

Basic Electrical Technology
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Lecture - 35
3 phase Transformer – 2

Hello everybody, in the last class we discussed about the 3 phase circuits, we continued our discussion of the 3 phase circuits and progressed naturally into the discussion of 3 phase transformers and the 3 phase transformers; basically it is very similar to what we discussed in the 3 phase circuits you have three coils on the primary side and three coils on the secondary side, we connected **the primary** three primary set of coils and the secondary set of coils in different topologies.

So, as there are two main categories of 3 phase connections that the star and the delta we connected the primaries and the secondary in these various combinations that is you have the delta delta connection that the primary side delta secondary side delta, you have the delta star connection the star delta connection and the star star connection. So these four configurations we studied had a look at the various relationships between the phase the phase the phase circuits and the **line side** line side parameters of the primary and the secondary side and we also were able to study the phasor diagram for these four types of 3 phase transformers.

And then we summarized, towards the end of the last session we summarized the **the** different types of the four different types of 3 phase transformers as I am showing it here on the page; the relationship between the line voltage and the line currents.

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	Line voltage	Line Current
1. DELTA-DELTA	$E_L \rightarrow nE_L$	$I \rightarrow I/n$
2. DELTA-STAR	$E_L \rightarrow \sqrt{3} \cdot nE_L$	$I \rightarrow I/\sqrt{3}$
3. STAR-DELTA	$E_L \rightarrow \frac{nE_L}{\sqrt{3}}$	$I \rightarrow \frac{I}{n} \cdot \sqrt{3}$
4. STAR-STAR	$E_L \rightarrow nE_L$	$I \rightarrow \frac{I}{n}$

$n = \text{turns ratio} = \frac{\text{secondary no. of turns}}{\text{primary no. of turns}}$ for each coil

So you see that in the delta delta connection the terminal voltage on the secondary side is just by a factor of n, n times the primary terminal voltage and in the case of star delta the secondary terminal voltage is also multiplied by root 3 and in the case of the star delta the secondary terminal voltage is divided by a root 3 and the star star also you have a terminal relationship of with a factor of n.

Note that with respect to the delta delta and the star star here if we have let us say in both cases a given a given voltage in that case the windings of the transformer here will have to withstand a higher voltage; because let us say you have a 400 volts system and the windings of the primary side should withstand 400 volts and the windings of the secondary side should withstand n times 400 volts because the in the delta delta connection the windings come directly across the terminals or the line.

In the case of the star the windings of phase quantities the voltage of the windings are root 1 by root 3 times the voltage that are coming across the terminals so the windings will have to withstand whatever quantity on the primary or the secondary by root 3 times. So it should only withstand 1 by root 3 times E_L and 1 by root 3 times nE_L in the case of the star star connection.

Of course **the** for the same power **the currents on the** the line currents will be the same but the phase currents in the case of the star will be higher compared to the delta so that is where the compensation is. So in the case of the delta delta for the same power and voltage ratings **this will have** this is supposed to have a higher core cross section area in the case of the delta delta to withstand a higher voltage but the gauges of the wire will be thinner and in the case of the star star it can withstand a lesser voltage but the gauges of the wire will be thicker.

Anyway depending upon the application **the** and the relationship between the voltage and the currents **the one** one of the four types of configurations or topologies can be chosen. There is one more interesting configuration which will have applications in some of the circuits and that is a transformer which takes as inputs the 3 phases a b c where the voltages of the 3 phases are displaced 120 degrees apart all having equal amplitudes effective amplitudes and the outputs will be two phases, I will call this one as alpha and beta. So what this transformer does is a 3 phase to two phase conversion.

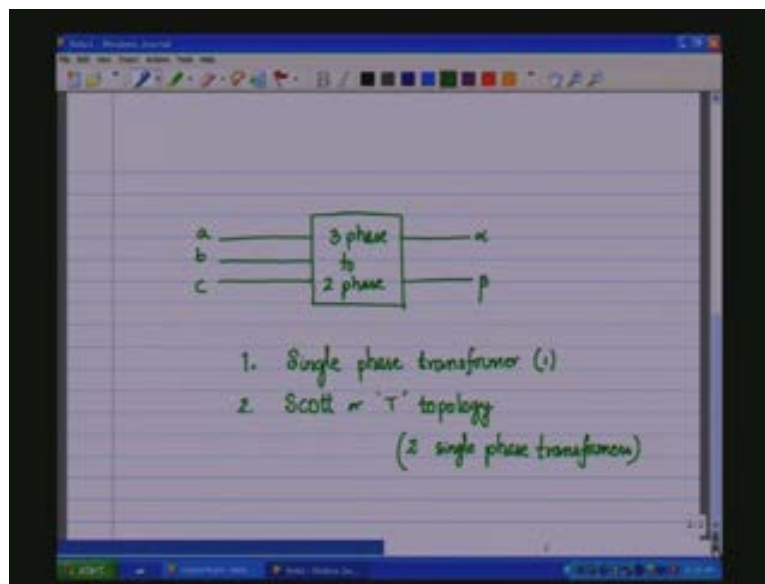
Now if you look at the practical application of this one may wonder **what** where it can be applied. of course **in** some of the motors are two phase motors or in the case of some applications where you have a 3 phase mains available but the motor is a single phase motor a single phase motor **can the** can be designed such that you do not need that capacitor because some of the single phase motors need the capacitor to produce a rotating field **which we will discuss much later**. The two windings of the two phase transformer can be used for such an application of rotating a **3 phase** single phase motor.

There may also be few other applications where the 3 phase to two phase conversion can be used and that **that** probably would be in sensing a 3 phase signal like a current or the voltage then converting into two phase coordinates which will give a resultant especially in applications like vector control or 3 phase control and those kind of applications where you need to convert from a 3 phase to two phase system and this could be a sensing transformer which could do that job. Anyway there are few applications for these.

Now how does this come about?

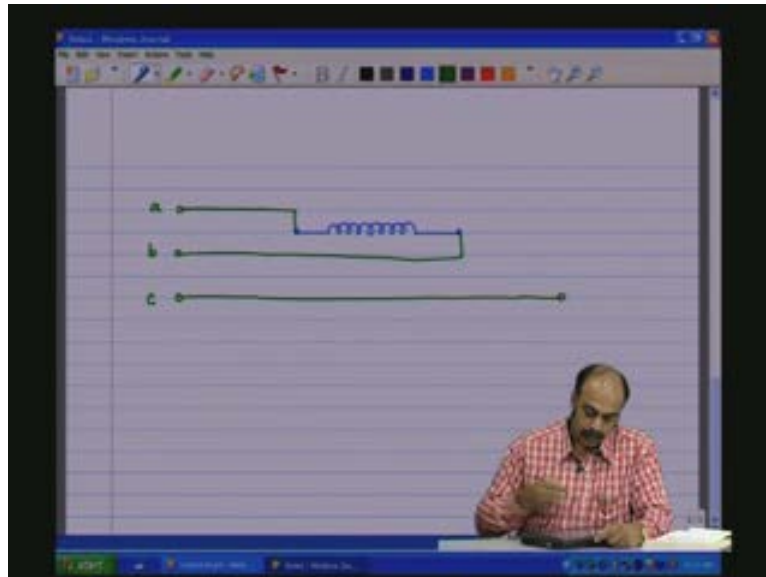
There are two methods; there may be more methods but anyway I will explain to you, two methods: one is using a single phase transformer single phase transformer but we will use just one single phase transformer. the other method it is called the Scott or the T topology where two single phase transformers are used two single phase transformers are used two single phase transformers are required. Let us have a brief discussion on these two topologies before going onto the next topic because they are interesting and then it can have some interesting and ingenious applications.

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So let us say let us start with the fact that 3 phases are available to us, lines a b and c these are available to us and let us make the following connection. And I have a single phase transformer which is the primary, I am going to take the primary and to the primary terminals let us make the connection the a phase connection here, the b phase connection here and the c phase connection is that the c line just goes goes out like that without getting connected to any part of the transformer.

(Refer Slide Time: 11:13)



Now let us take the midpoint of this transformer and take that out okay; of course now the polarities. There is a dot here, now the secondary of the transformer is the other phase that we take out. Or equivalently let us first let us first discuss with just this primary coil with respect to the dot so that we understand the various phasors.

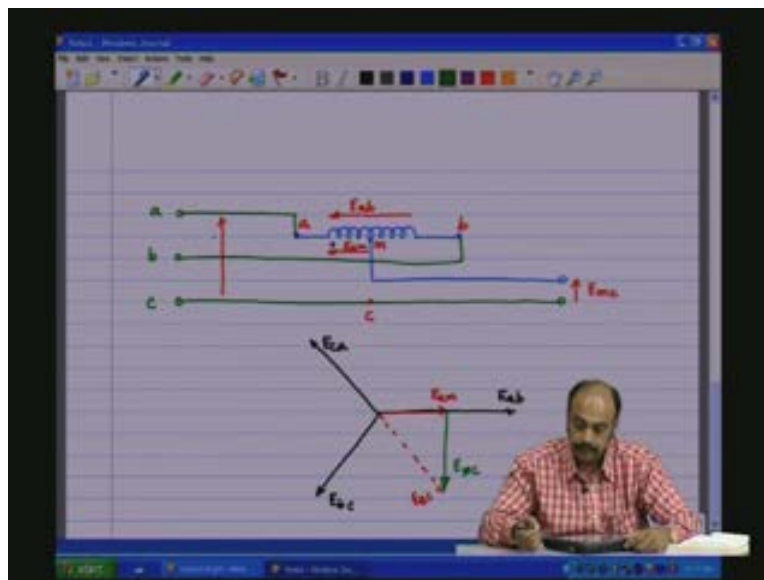
Now let us..... this of course is a, this is b, this is a and this is b and this point we will call it as m okay (Refer Slide Time: 12:35). Let me make a dot here and this is c. Now let us draw the vector diagram phasor diagram. Now we know that a b c's are as follows. So, if I am having E a b along this, E b c will be 120 degrees lagging E a b then you have E c a another 120 degrees lagging E b c or 240 degrees lagging E a b. this is Now what is the potential E a m? So this is E a b; now what is E a m?

As it is at the midpoint of the winding E a m will be half of E a b and this is E a m. Now what is the potential here?

Now this is E m c. E m c E m c is equal to E c E a c minus E a m will be E m c. Now E a c is actually the reverse of this so it is actually reverse of this which is E a c or minus E c a and this E a c minus E a m minus E a m will be will be so E a c minus E a m will be E m c. This E m c or E

a m plus E m c is going to be E a c okay as you look at the diagram. It is clear that Kirchhoff's voltage law and this loop.

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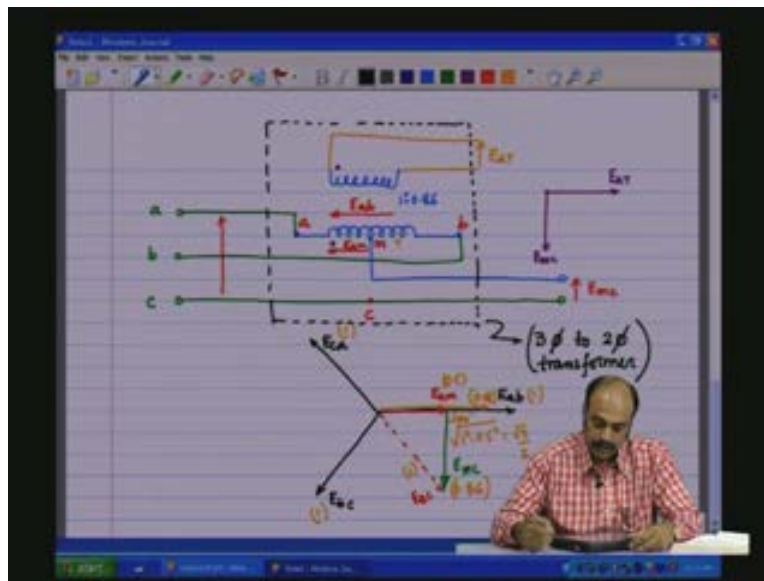
So if we see here E m c the value of E m c, now if we take that this is unit-wise if this is one unit, this is one unit vector, this is one unit phasor this will be 0.5 unit phasor, this is also 1 in amplitude so this is going to be square root of 1 square minus 0.5 square which is equal to root 3 by 2. So this would be 0.86 units.

Now see that E m c and E a b are 90 degrees with respect to each other, they are 90 degrees with respect to each other which means they are orthogonal with respect to each other. So, E m c and E a b together can form a two phase system if their amplitudes are equal.

Now E a b is having an amplitude of 1, E m c is having an amplitude of 0.86 so let us take tap from here where is the 0.86 with respect to the winding here and if we take E and let us say this is the tap point okay and this is E a T so our E a T will be 0.86 amplitude. So E a T and E m c will form an orthogonal set that is you will have E a T and we have here E m c. So, instead of using a tapped winding we could use the secondary of the single phase transformer with a

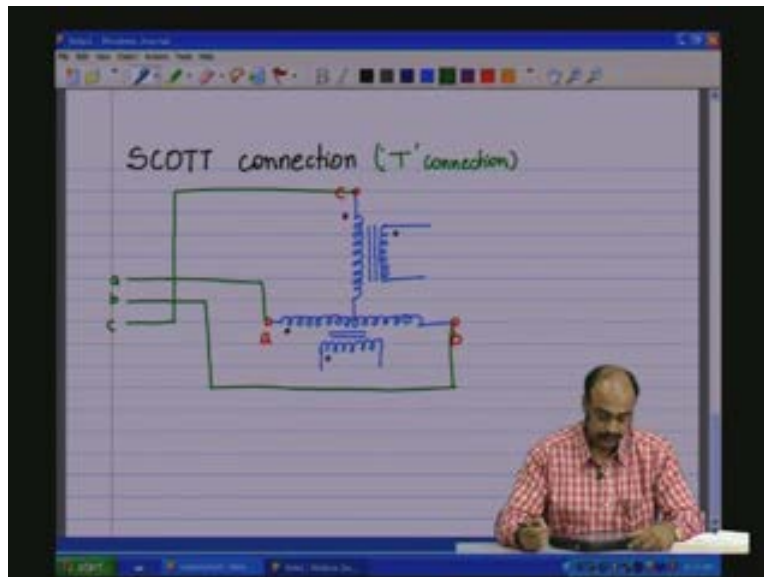
suitable turns ratio of 1 is to 0.86 then **one could then use** under such conditions one could use the second wave of the transformer with 1 is to 0.86 as the turns ratio then the dot polarity as shown here this will give E a T and E m c, this would be a 3 phase to two phase system. So this system what is being shown here is a 3 phase to two phase transformer.

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Now let us look at the second method which is the SCOTT connection. This also is similar. We have two transformers; let us say there is one transformer which is connected like that with its secondary like this then there is another transformer the primary is like that (Refer Slide Time: 21:10), the secondary is like that. So we have..... this point is a, this point is b, this point is c with the following dot polarities. We have the dot here and the dot here and dot here. We have a 3 phase system a b c where a is connected here, b is connected here and c is connected here. So this looks like a T therefore this is also called as T connection.

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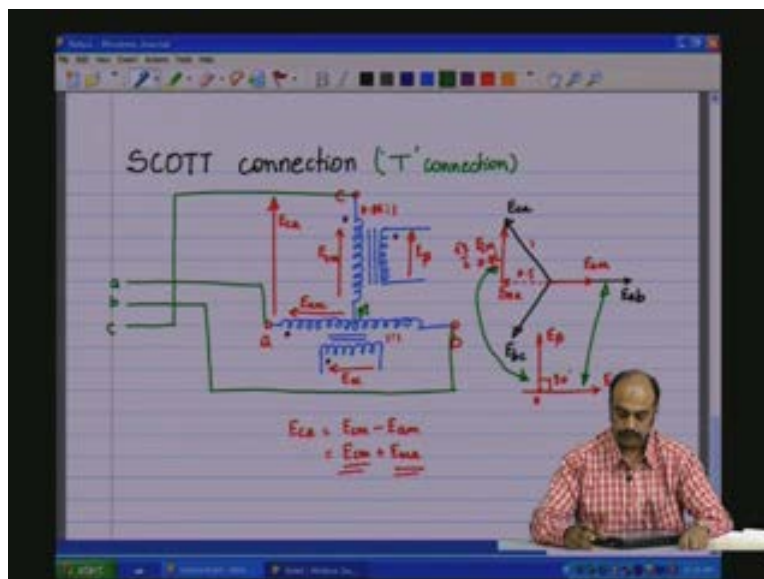


Now this is the center tap and we will call this as position m. Now if we tick the vector diagram E a b again..... so I have E a b, E b c this is E c a; this is what you get from the supply through the source. Now E a b, E a m are in phase because these are the same winding so E a m and it is at the midpoint and therefore we will say this is E a m. Then E c m; so what is E c m? E c m is E c a so this is E c a and this is E a m **that is E a m** and this is E c m. So this is E a m and this is E c a, this is E c m **this is E c m**.

Now **let us**..... E c m and E m a that is E m a is the reverse of this plus E c m should be is equal to E c a. Now E m a is nothing but minus of this, this is E m a and this is E c m. **are you getting it** E c a equals..... look at the Kirchhoff's voltage law along this marked things E c m minus E a m **look at the arrow direction** this is equal to E c m plus E m a. So these are the two vectors which are combined. E m a is nothing but negative of E a m just put in 180 direction then plus E c m should add up to E c a. now this is having unit 1, this is having unit 0.5 and therefore this has a unit amplitude of 0.86 or root 3 by 2. Or in other words, you can say that this angle is 30 therefore cos of 30 is 0.86 or root 3 by 2. So what you get here for E c m is 0.86 the amplitude of the.....

So if we have let us say a ratio of 0.86 is to 1 then this will get amplified and you will get here E you will get here let us say E beta and here you will get E alpha. So E alpha is nothing but E a b and we could have let us say 1 is to 1 turns ratio. Now this gets stepped up from 0.86 to 1 and you have E beta so we have E alpha along E a b and then we have E beta along this direction, this is the 0 and it is 90 degrees with respect to each other; they are orthogonal. See that E c m is E beta E c m is E beta, E a b is E alpha. So E a b and E c m are 90 degrees with respect to each other phase shifted and therefore they can form a two phase system; only thing is their amplitude is; E a b has a unit amplitude normalized amplitude of 1 and E c m has a normalized amplitude of 0.86 therefore by adjusting the turns ratio of this transformer the beta side transformer with a turns ratio of 0.86 to 1 one can equalize the two phase output. So this is another two phase transformer this is called the Scott connection.

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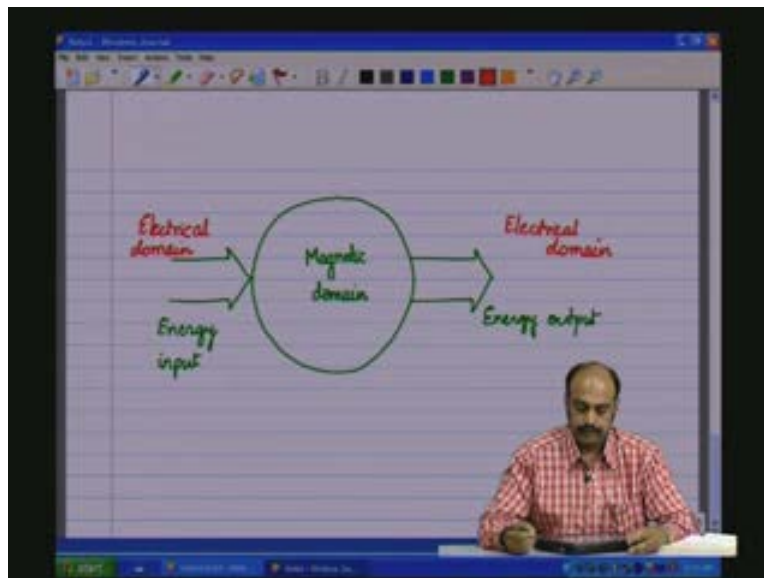


So till now we have been discussing about the 3 phase transformers and the various parameters in it and how they are related. But functionally they are very similar; in fact, exactly similar to the single phase transformer, it uses the same principle that is the Faraday's law of electromagnetism which is the induced voltage is equal to n times d phi by dt that is the flux which is there in the core, it is composed of three independent separate single phase transformers

connected in various topologies; these three single transformers are then combined into a single core.

The next transition from these 3 phase transformers would be into 3 phase machines and these 3 phase machines the induction machine or the induction motor is very very similar to 3 phase transformer except now the power or the energy is coming from the electrical domain and going into the mechanical domain, it also goes into the electrical domain like in a 3 phase transformer electrical domain to magnetic domain to electrical domain; in the induction motor you can have electrical domain to magnetic domain to electrical domain and also to mechanical domain. So we have a system a central **call drum** or the drum **which can** which we say is the magnetic domain. So, to this magnetic domain there is an energy input, so this is the energy input and in the case of the transformer there was an energy output, this is an energy output. So the transformer is a two port system: there is an input energy and output energy and this is in the electrical domain **this is in the electrical domain** and this also is in the electrical domain the output; now this would be the structure of a transformer.

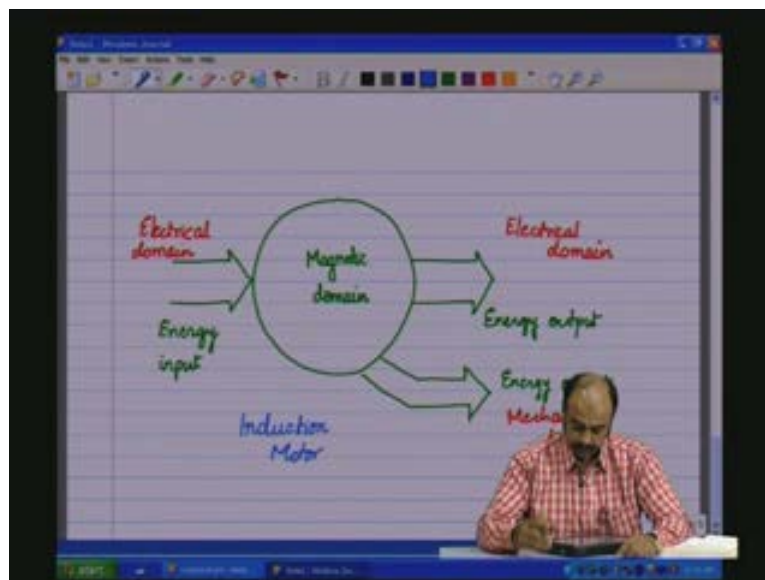
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Now if we had one more output; apart from the electrical output we have energy output in the mechanical domain **in the mechanical domain** so this is the basis for the induction motor. Induction motor is like a 3 phase transformer where it takes energy from the electrical domain and then puts it to the mechanical domain. There is also a class of induction motor where part of the energy can also go into the electrical domain like in a regular 3 phase transformer and part of it can go into the mechanical domain. So let us study the induction motor which is probably the most ubiquitous motor that you would find in in most of the applications all over the world something like 75 to 80 percent of the prime movers are induction motors. The everyday pumps that you use for pumping water from the sump to the overhead tank there the induction motors work on the induction principles. The motors that are used for the cranes induction motors, the motors that are used for the fans, the blowers they are all induction motors.

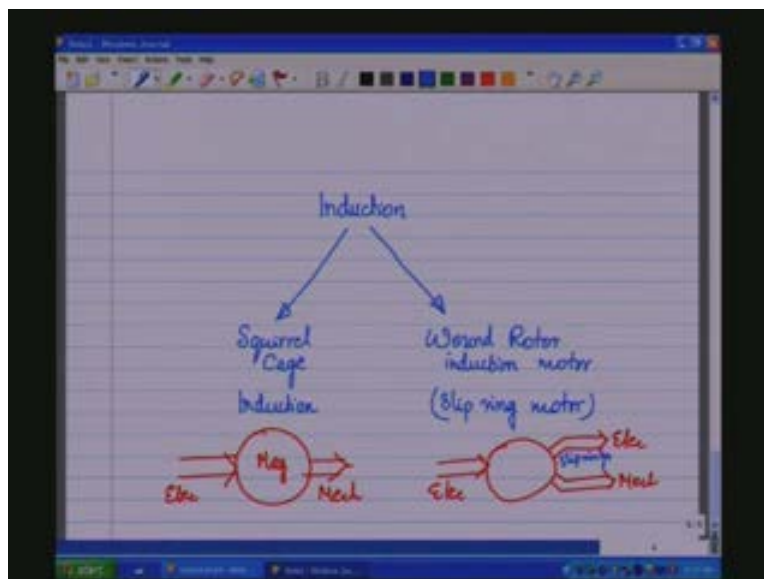
Today the induction motors are also used for precision mechanics, spindle drives and speed controlled drives and also in feed drives which require very grade precision they are all induction motors. So majority of the prime movers that you see are induction motors.

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So it is essential that we know something about this very popular motor which is used in the industry and everyday applications. Now, induction motors come in two varieties two major varieties: one is called the squirrel cage induction motor the other is called the **wound rotor** induction motor or slip ring motor. So, as the name suggests here, in this case the energy enters from the electric domain and goes to the mechanical domain and in this case there is a possibility for the energy entering from the electrical domain to be tapped either to the electrical domain or through the mechanical domain. So, by means of slip rings that we discussed while we were discussing the DC generator the principle is precisely the same.

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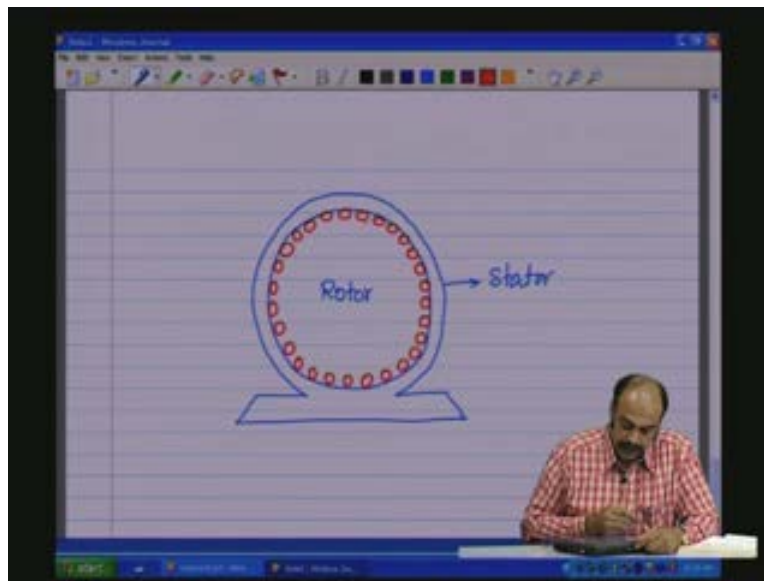
So what makes the induction motor move?

Before we look at the structure we should understand the basic principles of the motion of the induction motor. You see that the induction motor is composed of the shaft which is the rotating part of the induction motor and that is called the rotor and then there is another part which is fixed in stationery which is fixed and stationery and that is called the stator.

Now the rotor has on it the conductors; all around the circumference of the rotor you have conductors. The conductors in the case of the squirrel cage induction motor are shorted at both

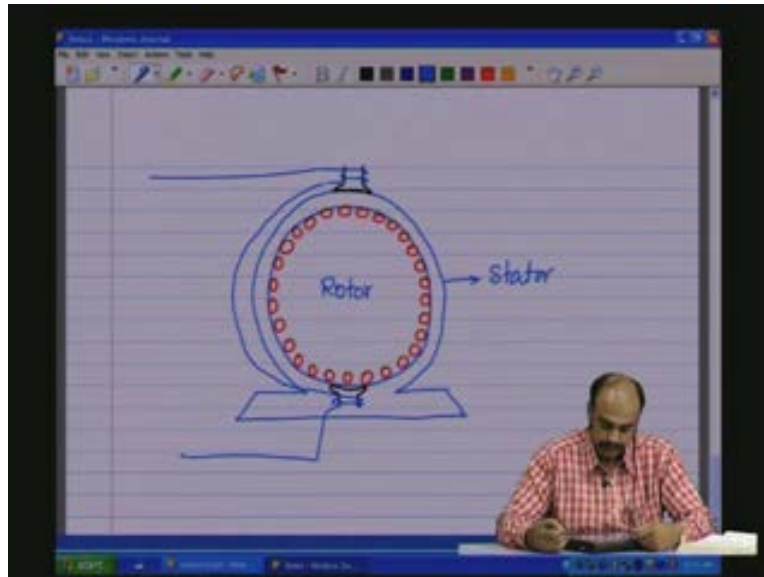
ends such that the rotor look like a squirrel cage so that is why the name the squirrel cage induction motor. And in the case of wound rotor these rotor coils are brought out through slip rings and brushes like in the case of the DC machine. But through slip rings not commutator **mind you so** which means the current in the external electric circuit is also AC.

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So we have these rotor conductors and then on the stator also we have coils but the coils are positioned in a manner which will provide **field** spatial field in the spatial coordinates. So let us see how that is provided and that is basically done by having some coils here let us say. So let us say we have **we have** some construction here and you can have a coil here and this coil goes around and connects to this pole and comes out. So like that there are many poles around which the stator coils are wound and we have the field which is getting generated.

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Now let us look at a segment **let us look at a segment** of this induction motor here. So you see that we have..... let us have some conductors of the rotor these are conductors of the rotor and of course these conductors go back this way (Refer Slide Time: 41:06) and so on. So we have the conductors which are mounted on the rotor in this fashion and let us say there is current through the rotors. That is we have current flowing through the rotors and also let us say that there is a field of density B .

So we have a field flux of density B and there is a motion, that is **this road** these conductors are rotating and these conductors have a length ℓ . So, if you recall the Lorentz force we have the field B then we have we have a current I which is flowing through the conductors there is a current I which is flowing through the conductors and this is going to provide a force and that force is $BI\ell$ $BI\ell$ this is called the Lorentz force.

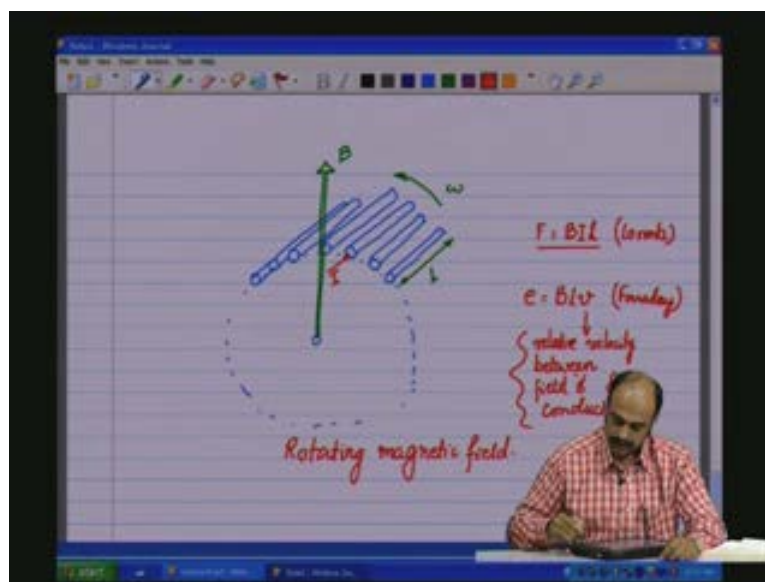
Now what causes the current in the conductors and that is by the Faraday's law. See that there is a force; by Faraday's law there is a voltage e induced and that is given by $B\ell v$ where v is the velocity of the conductors, velocity with which the conductor moves relative to this field or the relative velocity we will call it the relative velocity between the field that is B **and conductors**

and the conductors. So there are two ways in which to bring about the relative velocity and keep the field fixed as we did in the case of the DC machine and the conductors were moved. Or you can make the field rotate and the conductors also moves and tries to catch up with the field. So you have these two effects which come into play in the case of the induction machine.

So first of all how do we make the conductors rotate or how do we create this relative velocity because that is what is going to induce a voltage and the rotor conductors and that is going to create I and therefore $BI\ell$; there will be a torque on the conductor which will make it move. So this would be the Lorentz force and this is the Faraday law. So the main question is how do we bring about this relative speed between the vertical the B the green B phasor or the B field and the conductors which are orthogonal to each other or how do we make the B cut the conductors.

So in the case the induction machine because we have a 3 phase system it is possible to generate a B phasor which is rotating in space; it rotates in space and that is called the rotating magnetic field **rotating magnetic field**.

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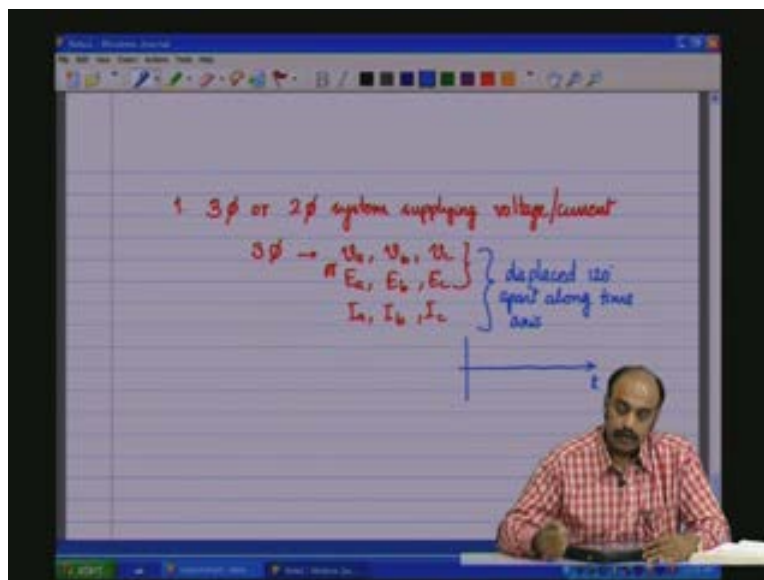


So how do we generate this rotating magnetic field?

The rotating magnetic field is generated by a combination of constraints that are applied. One is we need to have let us say a 3 phase or two phase system supplying the voltage or current.

Now let us take for example for now just a 3 phase system. So, in the case of a 3 phase system we have V_a, V_b, V_c or we will say E_a, E_b, E_c and then you have I_a, I_b and I_c these are the three this is the not this is the three line voltages and the line currents. Now all are having the same magnitude and displace 120 degrees apart and this displacement 120 degrees apart is in the time axis. Now these are displaced 120 degrees apart along time axis which means the displacement between I_a, I_b, I_c 120 degrees apart is along the time axis which when we talk of as phasors in the spatial coordinates it reflects as 120 degrees three phasors.

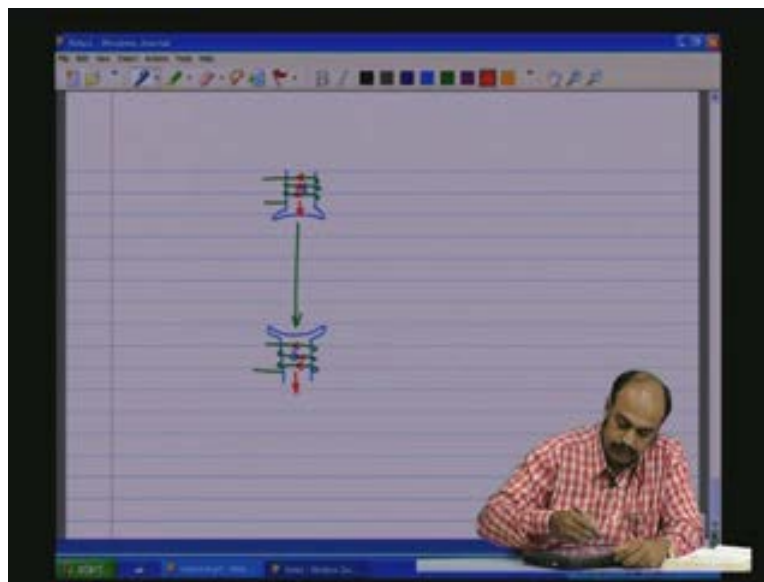
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Now let us make one more condition the second condition. There should be three field coils on the machine there should be three field coils on the machine which are placed 120 degrees apart in space so this is the second condition that is needed to generate a rotating magnetic field. Let us see how it comes about.

So let us say we have **let us say we have a we have** a pole which is like that and the other end of the pole which is like that. Now let us say if this is the North Pole and this is the South Pole we are having a field direction which is like that north to south. So this means that we have some windings on this and let the current flow in this direction which will give a field in this direction and we should have also a coil wound here with the current which flows in this direction such that we have the field. So these two will aid and we have a field in this direction.

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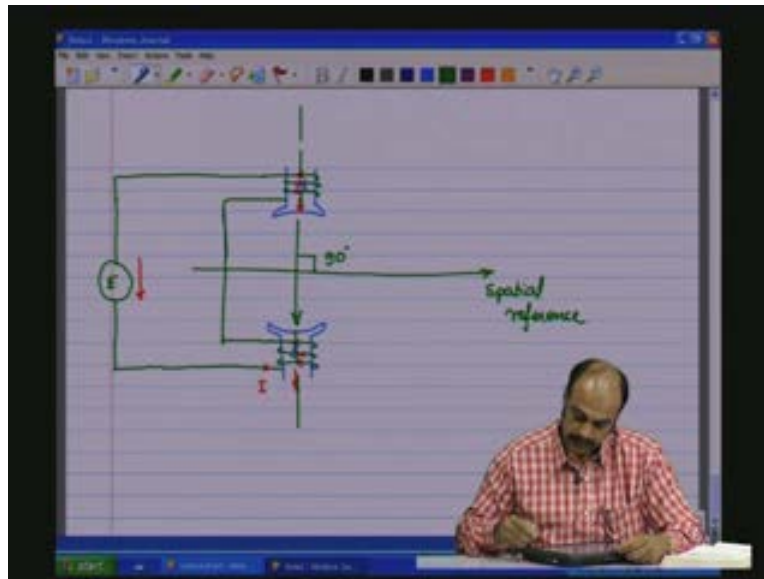


Now we want to have the same current to flow through both that is a current let us say I which flows through this coil and let us link this coil to this and this is brought out and then given to a source **to a source**. So now this source this is an inductive reactance because of the coil and this is going to **and this is going to** pump a current in this direction as shown (Refer Slide Time: 53:25) as it comes in this fashion **sorry slight error in the connection here**..... so the current flows in this direction, goes, then gets connected here, goes through the coil in this direction and then it comes out here.

So we have now a field **this side**. Now this pole is physically located in space and let us say this is the plane **this is the plane** through the reference axis, let us say this is the spatial reference.

Then we say that this pole with an axis like that is 90 degrees located 90 degrees with respect to the reference.

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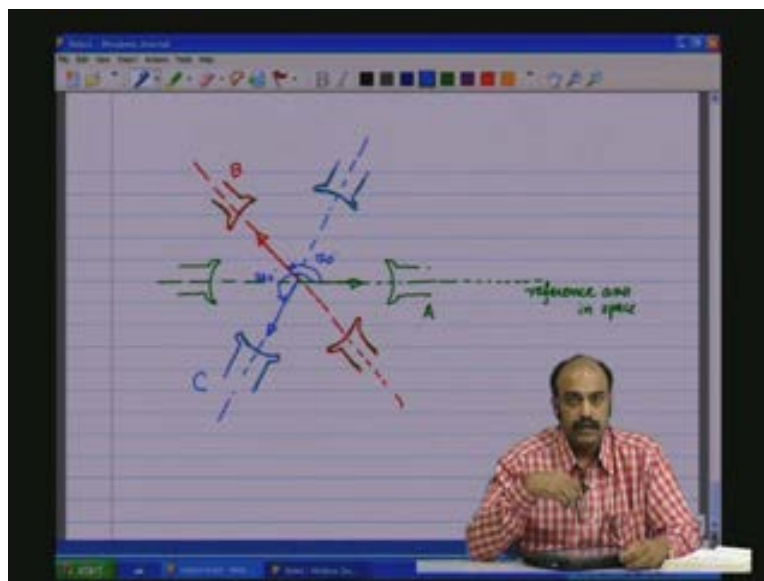
Likewise, let us say similarly I have a pole which is located in the following fashion. So let me have one pole which is one set of pole which is located like that as shown here so let me call this as one axis, let us say this is the horizontal axis **this is**, this pole set is at zero degrees with respect to the reference axis. So this is the reference axis in space **okay** this is spatial. Then let us have **another** another pole set which is 120 degrees displaced **displaced** with respect to..... so let me have one more set of pole which is like that and one more which is 120 degrees displaced which is of this nature. So we are going to say that these two are one pole sets, this is one pole set and this is another pole set (Refer Slide Time: 56:57). So this pole set is fixed in space this is not rotating this is fixed in space with respect to the other. So let us say that this green one is the A pole set, the red one is the B pole set and the blue one is the C pole set.

So, if you see **the if I** if I mark **the** a polarity in terms of dot or the north let us say these are the marks this is the north and this is the north then we have **sorry** some dot polarities let us say it could be any similar phase but this is the positive side and we have for the A and then we have

for the B so the A pole set axis is going to have the flux in this direction alone always there is no other movement, **the B pole axis** sorry the C pole axis is going to cause a field only along this axis and amplitudes here can vary depending upon the currents that are going to be passed through the C coil and the B pole axis will have the field only in this direction and the currents through the B axis B poles are going to modulate the amplitude of the flux here.

Now, by fixing these poles in space, fixed; now these are 120 degrees with respect to each other this is 120 degrees and this is 240 degrees now they are 120 degrees with respect to each other in space they are fixed firmly and then the flux density in each of these axis are going to swing only in those axis and they can be modulated only along those axis by controlling the currents through that axis.

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Now if we apply let us say the A phase current through the **A ac A pole** A pole set, the B phase current to the B pole set, C pole current to the C pole set then you will see that the resultant flux density will rotate with the frequency at which the currents are provided for the **pole axis** pole coils. so we will see how we generate this rotating flux with the means of the 3 phase currents I_a, I_b, I_c passed through these stationary pole axis as shown here to generate a rotating flux.

We shall discuss this further in the next class, thank you.