Fundamentals of Electrical Engineering
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Lecture - 59
Three phase Induction Motors (Contd.)

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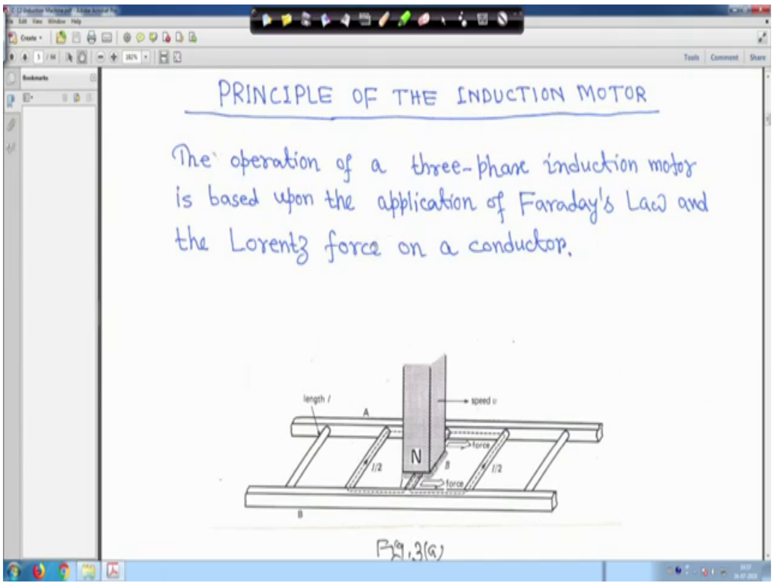

So, now principle of Induction Motor right so, the operation of three phase induction motor is based up on application of Faraday's Law and the Lorentz force on a conductor right.

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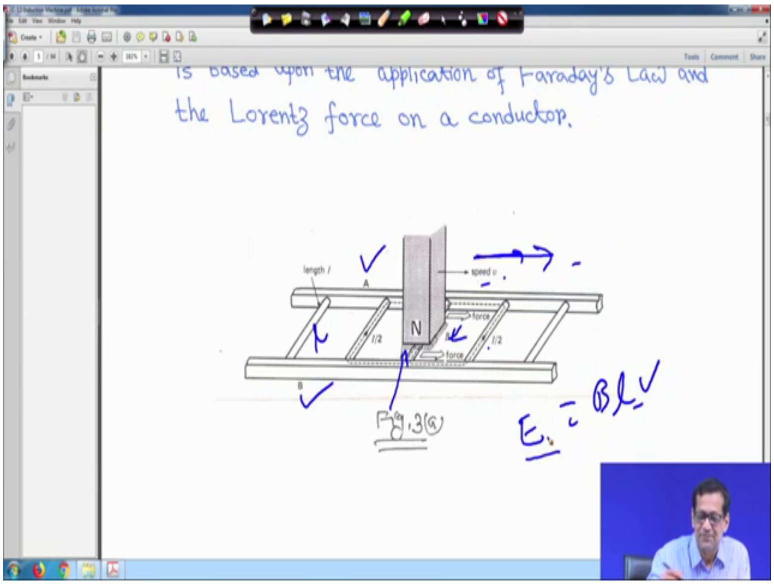

So, suppose you have a this is this is your this is your conductor having length l right and you have made a ladder and both sides so two bars are connected right. So, in that case all the materials are conducting. Now, the suppose a permanent magnet is placed on the top of this conductor. So, now, if you now this is A, this is B this is that conductor length is l and this actually flux density this is B flux density.

The if you drag the conductor right a sorry drag this magnet to the right hand side with a speed B say then flux will cut. Therefore, what will happen because of that a voltage E is equal to B into this the flux density B. So, a voltage E is equal to B into l into V will induce right. So, in the in that case what will happen that because of that the current will flow this is the current I and immediately that half of the current will flow through this half of the current will flow this conduct[or] you are what will call conducting your through this conductor right.

So, in that case as assuming that you are holding this ladder you are not allowing it to move, but if you make it free then what will happen? That that ladder also will move and the direction of the your what you call in the direction of the magnet as magnet is moving you are moving the magnet to the right hand side and keep a very little gap between this between this conductor and the magnet. So, in that case that ladder also moves there so, there will be a relative speed between that magnet and the ladder.

So, finally, that voltage E also will reduce and the current also will reduce or diminished right. So, from this only from this concept only the principle of induction machine has come that how it rotates because, it is a self starting so we will come to that right. So, in this case this diagram I have taken from a book right.

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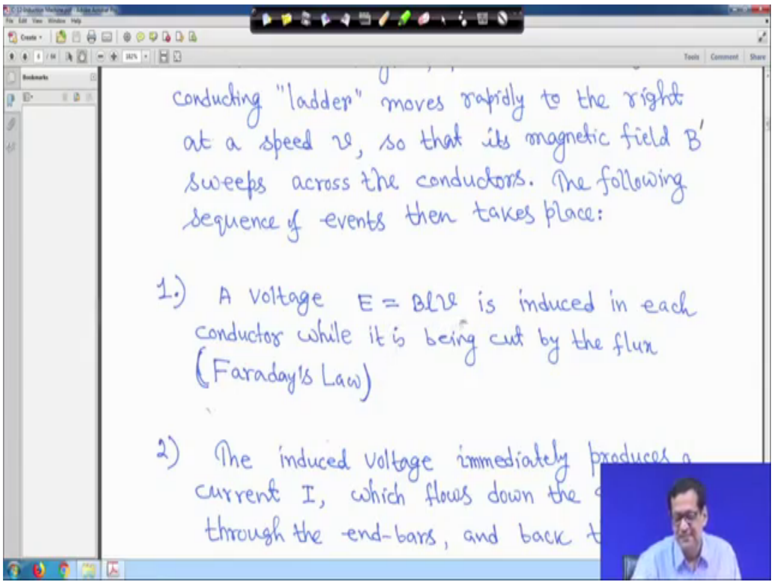

So, in this case the 4 things will happen a voltage E is equal to B l V is induced in its conductor while it is being cut by the flux so this is Faraday's law.

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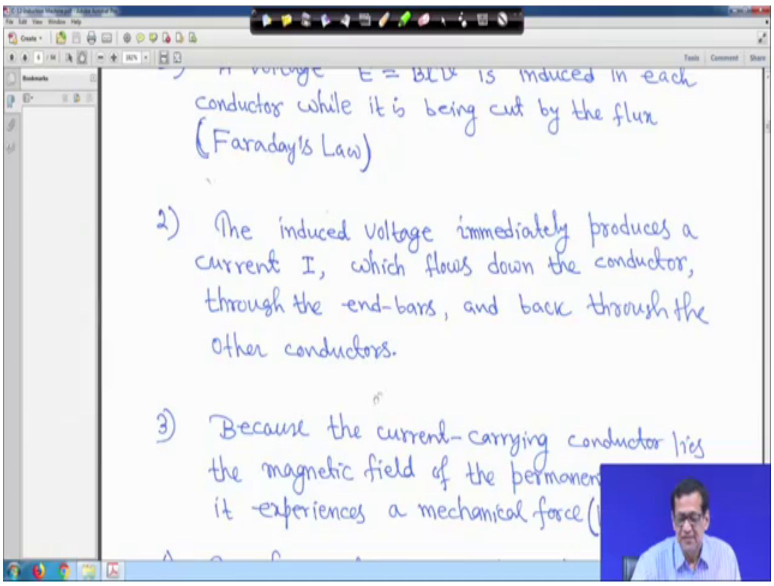

Now, the induced voltage immediately produces a current I which flows down the conductor through the end bar and back through the other conductors. So I told you current I and I by 2, I by 2 on both side right.

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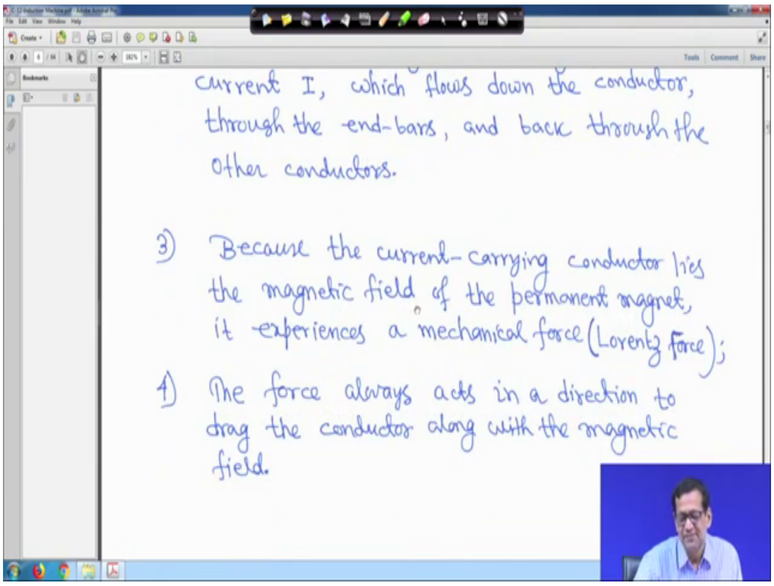

And because the current carrying conductor lies in the magnetic field of the permanent magnet it experiences a mechanical force that is called Lorentz force. And the force always act in a direction to drag the conductor you are along with the magnetic field.

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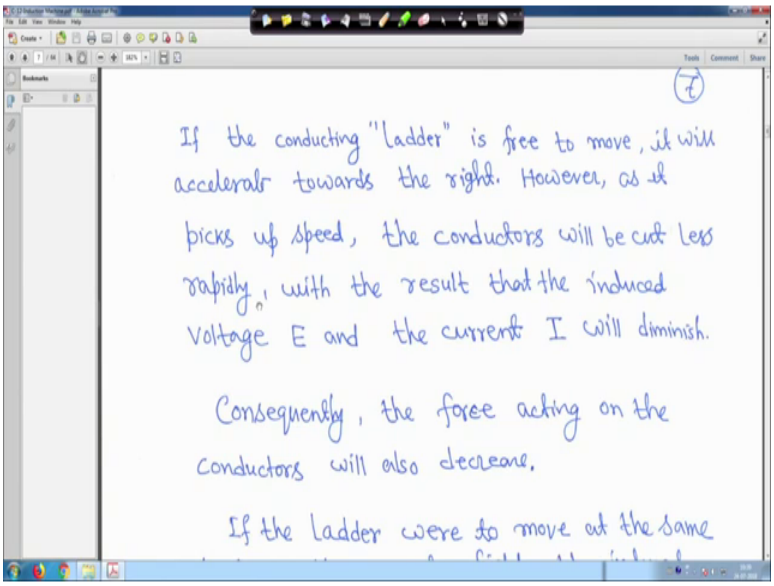

Now, if the conducting ladder is free to move now you are allowing to move they need to accelerate towards the right. However, as it picks up speed the you are conductor will cut less rapidly because relative speed will go down right with the result that the induced voltage E and current I will diminish.

Consequently the force acting on the conductor will also decrease right. So, if the ladder were to move at the same speed at the magnetic field the induced voltage E, the current I, and the force would all be 0 because relative speed will be 0 right.

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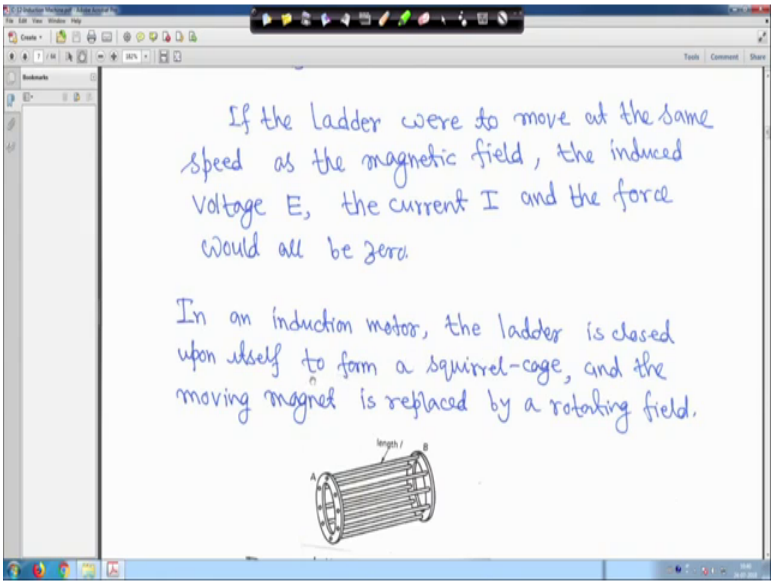

So, therefore, in an induction motor the ladder is enclose upon itself to form a squirrel cage. If you just hold it right so it looks like a ladder will look like a you are what you call the squirrel cage right. And the moving magnet is replaced by rotating field. So, there in this diagram in this diagram for the purpose of explanation we have taken a moving magnet. But in the you are what you call in the interaction machine it will be 3 phased magnetic field the rotating magnetic field.

And if you enclose this ladder it will look like a squirrel cage that is why these example is this diagram is taken. So, in this case you are what you call that it looks like your in an induction motor the ladder is enclosed upon itself to form a squirrel cage and the moving magnet is replaced by a rotating magnetic field right.

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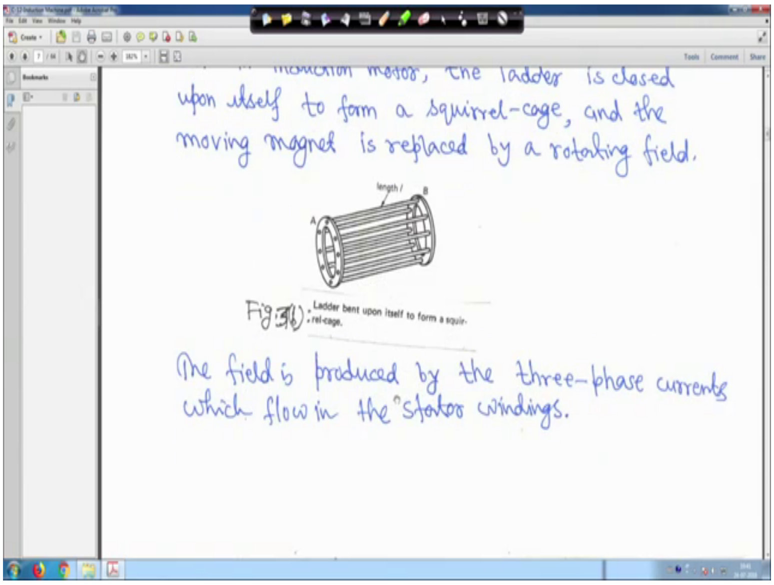

So, the field actually is produced by the 3 phase current which flow in the stator windings.

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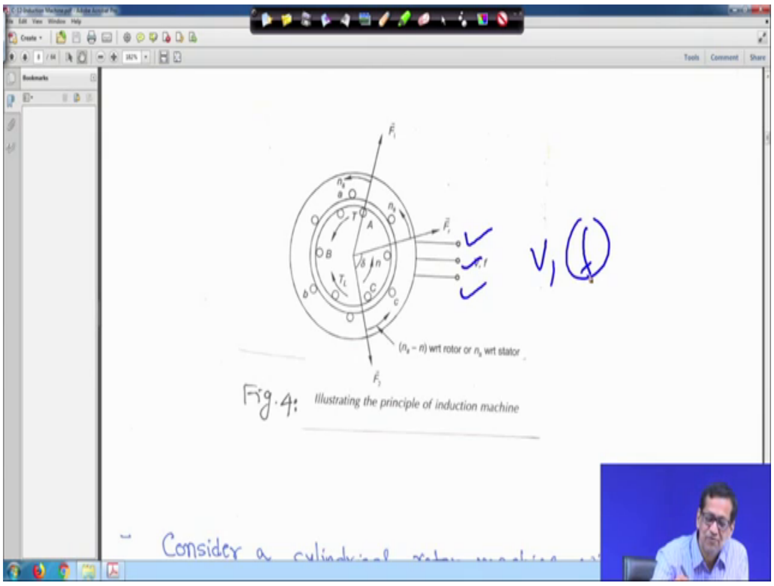

So, now, this is a schematic diagram this figure I am taken from a book right. So, this your what you call this part this or this your external circle, this part, actually this part this part, this part, external one this is actually stator, stator part right. So, and the and that other part this part which I making here this is actually say your rotor part right. And in between stator and rotor the small gap is there I told you this is that air gap right, this small gap this is the air gap right.

Uniformly it is uniform so I told you depending on the rating of the machine it may be 0.424 millimetre right or may vary also after the rating of the machine. So now this is your A, B and C this is actually 3 phases are there A B C 3 phase's right, 3 phases are there so it is schematically it is shown. Similarly, inside the rotor also you can see something this is actually direct T, T L, T L you need not bother now because we will see the basic thing only. And these are your what you call, these are your what you call the 3 phase terminals, the way you have seen 3 phase; A B C there also 3 phase terminals same thing.

And it is connected to a bars were called infinite bars where voltage and frequency is constant. So, what is infinite bars? Right now you need not bother. You assume it is connected to the 3 phase supply or voltage and frequency will remain constant right. So, now question is and your what you call at the speed n actually this is the speed of the rotor. And n is that speed of the your what you call that your rotating field. Now, 3 phase single phased circuit while we are studying, we were trying to find out some speed ns right; that is considering pair of 3 poles right.

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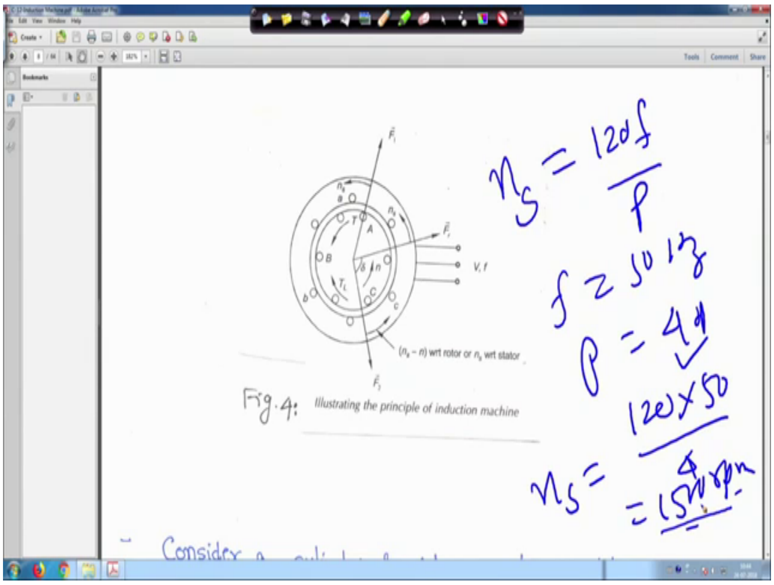

But, in this case we will take that one formula is there that synchronous speed is equal 120 f by P P is number of poles. For example, if f is equal to frequency is 50 hertz and P is equal to say 4 pole machine, that P is equal to 4 no question of pair only poles. So, ns is equal to your 120 into 50 divided by 4 right. So, it will be 1,500 RMP right see if induction machine is of your what you call that your generally you will find it will be your P, P or 3 pole 4 pole machines. So, in that case its speed will be later will see if it acts as a motor it is speed will be less than your 1,500 RMP right.

And if it is answers generator it will be just above 1,500 RMP we will not discuss about induction generator only little about motor right. And generally we will find it is a 4 pole machine, but the magnetic field; but the magnetic field at 3 phase magnetic field it is rotate at the synchronous speed ns that is safety pin 100 RMP for example. And this n is there this is the speed of the rotor which will be less than the your synchronous speed ns right. So now how now whatever this thing it is here so what will happen?

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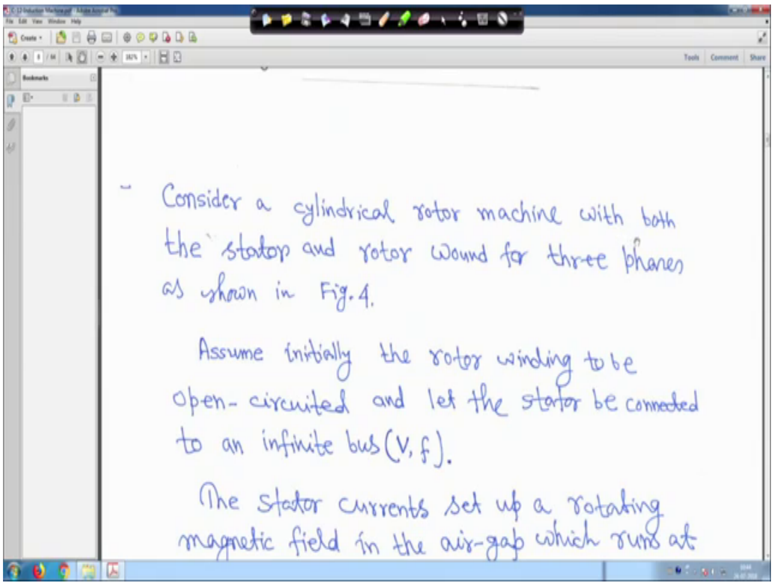

So, consider a cylindrical rotor machine with both the stator and rotor wound for 3 phase as shown in figure right. This, this upper part is a stator and inside circle is rotor and between is that air gap is there. Now, assume initially the rotor winding to open circuited and let the stator be connected to an infinite bar; that means, you assume the rotor is open circuited it is not short circuited. First for our understanding you assume the rotor is open circuited and it and stator it is connected to a supply where voltage and frequency both are constant right.

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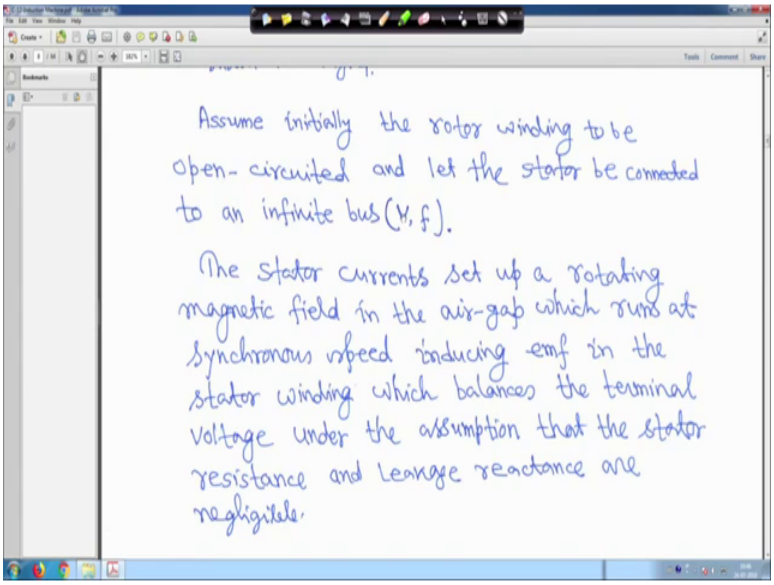

The stator current set up a rotating magnetic field in the air gap right. Which runs at synchronous speed inducing emf in the stator winding which balances the terminal voltage under the assumption that the stator resistance and leakage reactance are negligible. Now, as soon as you supply the your you when you are connecting the stator terminal to a voltage you are supply voltage right. So, naturally that voltage will also induce in your what you call in the stator winding.

And it creates a rotating magnetic field which rotate at a synchronous speed your what you call ns right. So, this F1 is given actually stator mmf or that F1 right. So, arbitrarily it is taken right, but this magnetic field rotating at a synchronous speed ns actually electrical engineering many things are not visible right. Like your magnetic field you can feel it, but you cannot visualise voltage current you can see the wave form other things you, but you can feel it, but you cannot see in your open eyes only you can see that wave form right.

So, a flux also it is not visible quantity, only you feel it right. So, similarly here your what you call already we were see their wave form the pattern, but eyes you cannot see that how is it right. So, so in that case the stator current set up a rotating magnetic field in the air gap which runs at synchronous speed inducing emf in the stator winding that is your F1 I showed you. Which balances the terminal voltage under the assumption that the stator resistance and leakage reactance’s are negligible right?

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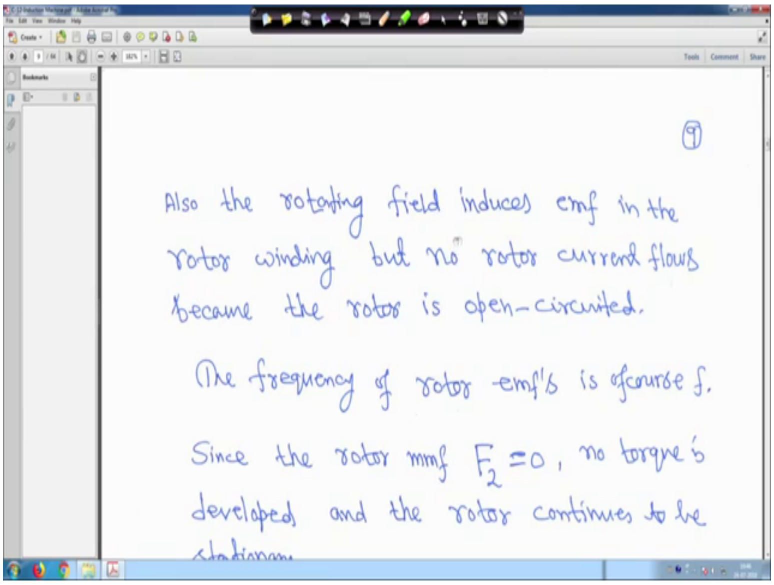

Now, also that rotor your rotating field induces emf in the rotor winding because rotor is also there. So, field is rotating so it will also induce your what you call emf in the rotor winding, but no rotor current can flow because we are assume the rotor is open circuited right. So, the frequency of the rotor emf of course, f because rotor is not rotating so frequency of the rotor emf is also f right.

Since the rotor mmf F 2 0 because rotor is open circuited so no current is showing. So, rotor mmf at this stage F2 is equal to 0; that means, this diagram that is arbitrary it is made it at F2 is equal to 0 right. So, in this case your there no torque developed and the rotor continues to be stationary so, rotor is not moving it is stationary.

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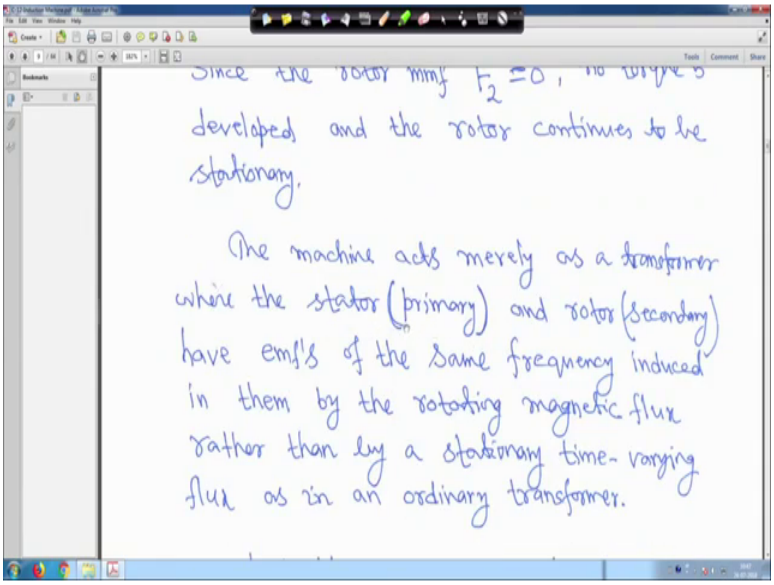

Now, the machine you acts merely as a transformer where the stator we calls a primary right transformer and the rotor the secondary have emf of the same frequency induced in them by the rotating magnetic flux, rather than by stationary time varying flux as in a ordinary transformer. Transformer we have seen suppose pi is equal to pi max your sine omega T right. So, but here it is a that was a stationary time varying flux as in ordinary transformer.

But, here it is a rotating your what you call magnetic flux because you are giving 3 phase supply to the stator winding. Now, let the rotor be now held stationery that is blocked from rotation. Now, rotor is not open circuit its short circuited, but you are not allow the rotor to rotate say you imagine and on the rotor winding be short circuited right.

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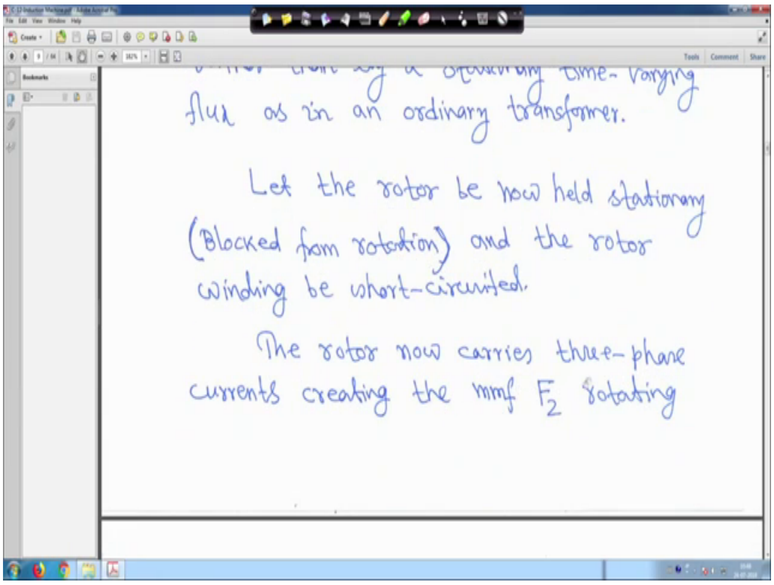

In this case the rotor now carries 3 phase currents creating the mmf F2 rotating in the same direction and with the same speed as the stator field. Now, if here it is in the diagram this is my F2, but we are not allowing the rotor to rotate here it is given ns minus n with respect to rotor or ns with respect to stator. So, when rotor is you are not allowing the rotor to rotate so it actually this F2 actually this ns actually what will happen that is the speed of this mmf right.

It will be just ns with respect to stator because, we are not allowing the rotor to rotate, but as soon as you allow the rotor to rotate within it will be ns minus n because relative speed with respect to rotor right. So, in this case let the rotor be now held stationary and the rotor winding is short circuited. So, naturally if the current will flow therefore, mmf will be there in the rotor right.

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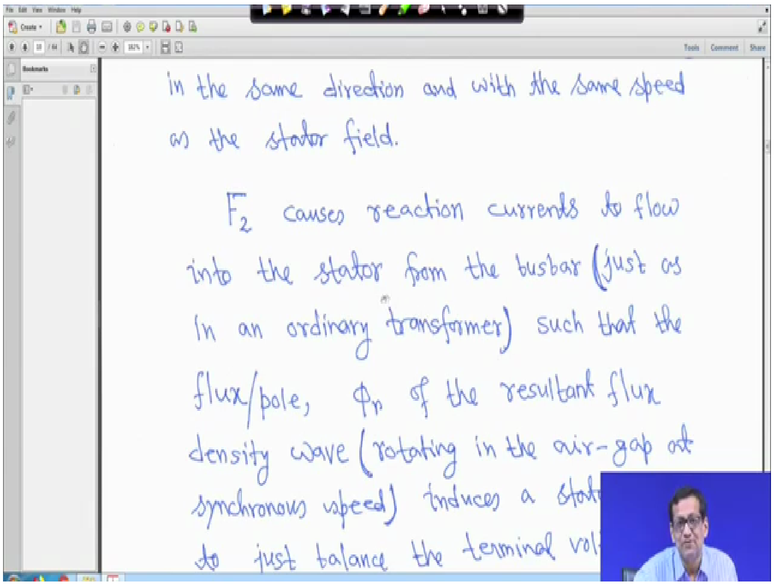

So, but with the same speed as the as a stator field because rotor is we are not allowing the rotor to rotate. Now, F2 causes like your transformer F2 causes reaction currents to flow into the stator from the busbar bracket whatever written just look into this. Such that the flux per pole that is phi r of the resultant flux density wave induces a stator emf to just balance the terminal voltage this is same as your philosophy is to some extent will be like transformer right.

So, F2 causes a reaction currents to flow into the stator from the busbar such that the flux per pole that is a phi r of the resulting flux density wave induces a stator emf to just balance the terminal voltage because now current is flowing through the rotor. Now obviously, phi r must be the same as when the rotor was open circuited right even when the machine is loaded also this phi r will remain more or is constant right.

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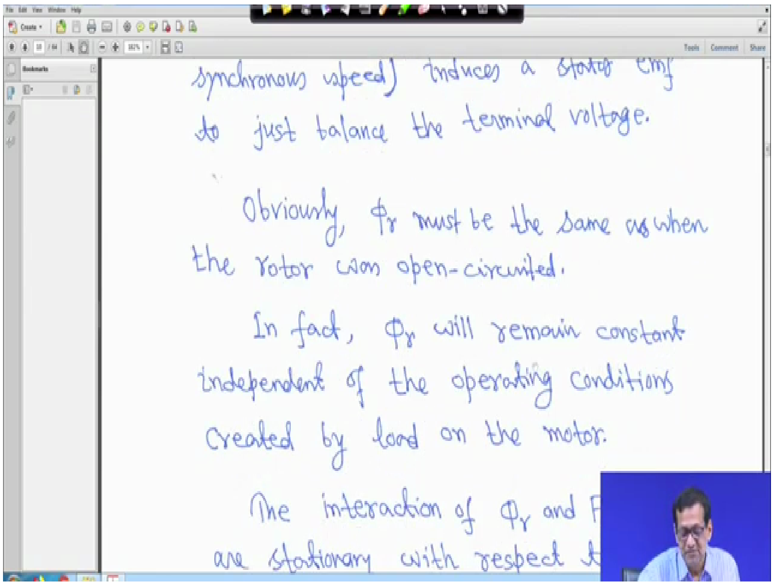

In fact, phi r will remain constant independent of the operating condition created by the load on the motor.

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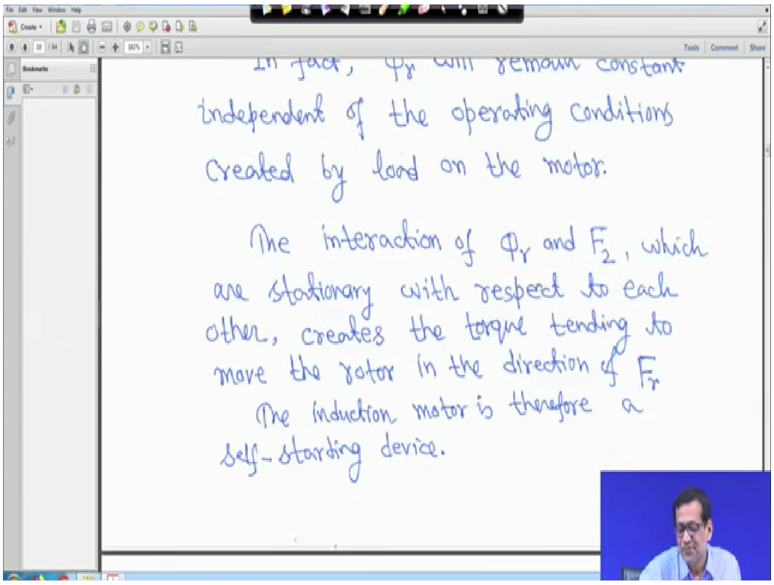

Now, the interaction of phi r and F2 that is the resultant flux phi r and F2; which are stationary with respect to each other right. Creates the torque tending to move the rotor in the direction of Fr. The induction motor is therefore, a self starting device right.

So, this interaction between phi r and F2 right which are stationary is respect each other creates the torque and tending to move the rotor in the direction of Fr. So, this is that your diagram this is your that resultant flux phi r and F2 will interact with each other and this will be the your what you call the direction of this area or direction will be your what you call this resultant will be Fr right.

So, this way if you look into this the this one right so, this phi r F2 which is with respect each other creates the torque tending to move the rotor in the direction of Fr the if that induction motor is therefore, a self starting device right.

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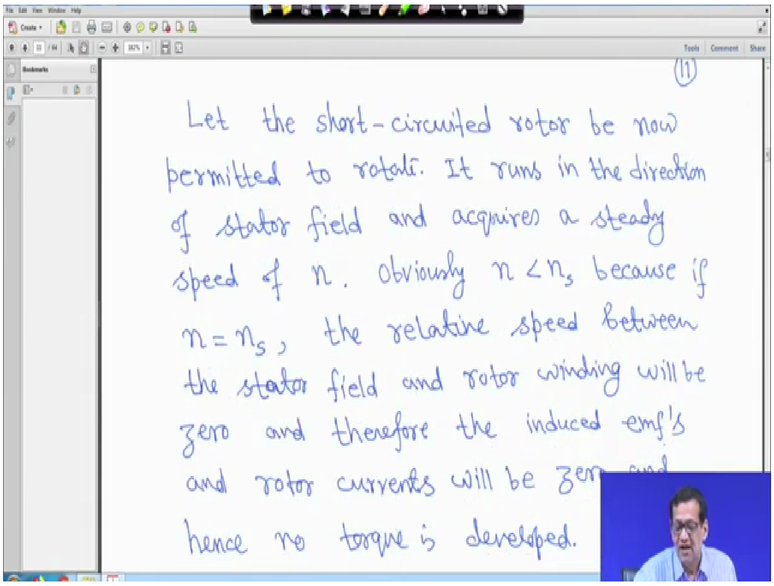

So, let the short circuit rotor be now permitted to rotate now you make it to free such that rotor will rotate. Now, if it rotate it runs in the direction of the stator field and acquire a steady state speed of n right. So, it will rotate in the direction of your what you call that your machine Fr right with that ns that same your synchronous speed. But now the rotor is rotating that a rotor will rotating in the direction of the your what you call same direction or the magnetic field. So, naturally what will happen this as rotor is rotating with speed n which is less than ns right which is less than ns.

So that means, rotor will rotate in the in that what you call in the same direction of the your, what to call that your rotating magnetic field. But it will never catch ns, if it catches ns then n relative speed will become 0 then right. So, in this case it runs in the stator field that acquires a steady speed of n; obviously, n less than ns. Because if n is equal to ns the relative speed between the stator field and rotor winding will be 0 right. And therefore, the induced emf and rotor currents will be 0 and hence no torque is developed right.

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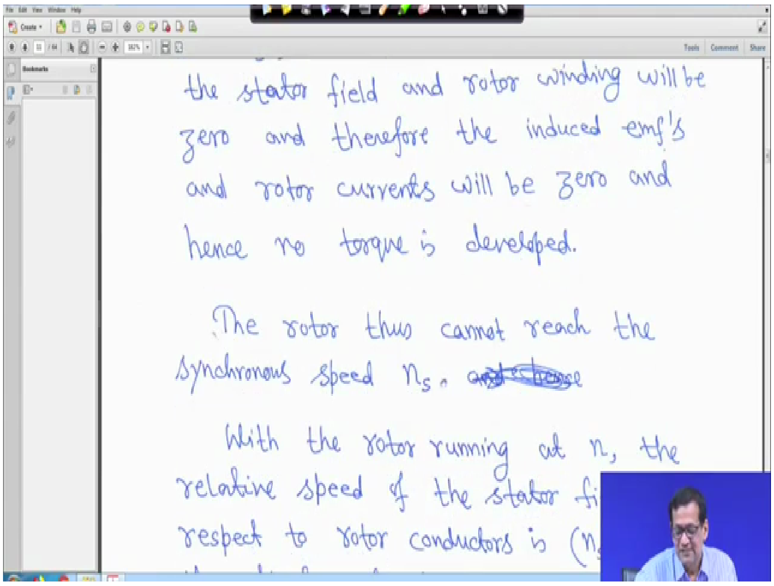

Therefore, the rotor thus cannot reach the synchronous speed ns it will slip actually it will be for induction motor it that n should be less than ns, with the rotor running at n the relative speed of the stator field with respect to the rotor conductor is ns minus n right. Because, both are moving in the same direction in the direction of the ns, the frequency of induced emf and current in the rotor is therefore, it will be ns minus n is equal to 120 f2 by P.

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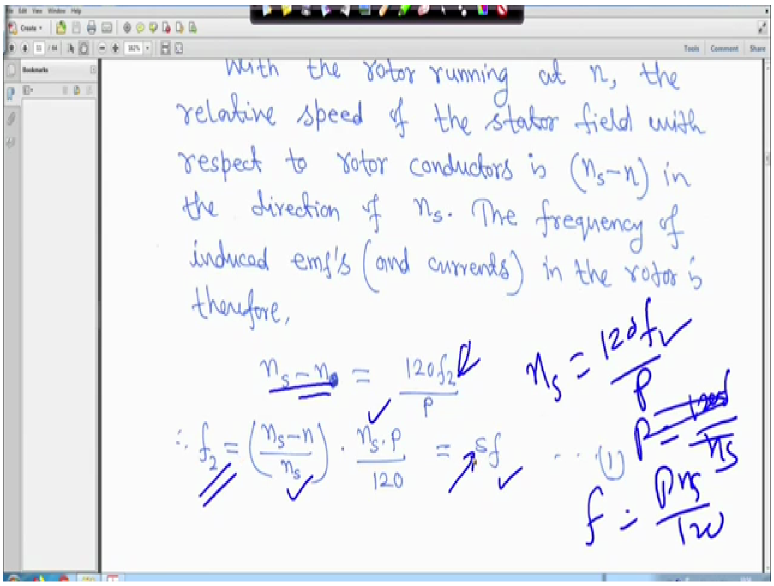

That is your f2 is equal to actually, this f2 is equal to actually it is rotor your frequency. And this is your ns minus n is your is the what you have to call that the relative speed and ns minus n 120 f2 upon P. Now, f2 is equal to can be written as you write f2 is equal to P into ns minus n upon 20 then numerator and denominator numerator and denominator you multiply by ns numerator and denominator right. And this part ns minus n upon ns this part we define as your s that is the that is you call slip right. And your and this one this part is f because ns is equal to 120 I showed you earlier 120 f by P.

Therefore, your P is your what you call P is equal to your this thing 120 f by your ns right. So, this one you can write is that is this is your what you call n ns into P upon 120. So, this is your this part is s and this part is your what you call f, f is equal to P ns rather than this one you write f is equal to P ns divided by 120 from this equation f is equal to. So, this s into f though rotor your frequency f2 is equal to s into f when rotor is moving with a slip s and s is equal to your ns minus n upon s right.

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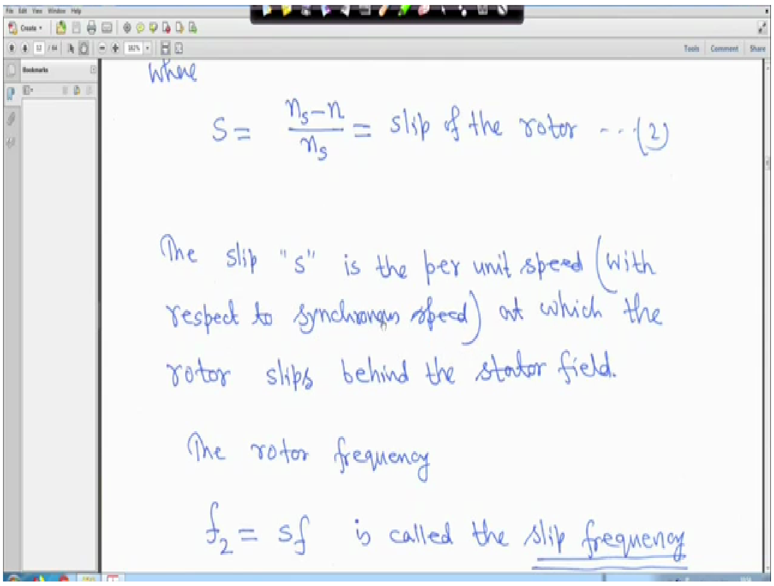

So, it is called slip of the rotor right the slip s is the per unit speed this is dimension less quantity with respect to synchronous speed at which the rotor slips behind the stator field right. So, ns minus n is the difference of the speed divided by ns it is a dimension less quantity so that is why we call the slip s right. The rotor frequency f2 is equal to sf is called the slip frequency.

But, when machine is stand still at that time s is equal to 1, because at that time n is equal to 0, rotor is not moving n is equal to 0. So, at that time your what you call s will be one at stands still. So, from equation 2 easily you can write n is equal to 1 minus s into n s so this is equation 3.

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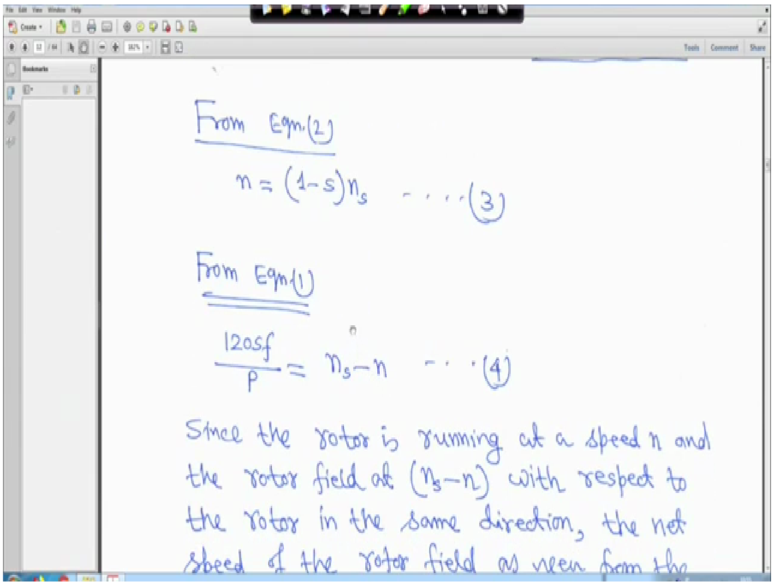

From equation 1 you can also write that 120 s into f upon P is f 2 is equal to sf right. So, that is why 120 sf upon P is equal to ns minus n this is equation 4 right.

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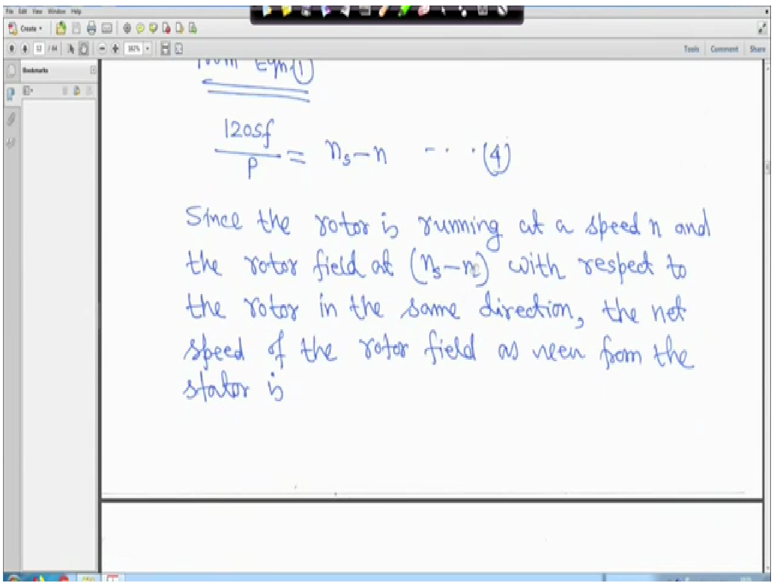

Since, the rotor is running at a speed n and the rotor field at ns minus n right with respect to the rotor in the same direction. The net speed of the rotor field as seen from the stator is it will be just n plus ns minus n is equal to n s.

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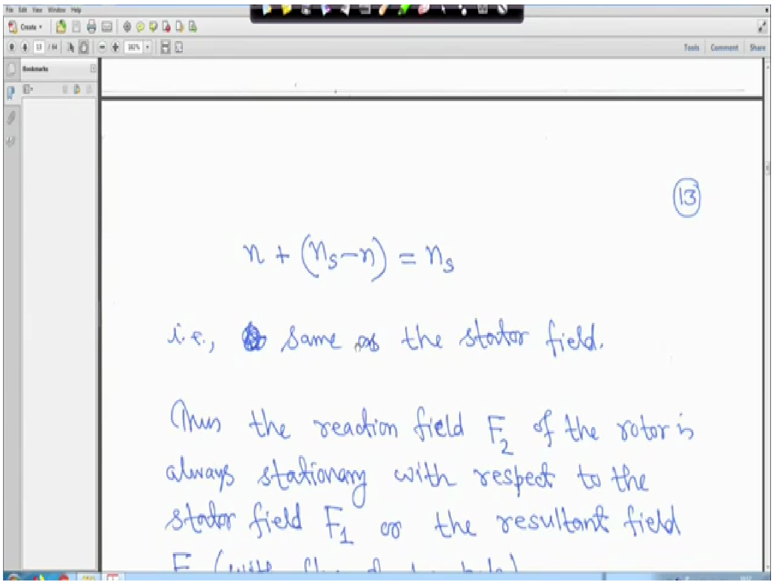

Look at that since the rotor is running at a speed n right and the rotor field at ns minus n right. With respect to the rotor in the same direction the net speed of the rotor field as seen from the stator is your n s. So, in this case again I am going back to the so, this diagram I am going back to this diagram so, this is your ns minus n with respect to rotor right and if it is your what you call if you add n right. So, what it will be actually same as your speed of the rotor field that is your ns and this is the direction of the torque is given will see little bit of that right.

And that is from this schematic diagram I thought it will be better your what you call it will be better understanding. And one thing is there this F2 F this what you call this F1, Fr, F2 all are your what you call stationary with respect to each other this is also moving with ns, this is also moving with ns, right. And so all these things will be stationary because, you are what you call therefore, this at this is the angle delta between Fr and F2 dash right so all these things will remain stationery. So, here so this is your what you call that with respect to the rotor that is same direction the net speed of the rotor field as seen from the stator is it will remain as your ns right.

So, that is same of the stator field that is rotor field and stator field both are moving at a same speed ns thus the reaction field F2 of the rotor is always stationery with respect to the stator field F1 or the resultant field Fr with flux phi r per pole right. So, that means, the your reaction field is F2 we have drawn right in the diagram of the rotor is always stationery with respect to the stator field F1 or the resultant field Fr right so all these things are remain stationary.

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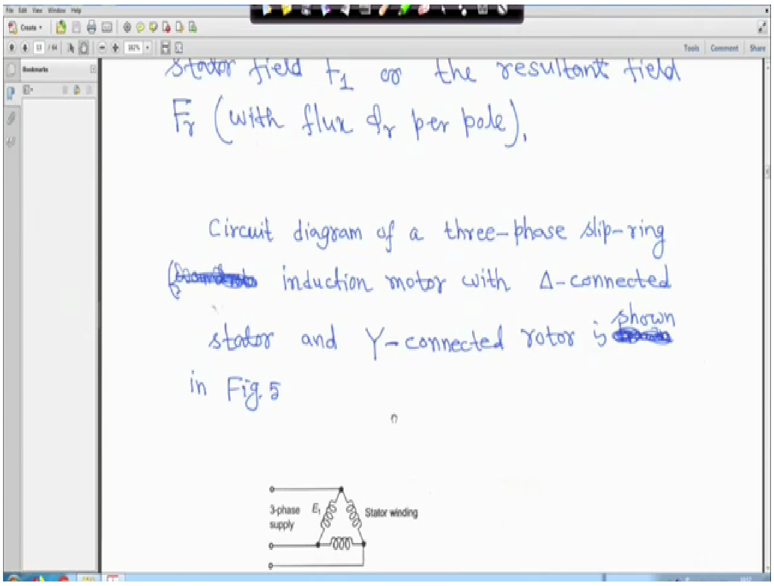

So, now circuit diagram of a three phase slip ring induction motor with delta connected stator and star connected rotor is shown in this.

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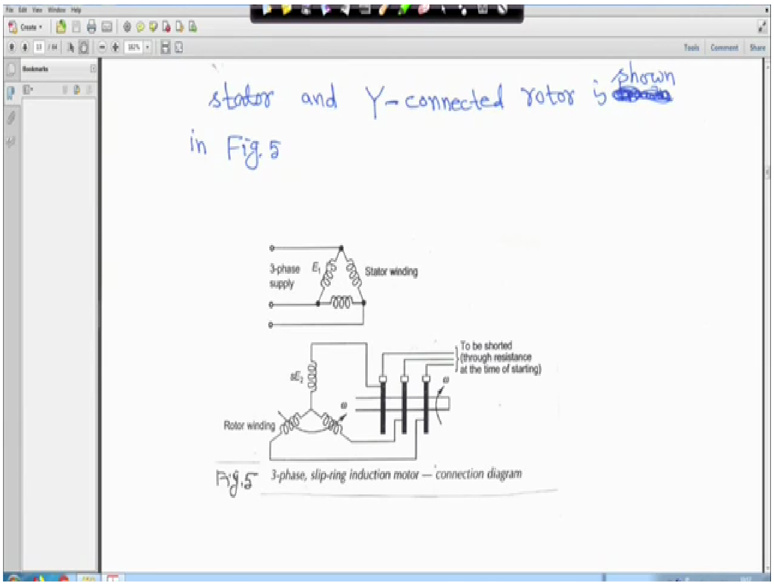

This is the stator winding, this is the three phase supply, right. And this the rotor winding this sE2 the voltage induced in the rotor we will see later right and this is your what you call that brushes are there, slip rings are there to be shorted through resistance at the time of starting. This will do it when you will (Refer Time: 21:30) in the 2nd and 3rd year when you will do the induction motor experiment right, 3 phase induction motor experiment at that time you will see this on rotor motor.

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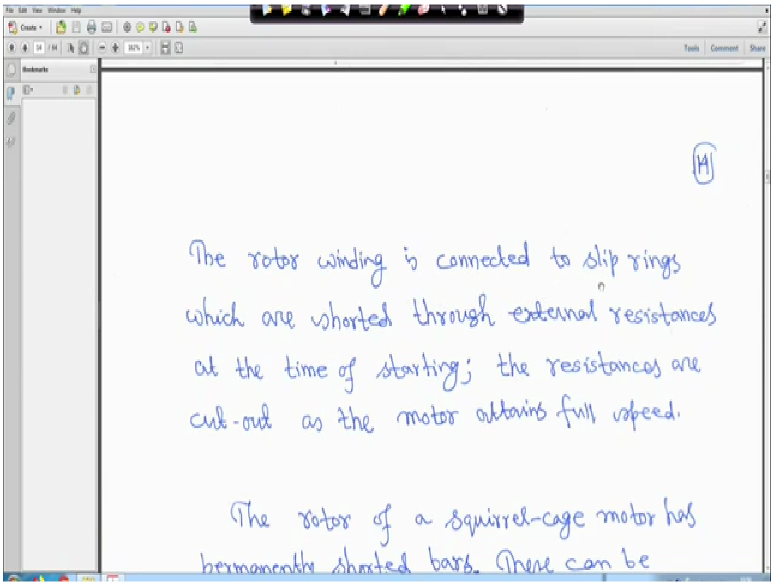

So, in this case the rotor or rotor winding is connected to slip rings which are shorted through your external resistance at the time of starting. The resistances are cut out as the motor attains full speed here it is resistance here at not shown here it is not shown here right.

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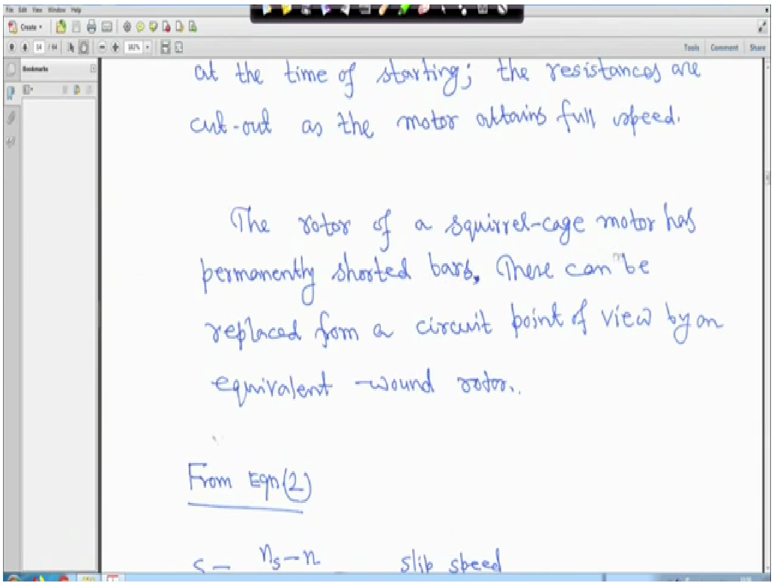

So, the rotor of this squirrel cage motor had permanently shorted bars there so this can be replaced from a your what you call circuit point of view by an equivalent wound rotor. In this case of in that case of squirrel cage motor all these things are not there because rotor itself is shorted.

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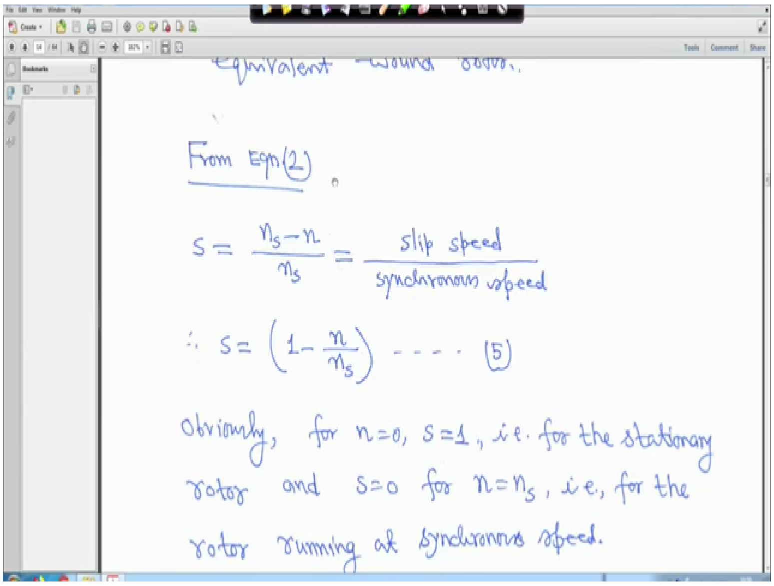

So, from equation 2 we can write slip is equal to ns minus n upon ns. This is ns minus n is called slip speed and this is your synchronous speed. Sometimes if it is the numerical if it is our slip speed then we will take the difference of these 2 ns minus n right, it will be for motor it will be always positive right. And therefore, s is equal to 1 minus n upon ns say this is equation 5. Now, obviously, for n is equal to 0 that is my rotor is stationery s is equal to 1 that is for the stationary rotor and s is equal to 0 for n is equal s that is for the rotor running at synchronous speed right.

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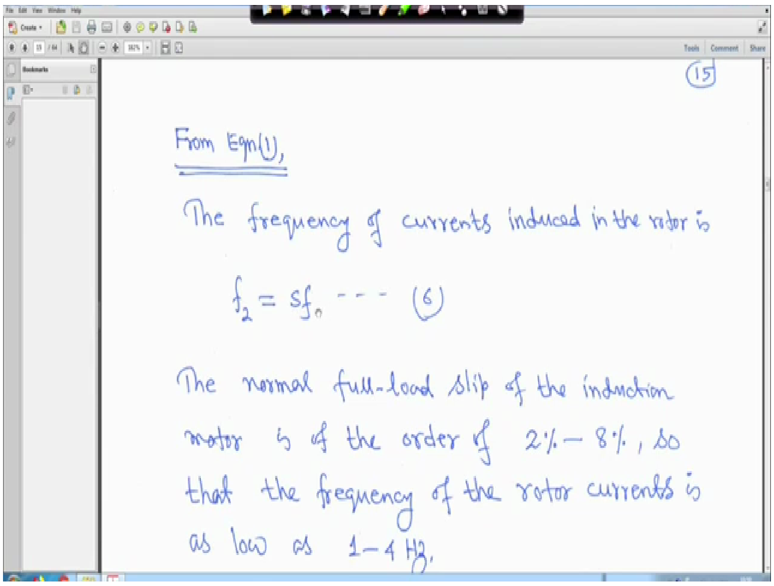

So, from equation 1; the frequency of the current induced the rotor is same as f2 is equal to sf this we have seen right. Frequency of induced your what you call your currents induced in the rotor is f2 is equal to sf this we have seen. The normal full load slip of the induction motor is of the order of 2 to 8 percent. So, that the frequency of the rotor current is as low as 1 to 4 hertz right. If it is 2 percent and slip is 2 percent that f is 50 hertz so, it will be hardly your what you call f2 is 1 hertz because, 02 into your 50 right.

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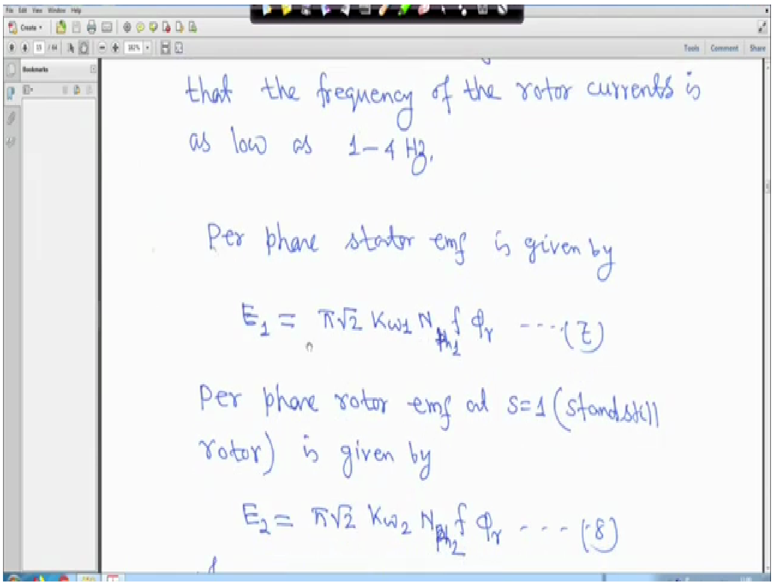

So, per phase now, next is the per phase your what you call stator emf is given by E1 is equal to say pi root 2, like transformer Kw1 N ph1, f into phi r. So, Kw1 is winding factor I am not discussing this here just you keep it in your mind, because more you will study in your electrical engineering in your 3rd year induction machine. And this is N phase 1 that is Nfh 1 that is the stator side actually number of turns will call Nph 1 and f frequency and phi r is the flux per pole.

So, per phase rotor emf your what you call at s is equal to 1 the standstill rotor is given by when s is equal to 1 rotor is at stand still at that time emf will be pi root 2 Kw2 Nph 2 f phi r, that is the way you do in transformer phi into root 2 multiply it will become I think 4.44 right. And this is winding factor Kw2 also call the winding factor of the rotor and as if this your primary side, as if this is your secondary side right.

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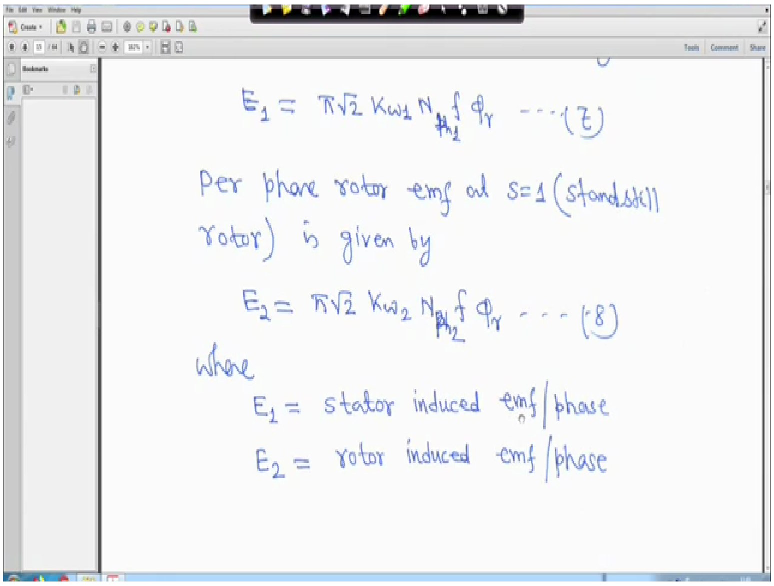

So, E1 is equal to stator induced emf per phase, E2 is equal to rotor induced emf per phase right.

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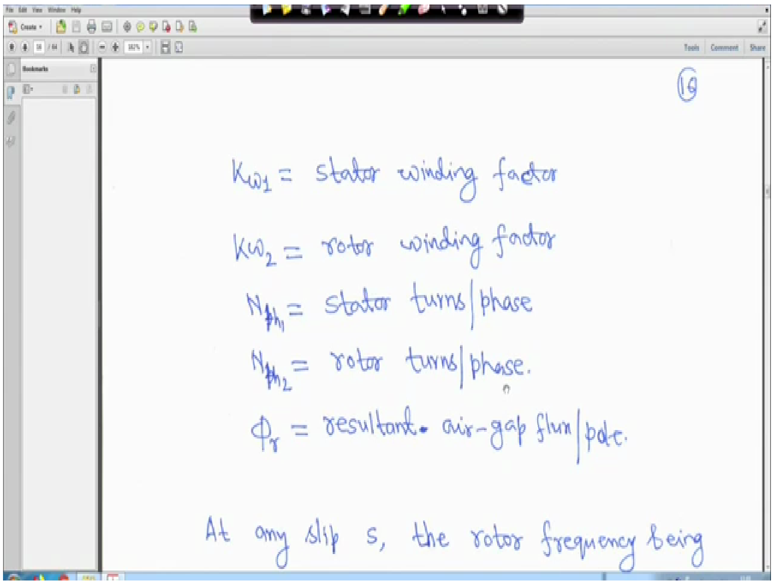

Kw1 is stator winding factor, Kw2 rotor winding factor Nph1 stator turns per phase Nph2 rotor turns per phase. The why you do transfer this thing and phi r resultant air gap flux per pole right. Now, at any slip s the rotor frequency being sf right any therefore, the rotor induced emf changes to SE 2. The rotor frequency now changes to your f2 is equal to sf therefore, the rotor induced emf actually will be it will be SE 2 right. So, if it is slip is one at that time it is E 2, but when that rotor is running it has some slip so, it is in this way will be SE 2. So, consider now the impedance of the rotor circuit for Z 2 is equal to r 2 plus jx2 when it is a standstill right when slip is equal to 1.

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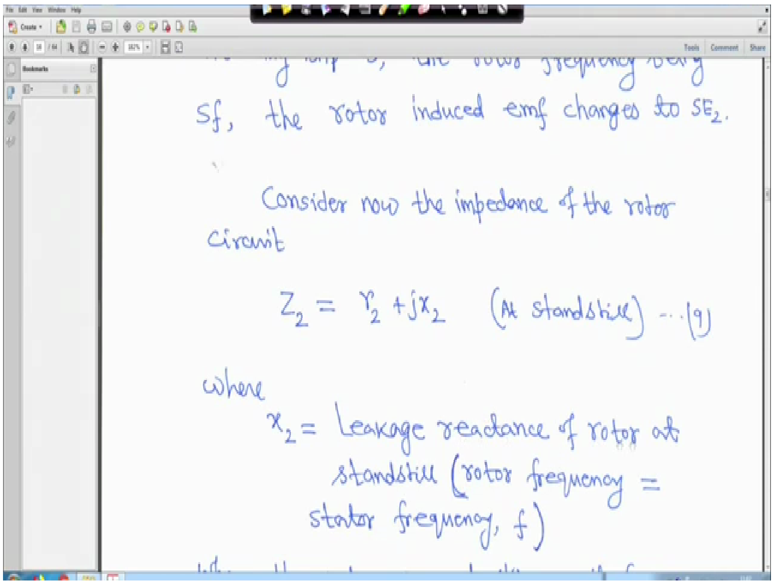

Now, when x 2 is equal to leakage reactance of the rotor at stand still, that is rotor frequency is equal to stator frequency of the time right so it is f.

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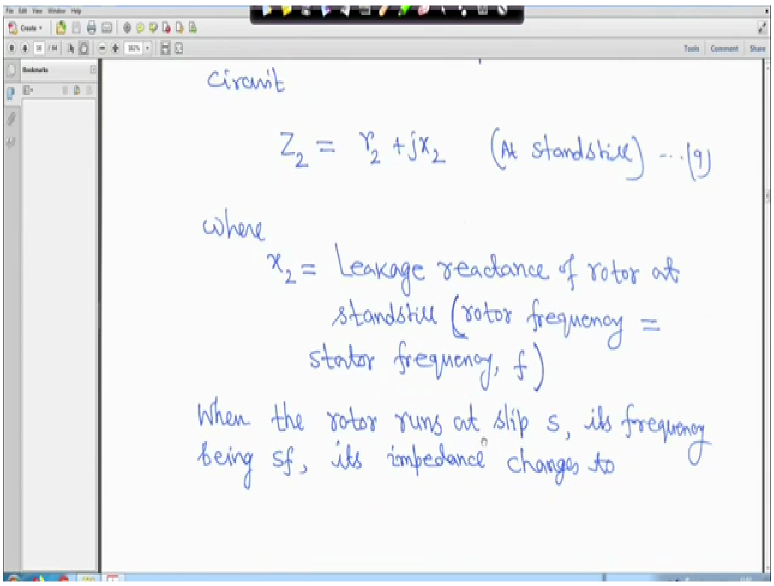

Now, when the rotor running at slip s at that time its frequency being sf frequency is changing therefore, it is impedance changes to your what you call r 2 plus jx2 right.

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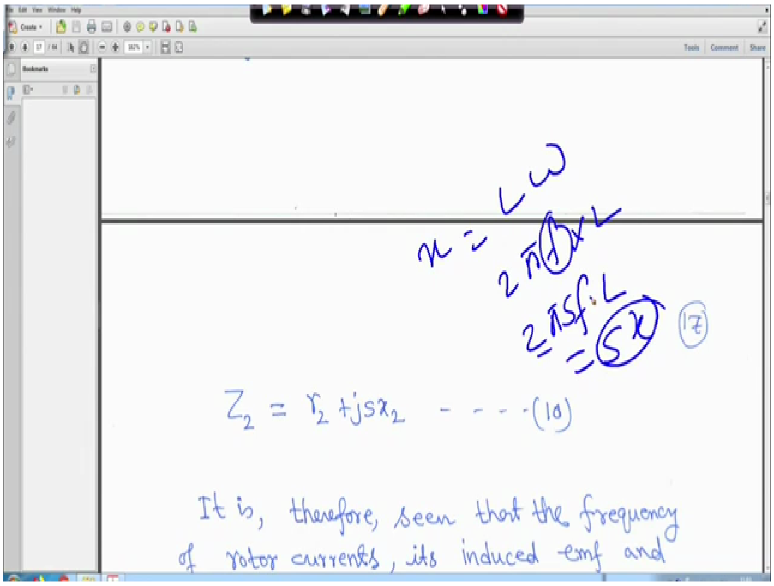

Because frequency is sf suppose where you make a this one where you make this one say general say x is equal to you know L omega right. Omega is equal 2 pi f so 2 pi into f your omega is equal to your 2 pi f this L omega into you write L right. So, but rotor frequency instead of f it will become f2 and f2 will be sf to this one into L. So, it will be your what you call 2 pi f the s is s into your what you call x right in general. So, this is your what you call your that is why the rotor frequency will be now rotor is running it is impedance will be r2 plus j s x 2, r 2 is resistance, but this reactance depends on the frequency.

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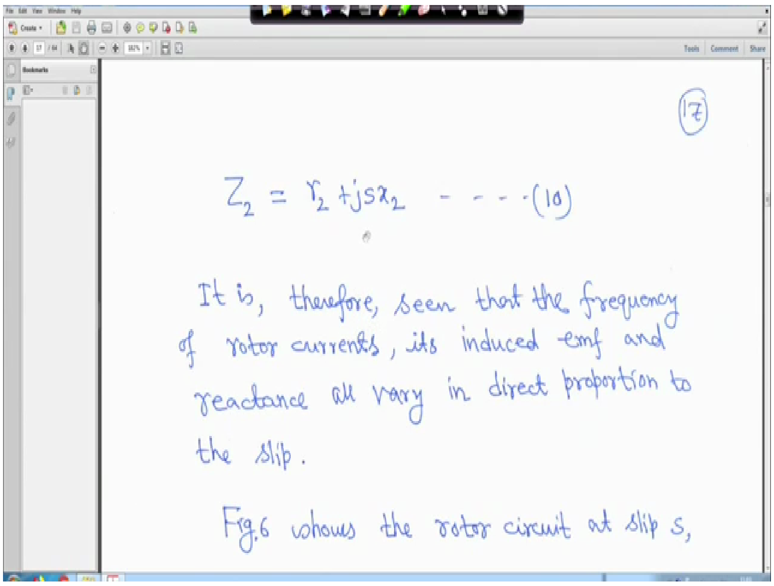

So, therefore, it is it is therefore, seen that that the frequency of rotor current is induced emf and reactance all vary in direct proportion to the slip. Because when a rotar rotating it is frequency is changing a induced emf current as well as the reactance also because this is this is f right. Because in general we know L omega, but in the case of rotor it will be f2 is the frequency f2 is equal to s f so, that is why s is here.

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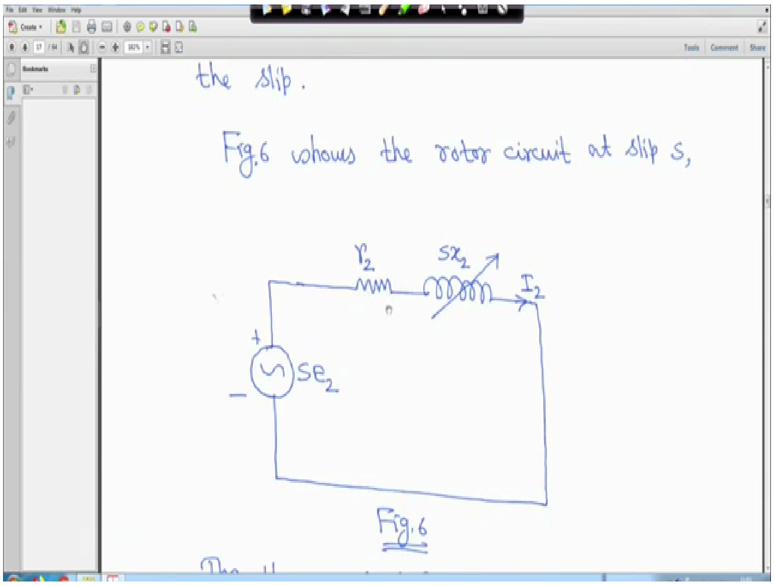

Now, this that figure 6 shows the rotor circuit at slip s this is the induced voltage say rotor circuit. Rotor itself is a short circuit thing so this is r 2 resistance this s x 2 it is given as a your what you call that a variable symbol right. And this is the current I 2 right so in this case your this is the rotor circuit because rotor is short circuited so it is a closed path right.

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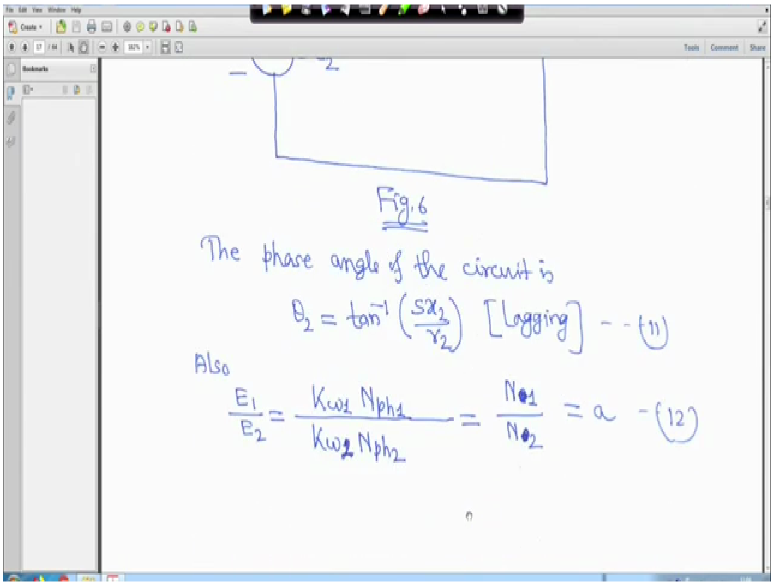

Now, the phase angle of the circuit theta 2 is equal to tan inverse s x 2 upon r 2 right so this is your theta 2 that is the lagging. Now, also E1 by E2 if you this expression this expression if you make, here it is written that this expression you make it E1 by E2 you just divide E1 by E2 then it will be like this. E1 by E2 if you make then it will be Kw1 Nph1 upon Kw2 Nph 2 that is N1 upon N2 say right. N1 is equal to Kw1 Nph1 N2 is equal to Kw2 Nph 2 that is equal to say a right.

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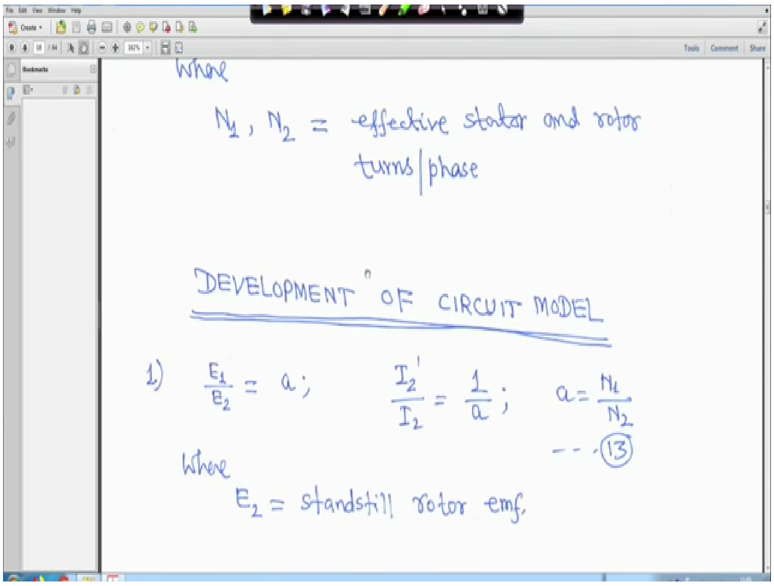

So, in this case where N1, N2 the effective stator and rotor turns per phase right. So, that is your we are make a like a transformer we are making it, now, development of circuit model next. So, circuit model is same as a transformer say E1 upon E 2 is equal to a, a is given N1 upon N2 and the current your I 2 dash upon I 2 is equal to 1 upon a right. The way we did transformer same way and E2 is equal to standstill rotor emf right.

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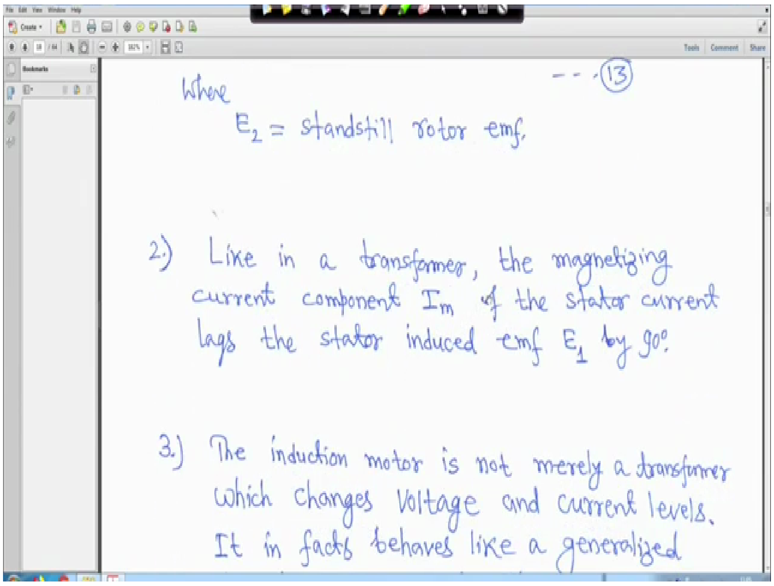

So, number 2 like in a transformer the magnetizing current component I m of the stator current lags the stator induced emf E1by 90 degree same as before.

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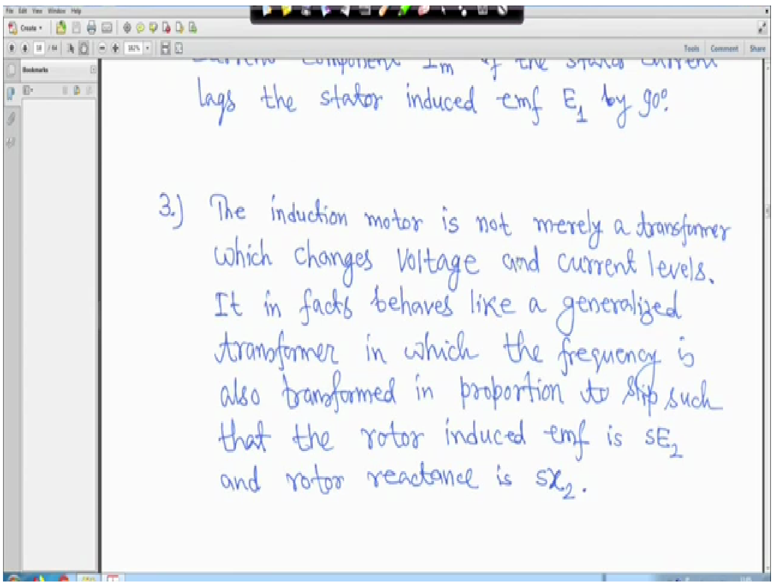

The induction number 3 the induction motor is not merely a transformer which changes voltage and current levels. It in facts behaves like a generalized transformer in which the frequency is also transformed in proportion to slip. Such that the rotor induced emf is SE 2 and the rotor reactance is SX 2 right so these are the certain things.

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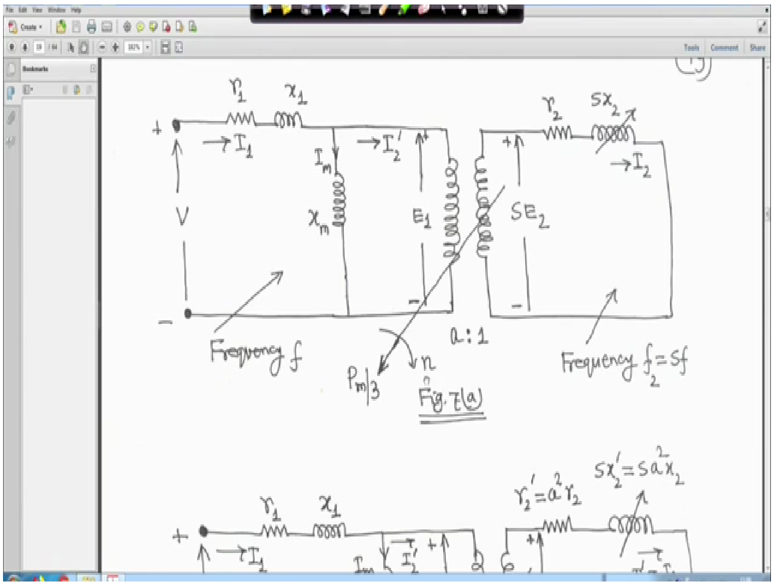

Now, the when will derive that equivalent circuit like transformer its core loss component is neglected. This is stator side and as in your transformer primary side r 1, x 1 current is I 1. This is I 2 dash right, this current is I2 dash I1 is equal to I m plus I 2 dash and this is your voltage for an ideal. Now, we make an ideal transformer right same thing these the voltage E 1 and this side is frequency f frequency is given mark is f right. And Pm will see it is a mechanical power output per phase that is why divided by 3, we will see later.

And this is figure seven a and this is the rotor circuit frequency is f2 is equal to sf and voltage induced of a rotor circuit just we saw SE 2, this is r 2 SX 2 and this is the current I 2 right. So, next one is this is the first circuit right, next one is and rotor is rotating with a speed of n here it is n right, here it is n it is given like this.

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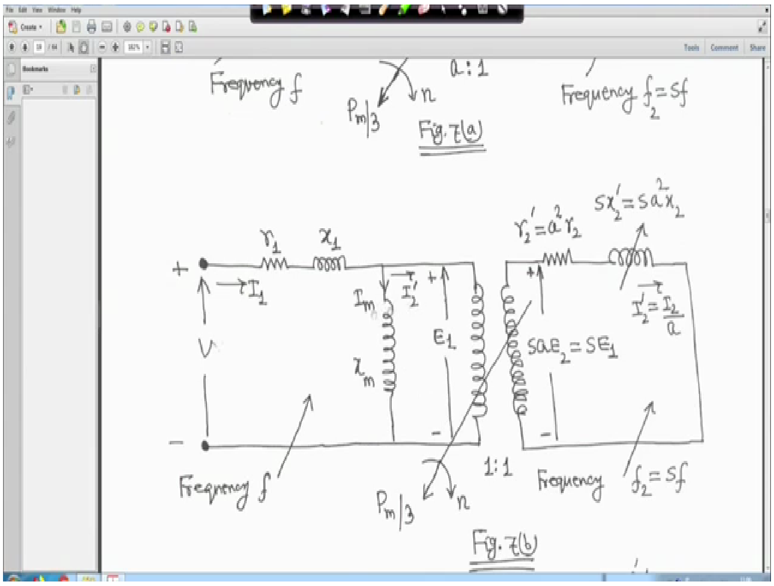

Now, next one is this derivation is later. Next one the this side remain left hand side remain as it is this is frequency f this is frequency f2 yes f2 is equal to sf. Now, this is rotor circuit this is E 1 this part will be SE 2 is equal to SE 1 here it is ratio is a is to 1, here it is a is to 1, a is equal to your n 1 by n two; a is equal to n 1 by n 2. So, here it is your ratio is given a is to 1 right so, in this your what you call now in this case it is 1 is to 1 and all these transform all these things transform.

This transformation is shown later the way you do the transformer almost similar it will be there r 2 dash is equal to a square r 2, s x 2 dash will be s into a square x 2 and current here this side is I 2 I 2 dash right. Now here if you look into this I 2 dash is equal to your then I 2 dash upon I 2 is equal 1 upon a. Therefore, I 2 dash will be is equal to your I 2 upon I 2 upon a right. So, this side if you transform it, it will become 1 is to 1, it will become I2 dash is equal to I2 upon a. And this saE2will become S a 2, SE1 this is 1 is to 1. Derivation I mean without derivation also it just little bit difficult do it you can easily do it this, but derivation is there later right.

Now, next is this right hand side you divide this thing by s. This all the parameters you divide by s this side it is now 1 is to 1, this all the side you divide by s. So, after saying this I will come to derivation at that time I will not come to this figure. So, what you do is that you divide all these thing by s, then if you divide everything by s then this will become E1, this will become your x 2 your what you call x 2 this x 2 dash divide by s it will be x2 dash. And if you divide by this one it will be r 2 dash by s.

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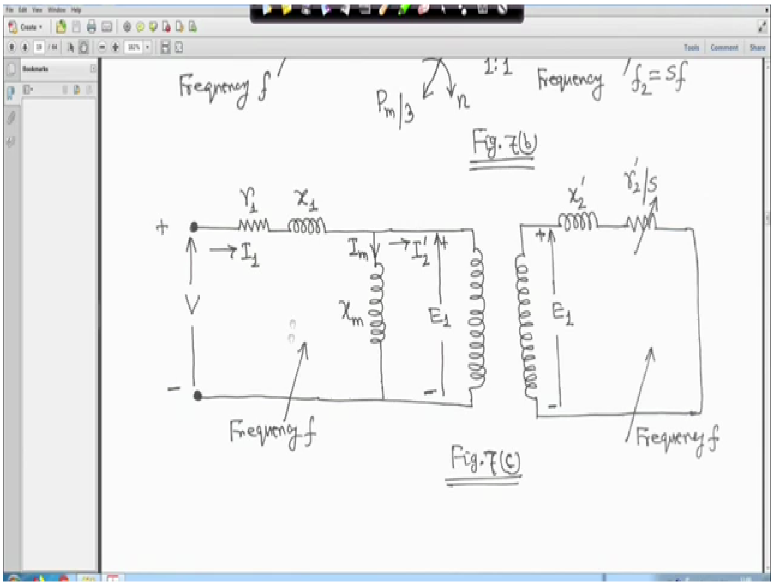

So, it will be x 2 dash r 2 dash by S and this is your what you call E 1 E 1. So, here it is not shown again 1 is to 1 right. So, this is frequency f this is frequency f naught right because everything is made in terms of this side right. So, now, here it is also because everything divided by S. So, here it is now equivalent circuit now it is f2 is equal to sf. Now, it is frequency is f because this is E1 this E1 this you have made it. Now the next what will do next as this is E1 this is E1 like transformer so this these two things will come to this side will bring it right.

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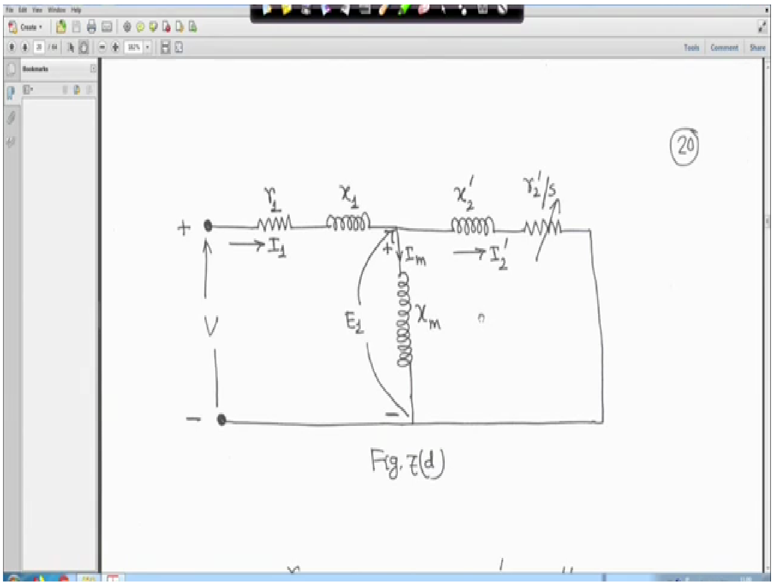

So, if you bring it is x 2 dash and r 2 dash and circuit is closed. So, this is your what you call induction machine equivalent circuit, but r c is not shown here we will show it. So, this is the equivalent circuit of the induction machine right.

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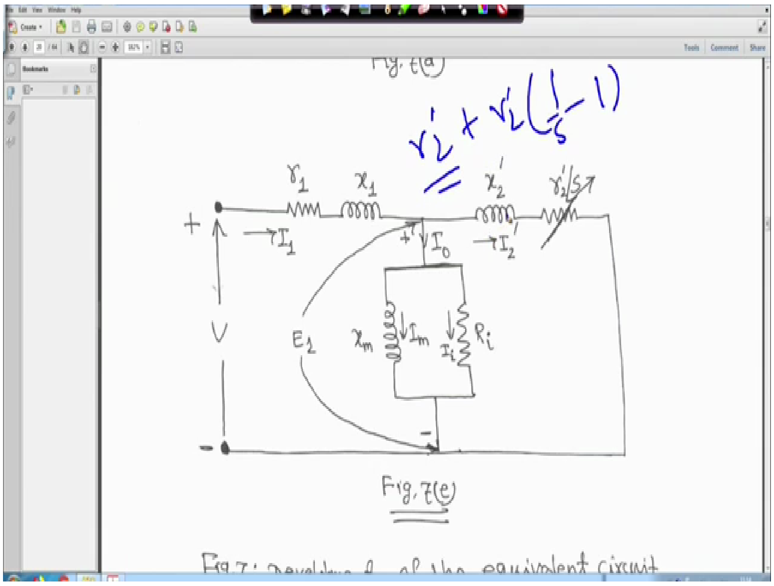

So, now if you had that core loss component like transformer, then this branch has come rest is same, but this branch has come. Now, how these things are coming.

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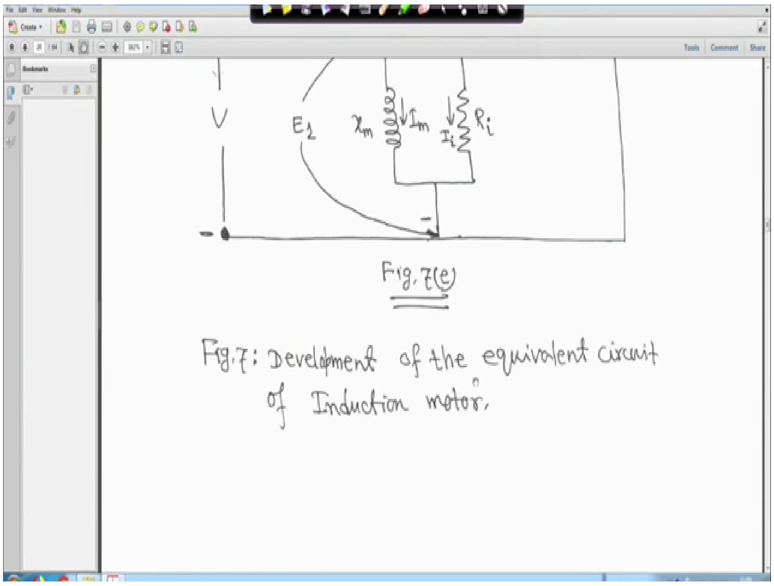

Now, this is the development of the equivalent circuit of induction motor now how things are coming.

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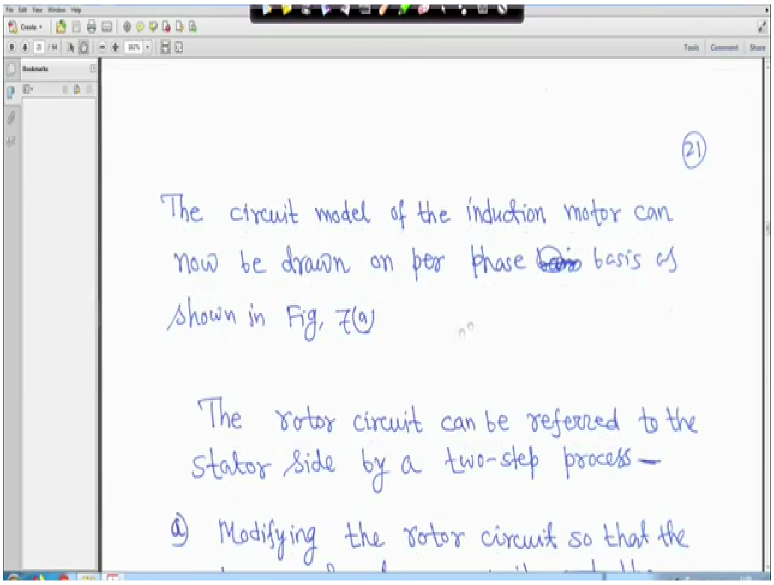

The circuit model of the induction motor can now be drawn on per phase basis as shown in figure 7 a. Now, all these things are I have told you so all this write up here just go through it right just go through it right.

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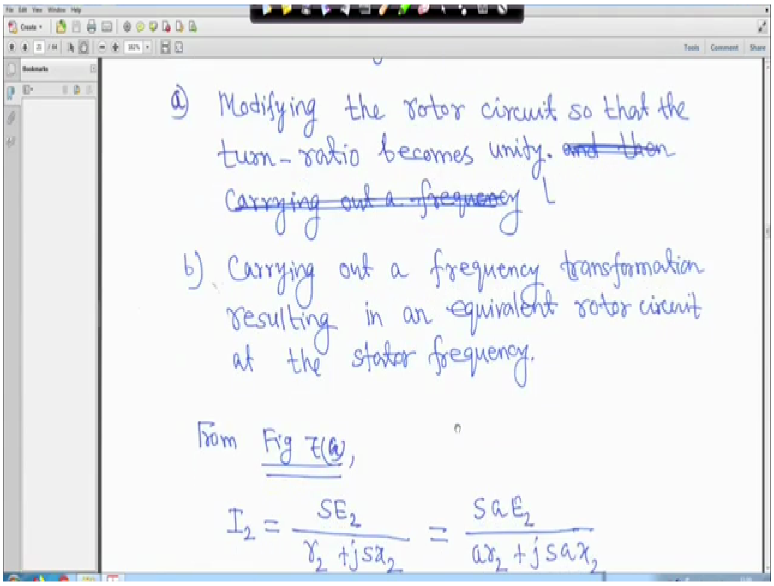

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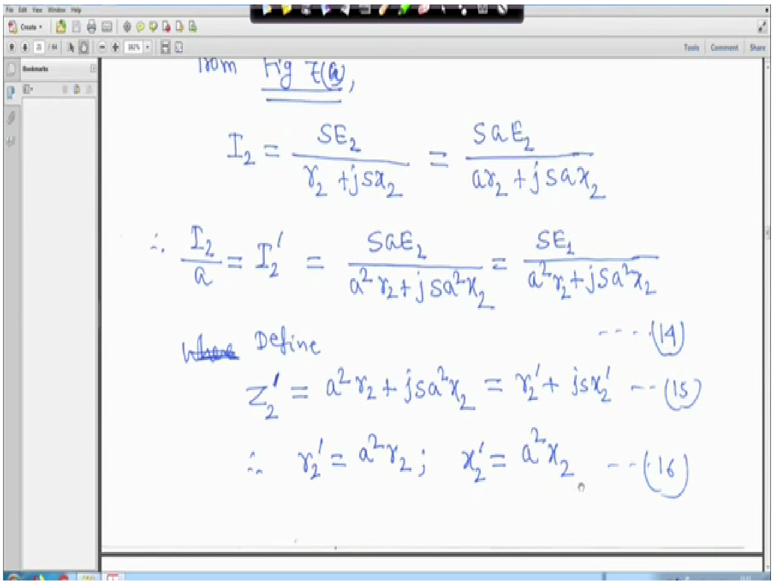

So, look at this derivation, I 2 is equal to you can write SE 2 upon r 2 plus j Sx 2; from that the rotor circuit diagram. In that first one figure 7 a, so in that case your you can make it you what you call numerator and denominator you multiply by a. So, Sa E 2 then a r 2 plus j s a into x 2; the numerator and denominator multiply by a. We know I 2 by a is equal to I 2 dash therefore, this I 2 denominator you multiply by a again. So, it is I 2 by a is equal to I 2 dash, so SE 2 a square r 2 plus j s a square x 2. So this part can be written as that your E2 can be your what you call these E2 can your a E2 can be written as E 1, because E 1 by E 2 is equal to a so it is SE1 one divided by a square r 2 plus j s a square x 2 right.

Therefore, define Z2 dash is equal to a square r 2 plus j s a square x 2 that is r 2 dash plus j S x 2 dash, r 2 dash is equal to this much, X 2 dash is equal to this much right. So, that is why whatever we have made it here; whatever we have made it here I am going to this circuit, whatever we made it here SE 2 then it is ultimately it is SE 1 easily you can make it right.

So, that is that is why this SE 1 is here so, similarly here it is we have derived it from that your what you call from this one this is actually SE 1. So, this is the equivalent parameter of the induction machine same as the transformer numerical also we will do to some extend this thing right or I 2 dash we can write SE 1 upon this thing so divide numerator and denominator by s.

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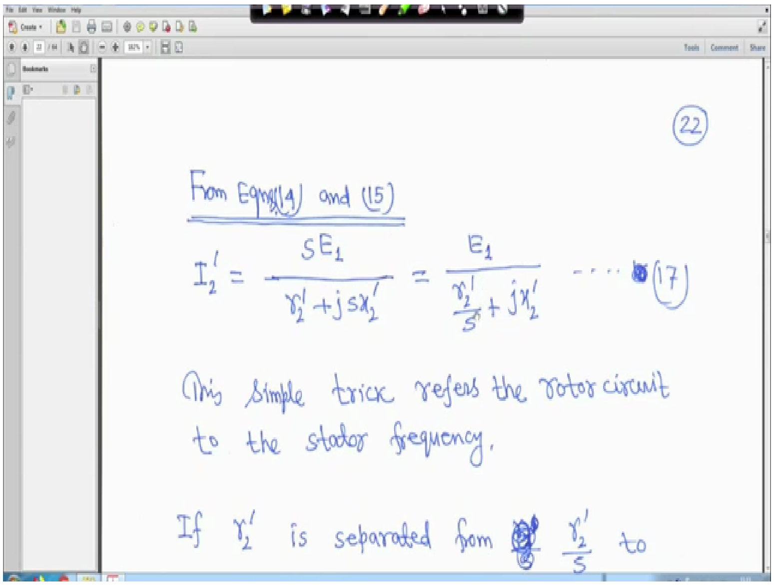

Therefore, it is coming I 2 dash is equal to E 1 divided by r 2 dash plus j x 2 dash that is the everything is transformed to the stator side right. So, this simple tricks referred to the rotor circuit to the your this simple trick refers to the rotor circuit to the stator frequency.

Because, at that time your what you call right hand this circuit is referred to your like your stator frequency because this circuit here it is now frequency f there also frequency f here it was sf here it is sf, but this one as divided by s. So, it this side frequency is f this is a frequency this is a simple trick right. So, this is your what you call that I2 dash. So, this simple trick refers to the rotor circuit to the stator frequency.

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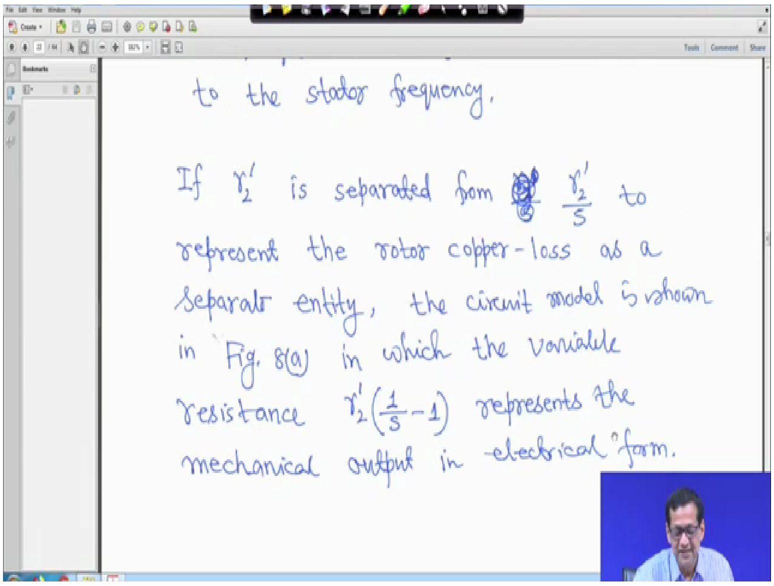

Now, if r 2 dash is separated from r 2 dash by s to replacing the rotor copper loss as a your separate entity the circuit model is shown in figure 8 a right. In which the variable resistance represents the mechanical output in electrical form; that means, your what you call.

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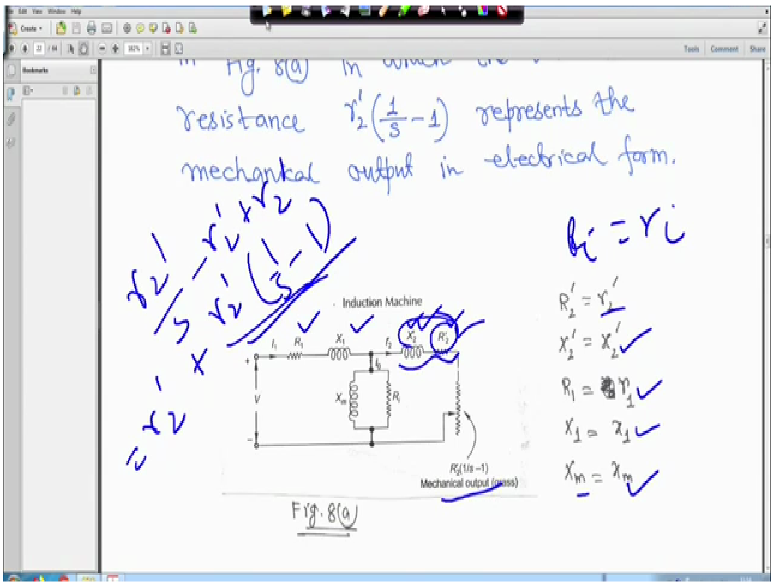

That means this your resistance is that is your you we got r 2 dash by s. This is the thing right, but stator your what you call a resistance basically r 2 dash. Therefore, what you do you subtract r 2 dash then add r 2 dash right. That means, this one can be written as r 2 dash plus you take r 2 dash common it will be 1 upon s minus 1 right. So, this again I have taken from a book so, this one if you look into that I have make it because I represent all the thing by small letter. So, basically R 2 dash is nothing, but small r 2 dash, X 2 dash is nothing but small x 2 dash, R 1 is nothing but small r 1, capital X 1 nothing but small r 1 and capital X m is nothing but a small x m and this is r i right.

This is the current I 0 similarly, your R i is nothing, but small ri. So, and this is separated right this rotor circuit this part is separated this is actually rotor reactance and this is your resistance and rest this is whatever this part right this is actually mechanical power output because R 2 by s; s is variable right so it is slip. So, just take it out take out this one rest will be R 2 dash into 1 upon s this is the mechanical power output that is called gross one right we will see that. So that means, this is this circuit actually this circuit is r 2 dash upon s once again I am telling you this r 2 dash by s can be made two things.

One is your you add r 2 dash plus you can write you take r 2 dash common then 1 upon s minus 1. That add r 2 dash subtract r 2 dash so this part is coming there what was circuit I have shown here. So, this part actually separated the rotor resistance is separated right. So, that is why this circuit is like this is actually mechanical output right. So, many meanings are there of this is a figure 8 a so, nothing this is basically if you add these two it will be r 2 dash by s right.

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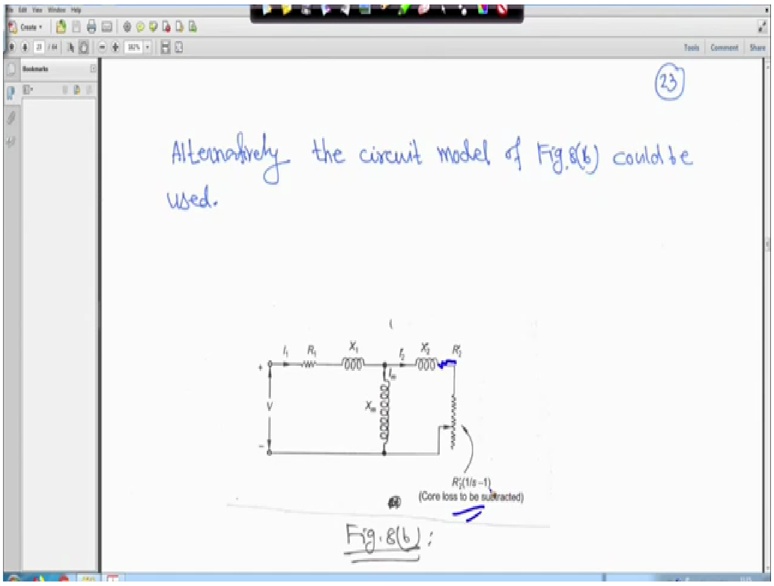

So, alternatively the circuit model of this thing could be used like this. I mean if you neglect that this component this Ri component. So, it can be your you is like this or your what you call R 2 dash X 2 dash R 2 Here it is actually just hold on here it is there is a this R 2 dash actually printing mistake is here R 2 dash would be there here right a printing mistake is there in the diagram. So, it is R 2 dash and this is your core loss to be subtracted, I mean here all core loss whatever was there so that branch is removed. But, for this part this R 2 dash 1 upon s here core loss alpha has to be subtracted if you remove this yes simplification right.

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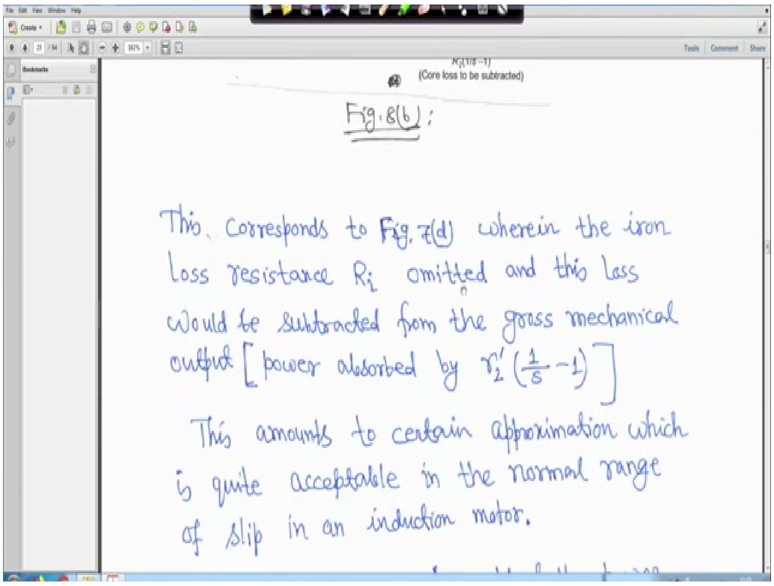

So, this is another thing; another thing is that the corresponding wire in the iron loss resistance R i omitted. And this loss would be subtracted from the gross mechanical output that is power absorbed by r 2 dash 1 upon s minus 1 this one right.

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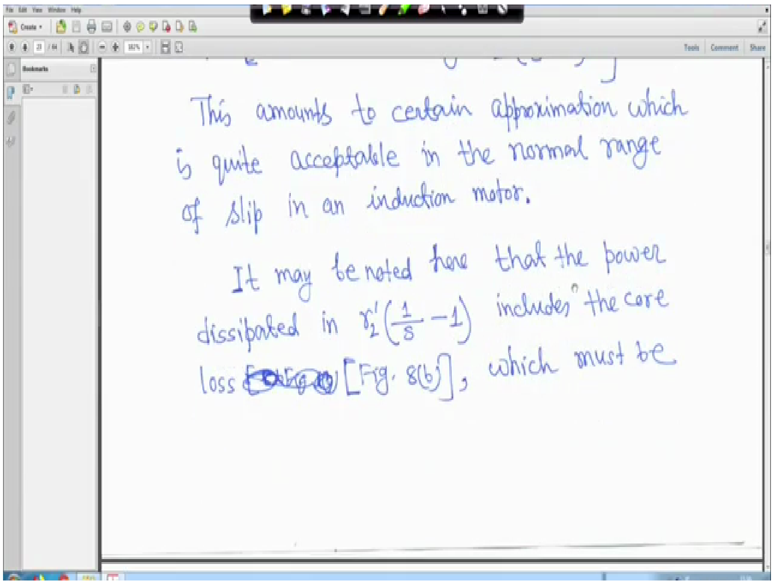

Now, this amounts or to certain approximation which is quite acceptable in the normal range of slip in an induction machine these an approximation.

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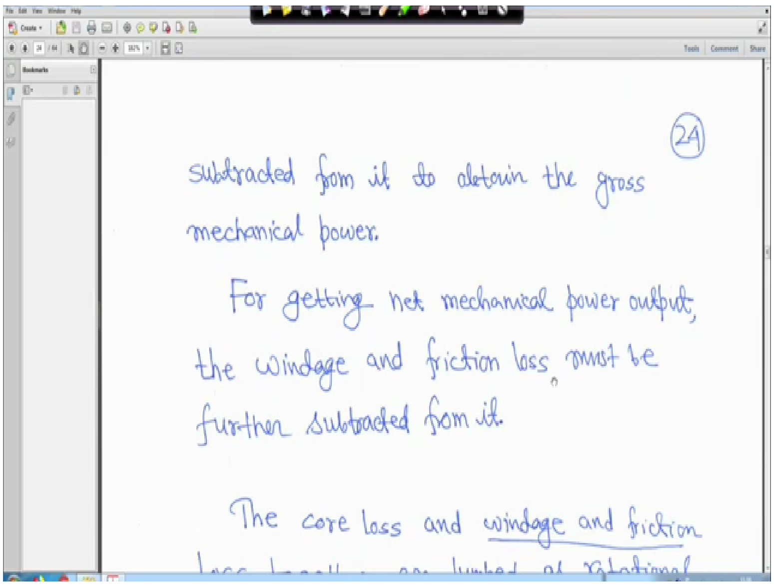

It may be noted that the power dissipated into r 2 dash into 1 upon s minus 1 includes the core loss that is figure 8 b, which must be subtracted from it to obtain the gross mechanical power when will do the numerical. So, few numerical I will show you; for getting net mechanical power output the windage and friction loss must be further subtracted from it.

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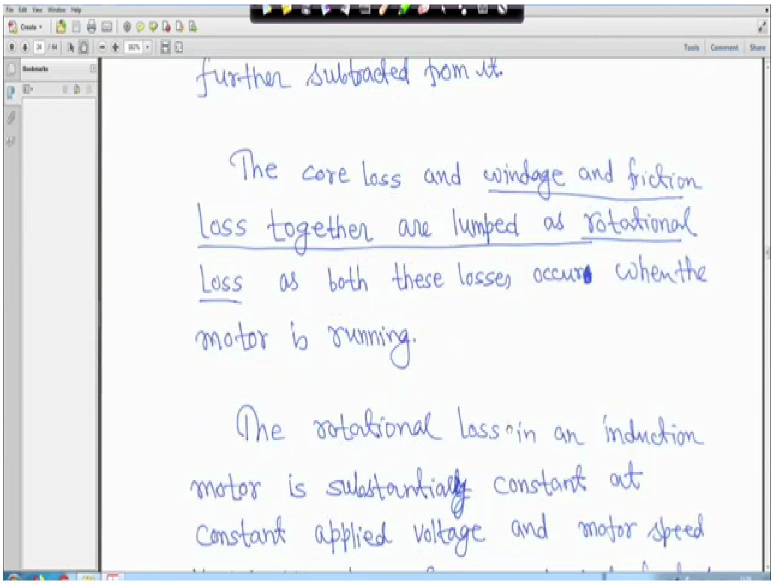

Windage and friction loss right fictional loss sometimes we called is a rotational loss that will be given few some percentage of this right. The core loss windage and friction loss together are lumped as rotational loss as both these losses occur when the motor is running right. So, the rotational loss in an induction motor is substantially constant right.

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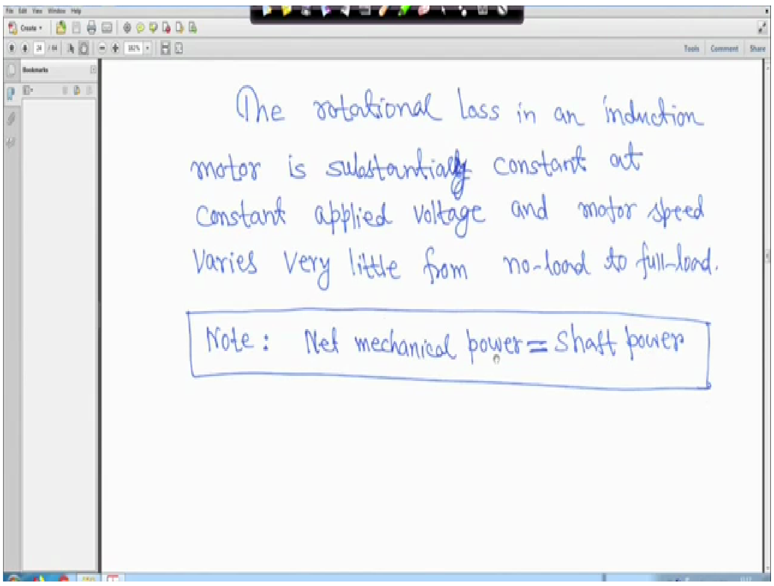

At constant applied voltage and motor speed varies very little from no load to full load not much change in the no load to full load. Only thing is that for numerical solving net mechanical power is equal to shaft power this thing you have to keep it in your mind, shaft power means net mechanical power right.

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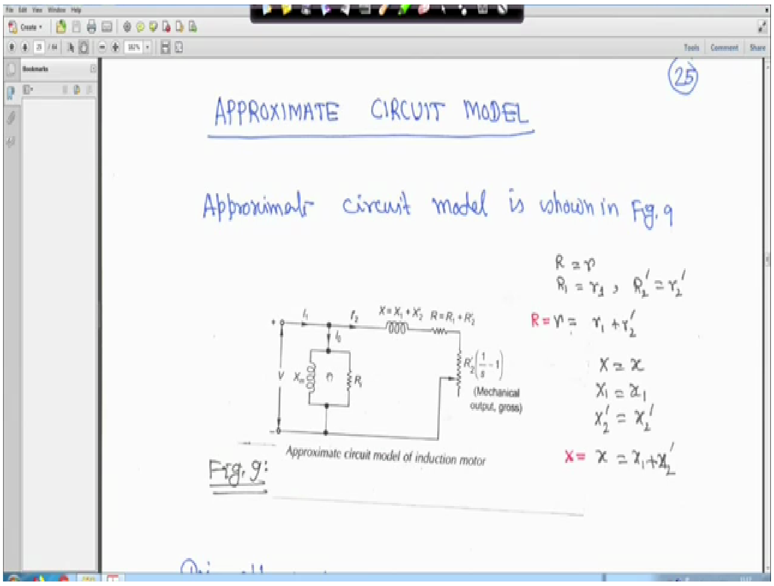

So, another thing is the approximate circuit model; approximate circuit model is shown like this. That means all these thing this branch put here only another (Refer Time: 40:39) club it together, but this kind of analysis will give you erroneous result because, like a transformer this I 0 actually very small right. But, in induction motor it will be maybe 30 to 50 percent this I 0. So, this kind of calculation if you do for simple and simple using this simple circuit result will not be accurate because, this I 0 will be very high for induction machine it will be 30 to 50 percent right.

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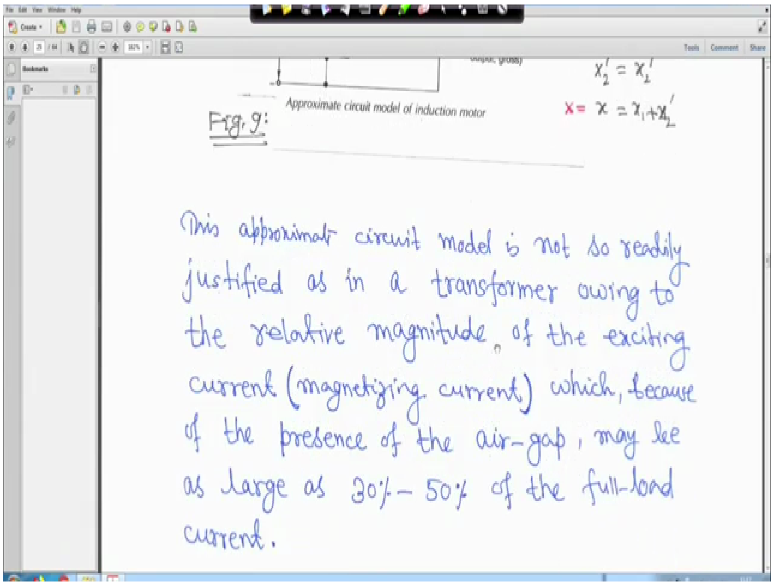

So, this approximation everything what I said it is written here right everything is written here.

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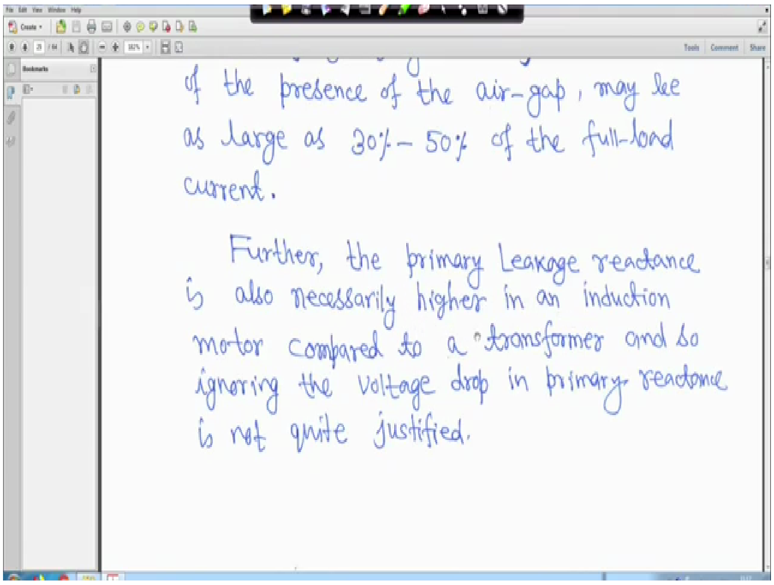

So, further the primary leakage reactance is also necessarily higher your what you call higher in an induction motor compared to a transformer. And so ignoring the voltage drop in primary reactance is not quite justified right. So, induction machine you have to when you solve the numerical you have to consider your what you call that your accurate model right.

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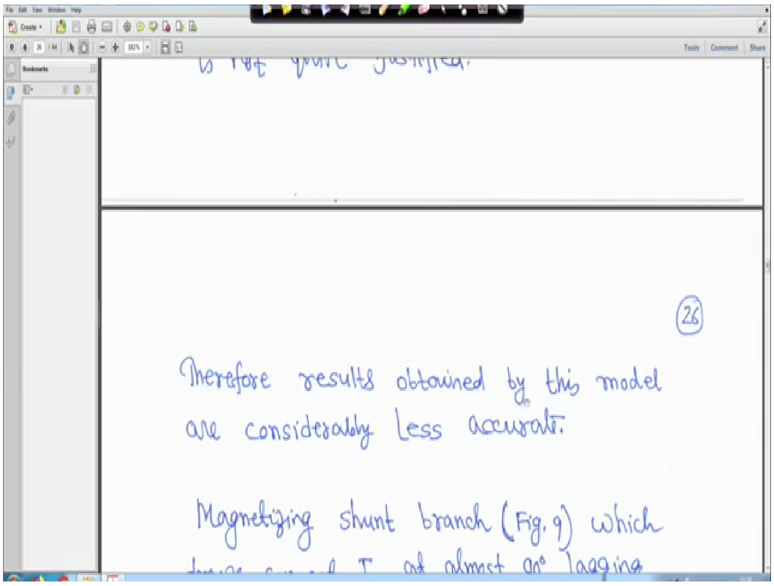

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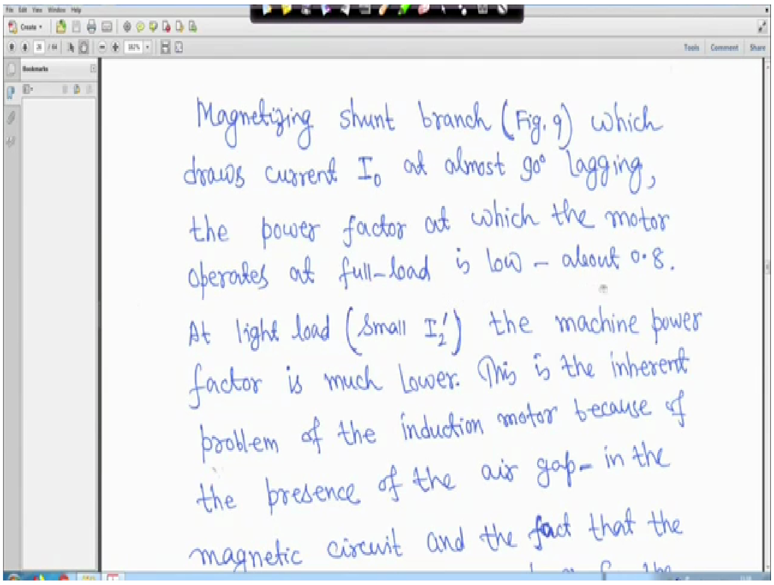

So, therefore, the result obtained by this model are considerably less accurate right and this I told you magnetizing shunt branch which draws current I 0 at almost 90 degree lagging. The power factor at which the motor operates at full load low about 0.8 at light load that is small I 2 dash the machine power factor is much lower. This is the inherent problem of the induction motor because of the presence of the air gap in the magnetic circuit right.

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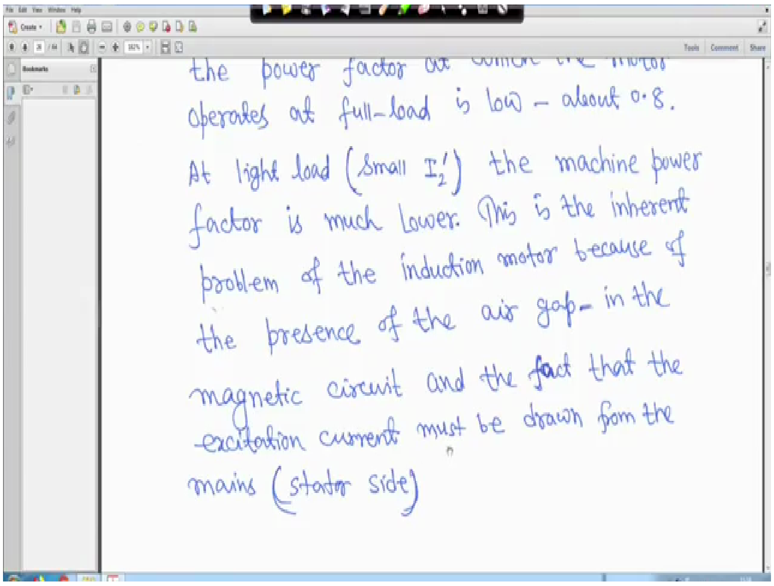

And the fact that the excitation current must be drawn from the main that is the stator side right. With this thank you very much we will be back again.