical angle with a protractor I can measure the angle between 2 straight lines like that. But then what is why it is necessary to introduce another angle theta e let us try to understand.

(Refer Slide Time: 19:34)
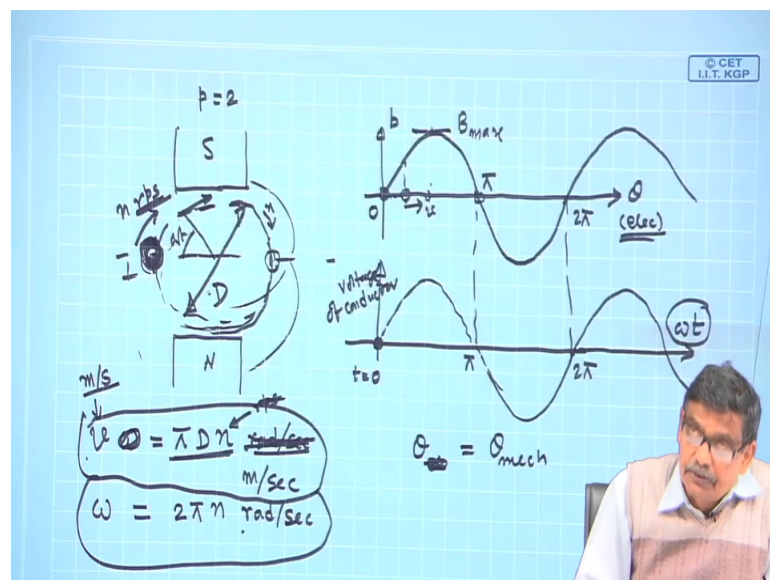
Suppose you have a 2 pole structure I will roughly draw. This is suppose north this is suppose south north south and you have a single conductor let us try to understand and it is moving with some angular speed or velocity suppose it is moving with a speed n r p s and the b distribution we know it will be whatever is the b distribution. Suppose the b distribution is like this fundamental component of b distribution along this angle theta, where from I am measuring the angle theta in this particular case it looks like when the conductor is in this position it is one half is North Pole and other half is South Pole.

So, South Pole zone begins from here from this horizontal position. So, suppose the conductor was here and suppose the diameter of the rotor is D, D is the diameter of the rotor and if I say and it is a 2 pole machine p is equal to 2 number of poles 2 and this

north south as I told you might have been produced by a coil I do not bother cares to indicate that ok. A south North Pole has been created as stator iron has become magnetized and now in the rotor there is a single conductor moving with n r p s rotation per second.

Now, what will be the induced voltage, induced voltage if this is b distribution the induced voltage and suppose the conductor was in this position at t equal to 0 t equal to 0 ok. This axis is position means phase no doubt but it now indicates the position of these conductor as time passes.

Now this is angle suppose this rotates in n r p s and then you can see the angular speed of this one will be nothing, but pi D into n so much radian per second. Now this is how the angular speed radian per second is related with rotation per second, you multiply by pi D n because in one rotation it covers 2 pi, therefore in 1 second it will cover a distance v is equal to pi D n I am I am so sorry v is equal to pi D n.

See 1 second one rotation means pi d meter the conductor moves in 1 second you are making n rotations. So, velocity in meter per second will be pi D into n that is all and omega speed in radian per second will be how much it will be 2 pi into n, because in1second it makes 1 rotation means 2 pi angle. So, in 1 second if makes n rotations it will be so much radian per second. So, these are the 2 things, why I have expressed v in terms of n because, the induced voltage does not depend on omega B lv so tangential velocity in meter per second all that matters.

Therefore, if you are rotating the rotor at some n r p s n and wherever the conductor is I must know the value of b at that position whatever position it occupies and what is the velocity v tangential velocity and tangential velocity in meter per second is this one pi d n. Now as you can see this point is important suppose I have started counting my time when the conductor was in this neutral position it has no voltage, but it is going there that is it has come here then the moment it comes under the purview of the South Pole there will be induced voltage in it, the magnitude of each will be this B this length of the conductor into this velocity which is pi D n you note.

So, it will go like this then it will come here it will have maximum voltage corresponding to B max, then once again voltage polarity dimension, but strength is decreasing it will become 0 here when the conductor will come here in this position and then when it

comes under the influence of north pole that it will be for so long time here b reverses. So, induced voltage across the 2 ends of the conductor reverses, therefore induced voltage will be also of this nature is not. Therefore, this conductor when it makes a complete rotation in this direction and this is suppose omega t, so omega t was 0 any omega t it was like this omega t was increasing.

Now, when it comes back to it is original position once again it will be 0 and the cycle will start repeating is not. Therefore, you see if you call this theta to be 0 here pi here 2 pi there. Similarly for the induced voltage this axis I have change to this is position no doubt, but omega t I want to know how the terminal voltage you will look like a against time, so this is 0, this is pi, this is 2 pi. The conclusion is in a 2 pole machine like this when the coil makes a 360 degree rotation your output induced voltage this axis is voltage in the conductor that will also make a complete cycle and that repeats.

Therefore in 2 pole machine we say theta electrical this is always electrical like that I will say, but time has a time is really not right to distinguish between mechanical and electrical angle. In fact, in 2 pole machine electrical angle and mechanical angle are same. So, theta electrical which I will not write only theta; theta electrical is equal to theta mechanical, why because if the conductor makes one complete rotation the output EMF generated which I want to see against time that will also make a complete cycle ok. I stop here in the next class I will continue with this that is very important concepts.

Thank you.