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

Lecture - 20
Distributed Coils Connected in Series: Resultant Voltage Due to Distribution

So, welcome to this 20th lecture.

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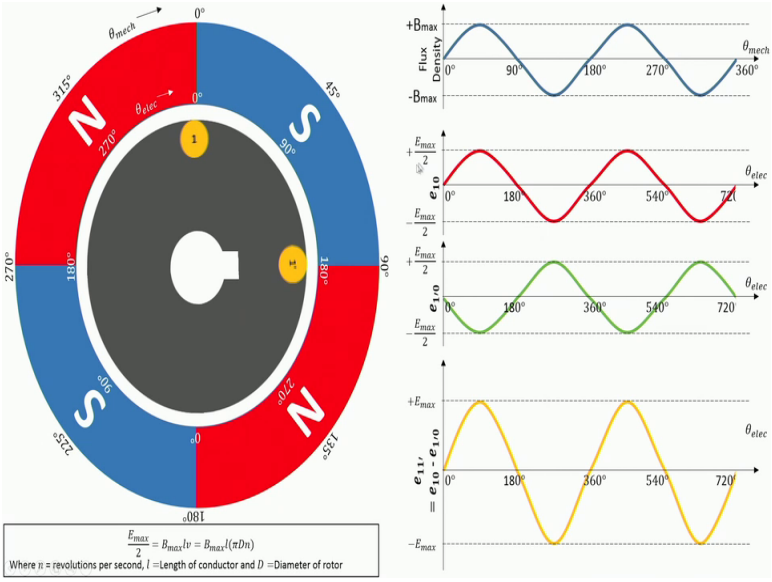

And first we will begin with in soft note that is whatever we have done, I will try to demonstrate. Nicely, it has been prepared by Professor Abhishek Chatterjee and I want to show you. In this diagram if you see this is the B distribution is not it and B distribution for a 4 pole machine. This 4 poles how they have been created? It has been created by there is winding on the stator and we have seen how to create 4 poles, 2 poles structure like that; 1 quarter become south pole, 1 quarter become north pole, south pole etcetera.

Therefore, this poles are created by the stator current and now on the rotor which is also an iron there are only suppose 2 slots. Now, here is a conductor which is perpendicular to this screen and the front end I call 1. And this is 1 dashed, it is the fronted coil that is the finish of this coil. So, there is a single coil. Why it is 90 degree, not diametrically opposite? Because, whenever 1 is under centre of the south pole it will become 1 dashed must be under the centre of the north pole. So, that you get 2 B l v voltage maximum voltage.

In this position neither of them are so, 90 degree mechanical is this separation which electrically means 180 degree. So, outer scale shows the mechanical angle and electrical angle scale is shown here. So, the coil span is 90 degree mechanical no doubt 90 degree mechanical 0 to 90, but it is electrically 180 degree mechanical. And, when this coil 1 coil side 1 moves by 360 degree mechanically you can easily seen 2 cycles of emf will be generated. So, this is the B distributions space, this is called space in space B is changing like this; if lines of force are entering to south pole I have assigned positive sign.

So, only fundamental component we are thinking. So, B max sin omega t this equations. Now, if this 1 1 dashed coil can they move in different velocities, no rotor if moves whatever velocity their there their position fixed in the slots. Therefore, they will move with the same velocity and in this developed diagram it looks like this linear diagrams. But, I will not write x distance because it is all angles I have to correlate with this figure.

Now if it is like this I will try to sketch what is the voltage across this across this conductor ends. It could be a multiple turn conductor several turns we have seen that, anyway this voltage 1 0, 0 is where at the back that is this point is this is 1, this is 0 I am calling ok.

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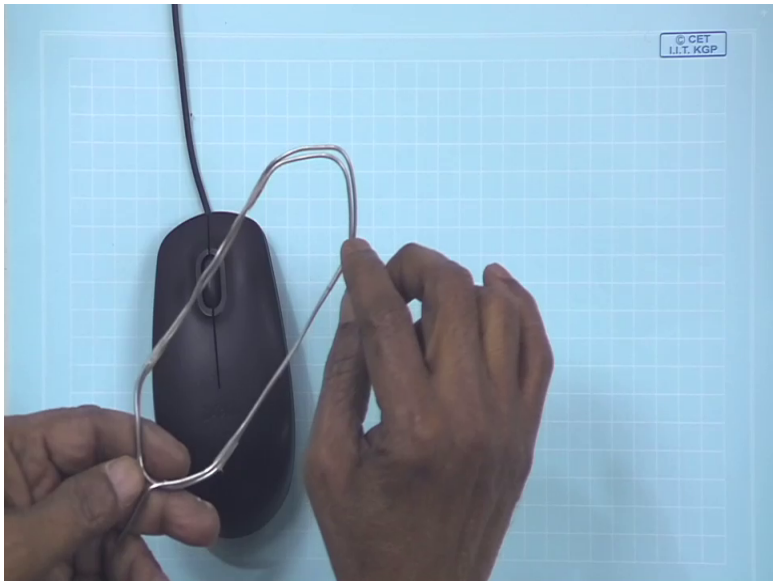

This is 1, this is 0, this is 1 dashed, this is 0 because why this is 0; because it is at the same potential. And, this part of this over end there is no voltage induced it is outside the

machine poles this side. So, there will be no voltage induced assuming that. So, the potential of this point and this point are same that I am calling o and this is 1 this is 1 dashed.

So, I will sketch e 1 0 and I will sketch e 1 dashed 0 and then the voltage across these turn e 1 1 dashed will be nothing, but the difference of this 2 2 waveform ok. So, let us see what happens if this coil now moves relative to this field, field is stationary. So, let us see what happens, as time passes e 1 0 will be same as B l v is not. Similarly, e 1 dashed 0 will be only thing is its polarity reverses, same type as that of B it will go and the difference of these 2 is this.

So, this is B l v, this I have called the final voltage in that term I have written this will be half half. So, E max is the voltage across the coil 1 1 dashed that I have fundamental amplitude is E max. Therefore, it each conductor 1 0 and 1 dashed 0 must be half that should be 2. So, this is how things goes. Note that I have shown, but the angles this is theta mechanical. Theta electrical is this will be 720 degree 90 degree is 180 degree, 180 degree is 360 degree. So, when the coil makes a 1 mechanical rotation you get 2 cycles of emf, 1 cycle of emf is 180 degree.

Therefore, this is how things goes on. This a very nice demonstration and you can see this expression also ok. Therefore, with this we will now come to our next topics, you keep this look at this demonstration it will perhaps enhance your understanding. But, in spite of all these things let us come to the lecture part. In spite of all these nice demonstration you should also mentally think what is going on, this is a good way a simple way to go back there. But, I must also physically know what is happening from the coil side it is moving and things like that so, this is the thing.

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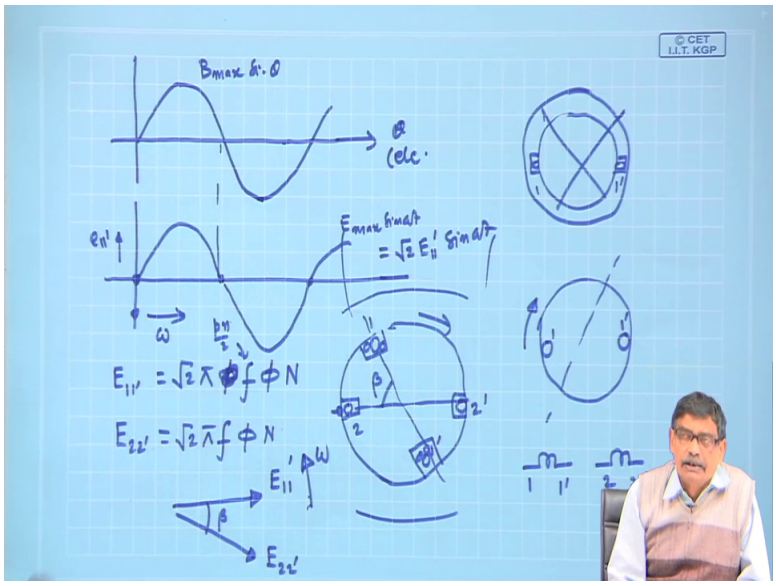

Therefore, if I neglect the harmonic component and assume the voltage to be sinusoidal assuming B to be sinusoidal like this. So, B max sin theta, this is theta electrical then the voltage across the coil e 1 1 dashed instantaneous value of the voltage will be also like this. This will be also sinusoidal which I am writing E max sin omega t which of course, E max is that root 2 into rms value.

We have calculated sin omega t and this I will call it like this provided I have started counting my time when 1 was here. And it is moving towards right with an electrical speed of omega radian per second that is all ok. Now, I mean very roughly sketching the things, if you have a single coil say 1 1 dashed. I am sorry in the rotor there is a single coil I will not draw the slots ok, I will avoid drawing this. This is suppose 1 dashed, this is 1 its means slots are there these are the coil sides etcetera and then your south pole is there.

So, 1 up of this is south pole and it is moving ok. It is suppose a 2 pole this is south, this is suppose north and this is the rms voltage, but what happens is this if you want to get a better voltage waveform your coil should be distributed. Better do not use a single coil you use a multiple coil, a number of coils each one is housed in 2 pair of different slots. And, then connect them in series in which way it will help you, one way is that emf produced by this coils when they will carry current it will be more sinusoidal. I told you it will become stepped and secondly, the better utilisation of the space.

So, what I do is this I have suppose a coil 2 pole structured am doing here 1 1 dashed. And, then I will connect another coil 1 1 dashed and this is 2 2 dashed and this 2 coils have their own separate identity with the terminals available to you. Suppose, the angle between them is beta some angle electrical angle all angles are electrical now. So, 1 1 dashed and 2 2 dashed now, I know how to calculate the rms voltage induced in 1 1 dashed and it will be sinusoidal.

Rms voltage of 1 1 dashed is root 2 pi phi phi then, f where f is p n by 2 f phi into N, N is the number of turns in 1 there the it maybe a multi turned coil. And second coil is identical coil same number of turns then rms value of 2 2 dashed will be equal to route 2 pi f and it is moving in a field created by stator south north etcetera it is moving in that field. So, root 2 pi f phi into N. So, rms values will be same. What will change, what will be the difference between the quality of these 2 voltages nothing really magnitude E max remain same.

But only thing will change when peak value is attained in 1 1 dashed the peak value of voltage you get, in coil 2 2 dashed that voltage will appear after this angle beta. Therefore, induced voltage in coil 2 2 dashed will simply lag the induced voltage 1 1 dashed by some angle that is all.

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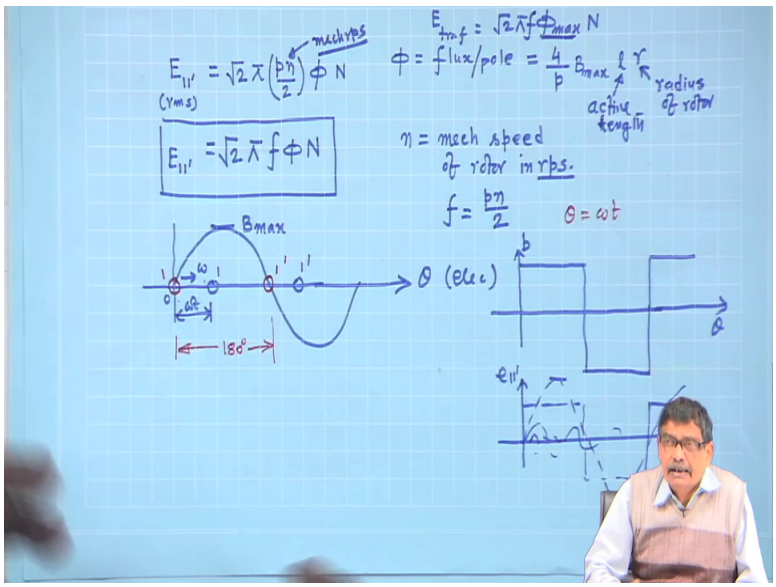

Henceforth, no point in referring to this fundamental diagram drawing 2 2 dashed moving tying to understand what is happening, which voltage is leading, lagging this that. I only picture this scenario in this way and see the direction of rotation.

And then I conclude if this is the voltage phases of 1 1 dashed in our Phasor diagram then E 2 2 dashed will be lagging it, by what angle? By the angle of separation between them that is the angle between these 2 slots that is beta; you know in case of drawing Phasor diagram this is how we draw. So, it has nothing to do with your rotation of rotor direction clockwise, then why you are drawing not like that that is once this sinusoidal voltage I have got.

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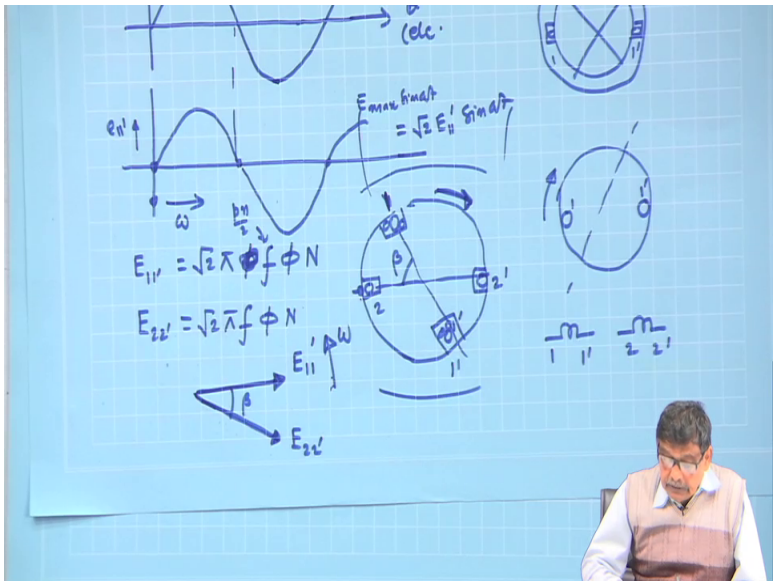

I can now invoke all the things which I have done in circuit theory because, they are sinusoidal voltages time varying. So, if E 1 1 dashed is there E 2 2 dashed will be there. Why? Because 1 1 dashed this is 1 1 dashed is there and rotor is rotating in this way and there is identical coil 2 2 dashed housed in this 2 slots. So, whatever is happening to 1 1 dashed now same thing is going to happen, in 2 2 dashed after this angle beta where time is there beta is the time required by 2 2 dashed to come to this position 1 1 dashed. It can be related with omega t. Therefore, if this is the voltage Phasor 2 2 dashed will be the voltage phasor of the second coil.

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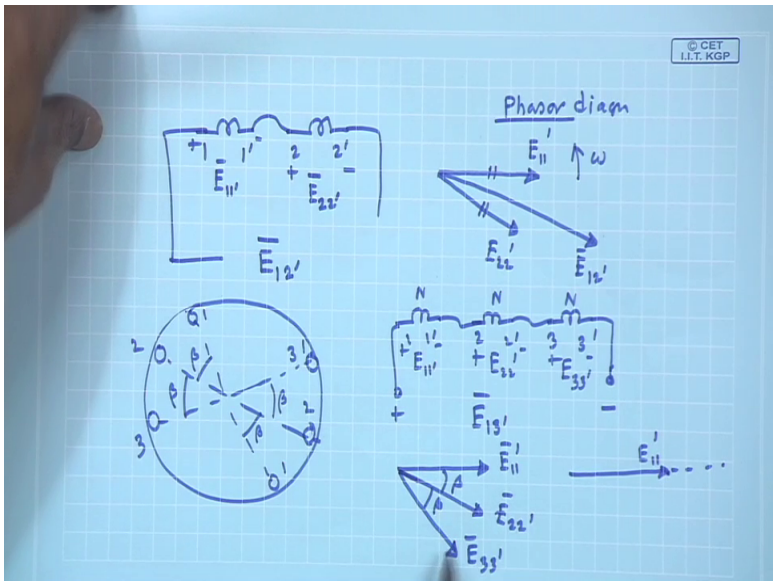

Then if this 2 coils and this diagram shorthand way of because, after all let us now come out from this very complicated diagrams stator, rotor, showing the coils ok. Coils are physical coins having 2 terminals 1 1 dashed 2 2 dashed, only thing I should know how they are positioned in the machine. And from that I have learnt that is voltage is E 1 1 dashed this is the phasor plus minus and this is the voltage induced in the second coil 2 2 dashed. This is also a phasor and this 2 if you now connect them in series and want to examine what is the voltage?

E 1 2 dashed 1 to 2 dashed, then that is that will be simply this one this is E 1 1 dashed, this is E 2 2 dashed. So, add this 2 and get the resultant this will be E 1 2 dashed; rms values the length this will be same because the coil is having same number of turns rotating with same velocity, moving with same relative speed as 1 1 dashed is doing. Therefore, everything remains same only thing whatever is happening to 1 1 dashed now this is the phasor diagram, mind you phasor diagram time phasor diagram.

All Phasors are moving with speed omega. What is omega? Omega is angular electrical speed per second. So, this is the scenario. If that be the case then if you connect another coil suppose this is 1 1 dashed 1 coil multi turned N turned capital N turns. There is another coil this; this, this makes 1 coil this is 2 2 dashed another coil, connect another coil 3 3 dashed. And, suppose the angle between them is all beta, this is also beta, this is also beta. Then how to find out this? So, there are now 3 coils 1 1 dashed.

Number of turns N number of turns N 2 2 dashed, number of turns is N 3 3 dashed and all these suppose are connected in series. So, this voltage is E 1 1 dashed, this voltage is E 2 2 dashed plus minus plus minus and this voltage is E 3 3 dashed plus minus. So, resultant voltage which will now be available only free terminals available is 1 and 3 dashed. So, this voltage plus minus E 1 3 dashed this phasor will be so first let me draw the phasor. This is E 1 1 dashed oh E 2 2 dashed is lagging 1 1 dashed by this angle beta.

So, this is this voltage E 2 2 dashed and E 3 3 dashed is lagging by another angle same angle beta. It could be different angle then also I will be there is no problem, but let us assume that they are equally spaced like this. Then what is the resultant voltage? Resultant voltage will be E 1 1 dashed plus E 2 2 dashed. So, better way of showing the resultant voltage because draw a 1 parallelogram then that resultant with E 3 3 dashed. It is much elegant way of showing the resultant is E 1 1 dashed.

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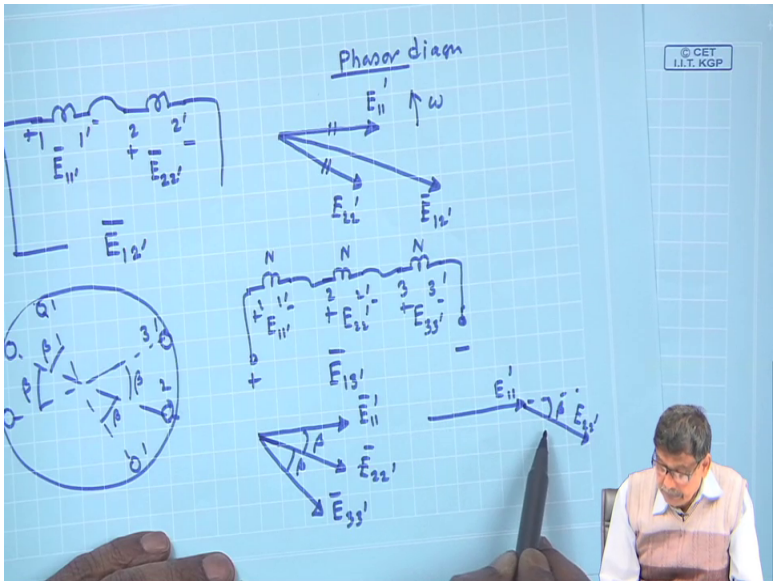

Now, to this you add E 2 2 dashed such that this angle is beta. I will draw it here because space is not there.

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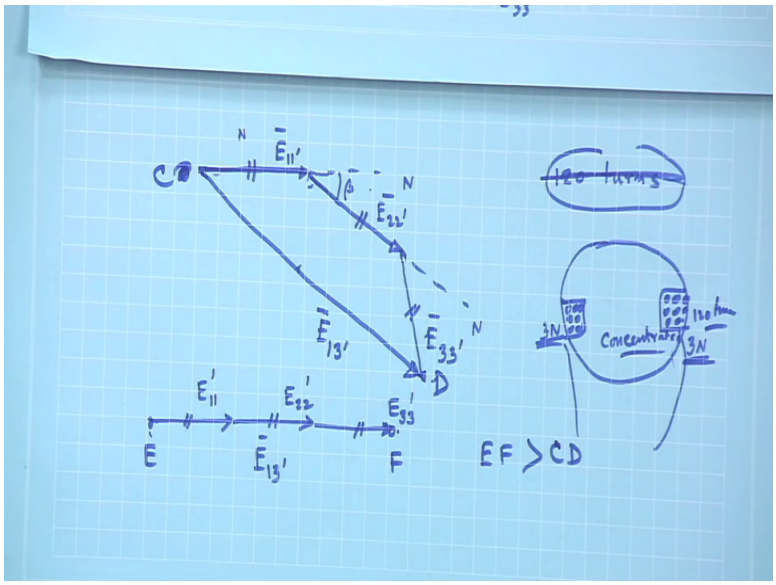

So, it will be better if you draw it like this E 1 1 dashed, then you add this voltage E 2 2 dashed, this angle is beta. And then with respect to E 2 2 dashed 3 3 dashed is lagging once again by the same angle E 3 3 dashed. And the resultant voltage will be the starting to the finishing point that is E 1 3 dashed this voltage will be this length. Each coil this length, this length and this lengths are all equal.

Suppose, I want to generate a certain rms voltage in a machine and I found out that I require 120 turns. And this rms voltage can be obtained by only taking 2 slots and accommodating all the turns here. All 120 turns that is 1 1 dashed 2 2 dashed and 3 3 dashed each one of them should have 40 turns. And they are all connected in this concentrated, this is called concentrated winding not distributed. In that case what is the problem? Problem is that so, much of rotor space is remains underutilized.

So, if coil 1 1 dashed 2 2 dashed and 3 3 dashed each one of them is having N turns N turns N turns that is total number of turns are 3 N turns. I am using to get a voltage across 1 and 3 dashed. Now, suppose somebody says you concentrate all the forget about this 120 turns; 3 N turns you concentrate here all the coils you concentrate in this positions. In that case E 1 1 dashed E 2 2 dashed and E 3 3 dashed they will be in phase. So, 1 1 dashed 2 2 dashed 3 3 dashed all are concentrated in 2 slots only diametrically provided you have enough space there let us assume.

So, if this thing rotates all these coils sides belonging to 1 1 dashed 2 2 dashed 3 3 dashed they will have similar voltage. Voltages will be in phase that is why 1 1 dashed 2 2 dashed 3 3 dashed will be phase. And therefore, ultimately 2 terminals comes out and resultant voltage will be E 1 3 dashed. So, in a concentrated coil all the voltages are in phase and obviously, this length and this lengths are all equal; I am just imagining instead of distributing like this all the turns here.

This coil you put in this slot 2 terminals 1 1 dashed, second coil all the turns you put here only 3 3 dashed also you put. So, you have put all together 3 N coils and then connect them in series 1 1 dashed 2 2 dashed 3 3 dashed and it is then moving in a magnetic field. Therefore, each one of them will have same rms voltage, their lengths are same. But, they will be also in time phase whenever maximum occurs to this coil sides it will occur to all the coil sides belonging to coil 1 2 and 3 similarly this fellow.

Therefore, if each of this coil gives the certain voltage obviously this length O, suppose I call this length to be C D. And here this length suppose I called E F; obviously, E F is greater than E F is greater than C D is not; obviously, is not because this you are not adding in phase. So, some voltage is always lost. So, this length is less than this length. So, you will get reduced voltage. Therefore, it looks like I want to utilise the periphery of the rotor. I then say you do that, but you get a reduced voltage with same number of turns I could get more voltage if coils were concentrated, that is the idea.

But still we go for distributed coils, the reason is clear. Reason is clear little voltage will be lost, we will found out and expression for that in the later time of the course. But, the argument is this losing voltage perhaps can be managed compensated by better increasing the strength of the south pole, north pole on the stator by increasing their excitation a bit. But, you get a better utilisation of the coil and second point is, if you want to generate a large voltage large turns will be required.

How can you accommodate all those turns in only a pair of slots, not at all a practical solution. Therefore, we will use always distributed winding and try to improve upon the nature of B. When these coils will carry current, they will produce B let it be mould like this looks like a sinusoid. And also it is understood that once you distribute the coils voltage loss will take place, but that voltage loss can be compensated by some other means like little bit of excitation we will increase.

Thank you.