Electrical Machines - II
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Lecture - 35
Introduction to Induction Motor (Contd.)

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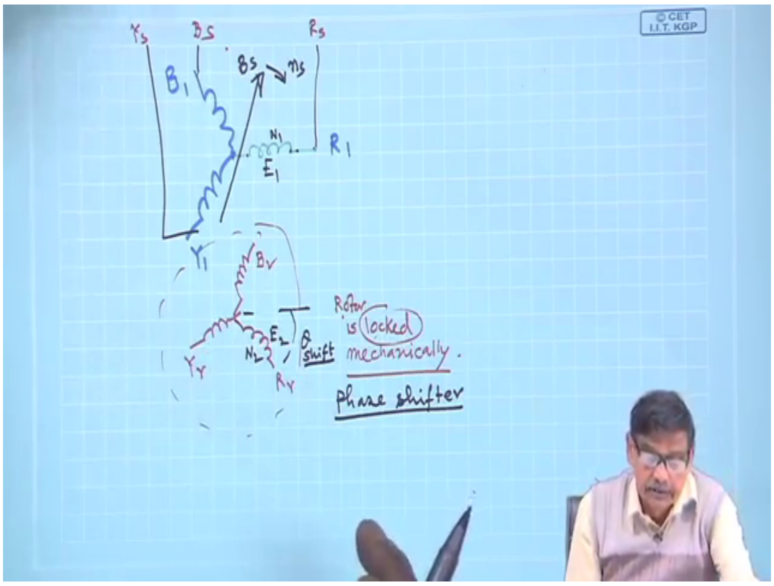

Welcome and we were discussing a machine, where on the stator there is a balance 3phase winding on the rotor there is a balanced 3 phase winding. And I will connect the stator with a supply Rs, Ys and Bs. Stator is of course stationary, and I will energise it, there will be a resultant rotating field. And on the rotor also I have a winding balanced 3phase winding having enter turns for phase. And suppose the rotor is locked, and it is not allowed to move, then what is going to happen, this rotating field is going to induce a voltage on the stator coils as well as on the rotor coils.

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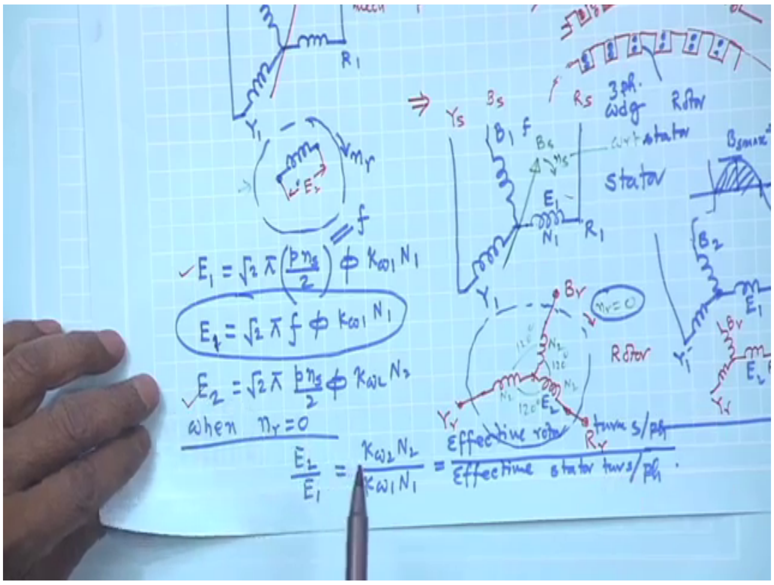

That is what I told E 1 will be there and as well as E 2 will be there. Now, if somebody says rotor is also locked like stator, stator freedom are stolen, because they are crowded, they are not allowed to move, then what happens is neither of them is allowed to move, but you apply a 3phase voltage on the stator then a rotating magnetic field results, there will be induced voltage.

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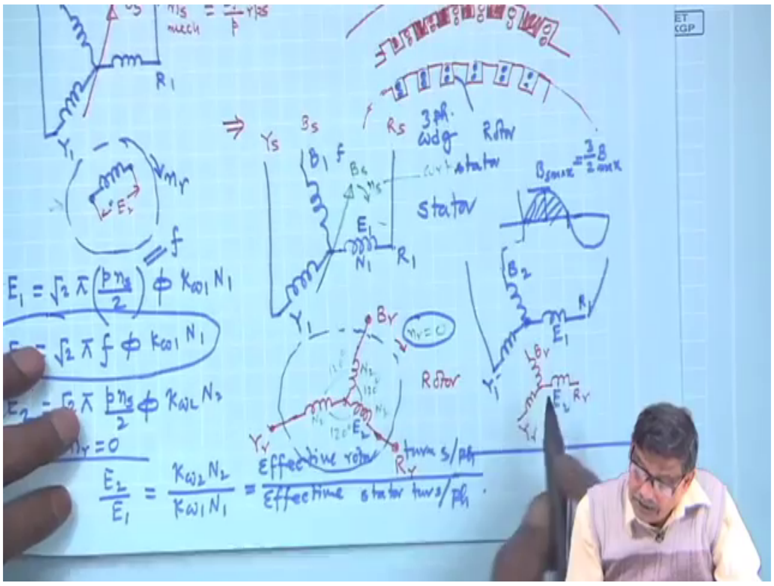

But the rotor may be locked either in this position or in this position when the R-phase axis are coinciding with the R phase axis of E phase etcetera. And we explain that if it is shifted R phase by some angle theta, the induced voltage in this will be also shifted and magnitude of that voltage will depend upon N 2 by N 1, and so I can also manipulate the voltage and as well as of course, frequency remain same, because p n s by 2 n s is the relative speed for both stator conductors and also for both rotor conductors. So, this was used earlier and called phase shifter ok.

So, this is the thing. For various purposes, it was used and some laboratories it is still some laboratories it is still available, you see measurement lab this that [FL]. Now, what I am going to tell you I will now remove this restriction that rotor is locked ok, then what is going to happen.

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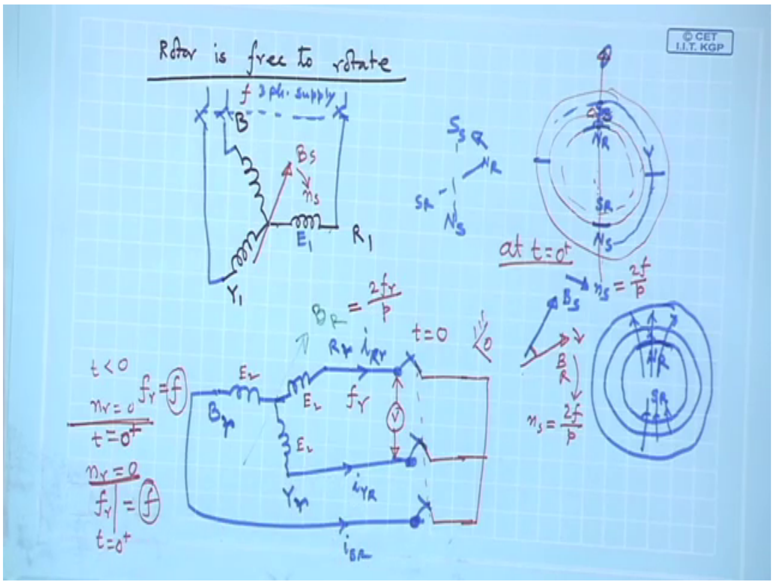

So, it is now like this rotor. And now rotor which house is the balanced 3 phase winding is free to rotate, no phase shifter thing I do not want to make. So, this is your stator supply R 1, Y 1 and B 1. And this is your rotor supply rotor coils, which initially I do not know, they may be anywhere R 2, Y 2 and say these are 120 degree please forgive me, this is 120 degree also R 2, Y 2 and B 2. And these are the rotor terminals I was calling it R r, Y r and B r ok.

Now, in this case you see this is very interesting, you energies this with the 3 phase coil suppose, you have a switch here with the supply 3 phase supply balanced close the switch. And rotor is suppose open circuited close the switch and result is known. There will be a B s, and it moves in this direction phase sequence is R b; it moves with mechanical speed.

And rotor coils are open circuited like this, and this flux also will cut this rotor phases, there will be induced voltage, [FL] under this condition. And with nothing connected like this, suppose there is a switch; and I will suppose, I will keep the switch this phases open initially will there be voltage across the machine terminals, if you connect a voltmeter, yes, because there will be E 2 per phase induced top same frequency and root 3 into E 2 will come here this voltmeter will create, and this will be a balanced 3 phase voltage ok, because the windings are specially 120 degree electrical apart phase windings.

Therefore although there will be AC voltages induced, but no current flows can rotor producer magnetic field, no, coil must carry current to produce its own magnetic field and only magnetic field present in the machine is B s ok. And B s, just it is like this there is a suppose magnetic field is at this point, these are stator coils, they are energised B s and rotor is there, but no current is flowing. So, B s is suppose like this at this time, it is vertical [FL]. If it is vertical, this do not forget that these are the lines of forces at that instant [FL].

What this becomes it is a two pole structure I have taken. So, this will become stator south pole and lines of forces are coming out from the surface. So, this has become N S half of the stator is S S N S like this. And while completing its path, I mean it will complete here, it will not go to here I just that vector, I were showing. Vector arrow is along the direction of lines of force inside the machine. So, it will go like this. So, half of this will become south pole and half is north pole, this we have seen extensively.

But you see a rotor coils are not carrying current no doubt, but rotor this the, this one lines of force are emanating, because of the stator field it becomes your some NR induced. And this becomes S R is not that, is this is the stator iron, what I am telling. This is only rotor iron, rotor coils are not carrying current. The moment you tell there are lines of forces moving like this, oh, rotor this surface must have become a north pole induced like a soft iron piece kept in a beside a permanent magnet, it becomes a induced magnet. But nonetheless note that this is N R, because lines of force from the surface of the rotor coming out, and lines of force are entering. So, so this is S R, these things are there.

But that is the rotor poles are also created, when rotor as is not carrying any current no doubt because of this induced poles in the rotor because of stator poles. But one interesting thing you see this, this N R and S R can S S and N R interact and give you torque, no, because there line of action is same, there must be some shifted thing if this is S S this N S, your N R, S R must be shifted here. In one of the lectures, I told you that then only it will experience rotor will experience a torque. Otherwise, this induced pole is doing nothing it cannot produce at least torque is that clear that is very interesting.

Although there will be induced poles, but the there is no angle between these two to give you a force or torque developed in the machine, so that will be there. Now, so with this switch open only thing what happens is this, because of this B S, there will be induced voltage here. And what will be the line to line voltage root 3 in to E 1, and it balance this balances the supply voltage if you neglect stator resistance and leakage reactance. If you neglect, this applied voltage will be balanced by the induced voltage E 1, E 1 here ok.

Similarly, in the rotor circuit, there will be E 2 induced voltage per phase root 3 will come here a balanced 3 phase voltage is available across the rotor terminals that will be the thing. Mind you the induced voltage in the rotor is balanced 3 phase. Now, let us imagine I have, I have close this switch, I have close this switch. If you close the switch, there was balanced 3 phase voltages; therefore, we expect and suppose it is shorted these windings are balanced all the impedances whatever it is on the rotor side they are equal. And therefore, it is expected this E 2 will drive some current in i R r i Y R and i B R is it not.

They are expected to deliver current, but nonetheless this currents will be balanced 3 phase currents, because it is after all in the rotor you have generated balanced 3 phase voltage, and you have close the circuit. Impedance in each phase is its own impedance that is our current will circulate. And therefore, balanced 3 phase current will flow also in the rotor coils. If that be the case then we know, what is going to happen, rotor coils carrying balanced 3 phase currents. Therefore, rotor 2 will develop a rotating magnetic field say BR, also in the direction from RR to YR to BR from leading to lagging phases.

And what is the speed of this rotating magnetic field, speed will be once again if f r is the frequency of the rotor 2 f r by p will be the speed of the rotating wheel. Let us imagine that initially the rotor was stationery when I close the switch. Mind you speed cannot change instantaneously, because it has got an inertia. To change speed instantaneously of a mass or a inertia you require infinite force, it is forbidden that is the Newton's law. It, it cannot, speed cannot change in no time, speed cannot have a straight jump it was 0 in no time, it has become 50 meter per second, no that is not possible, then acceleration must be in infinite. So, only thing it may approach to that condition, if you have applied infinite force that is not we are doing.

So, the rotor has got a finite inertia when it was not closed. Speed of the rotor was 0 at t less than 0 speed was 0. And the t equal to 0, I have closed the switch. At t greater just equal to 0 plus what I am telling rotor speed must be 0, speed cannot change. Let the rotor carry current whatever it does, it does, but speed instantaneously cannot change, it forbids Newton's laws of motion ok, speed cannot change instantaneously. Therefore, at t less than 0, n r was 0; frequency of the rotor was f, supply frequency we have seen a little bit earlier in the last class. So, frequency of the rotor current rotor was f.

At t equal to 0 plus n r is once again 0 still 0. Therefore, frequency of the rotor current at t equal to 0 plus is also supply frequency, it has not changed. Therefore, after we have closed this switch, I find that stator coils are supplied by a frequency f, rotor induced voltage, rotor has not yet started moving speed cannot change instantaneously, although current will flow in the circuit. Therefore, frequency of that current will be f.

Therefore, let us concentrate at t equal to 0 plus, what is the scenario, t equal to 0 plus the scenario is there is a stator field I will just draw this it, it was moving with n s. And the rotor frequency of rotor currents is also f. And it will produce therefore a rotating magnetic field which is suppose, I say I do not know where it is positioned, but, but I am pretty sure about this thing, there will be another rotating field now coming into picture B R say. And these also will move with what speed n s was equal to 2 f by p, and B R, what is the frequency of this current f, it will also move 2 f by p in the same direction.

The same direction I will further discuss, but it is not difficult to understand why it should rotate in the same direction. I will right now tell, but what happens is these at t equal to 0 plus, I note that there is a B S, there is also B R, two fields are there. And both of them are rotating with same n s. Therefore, a stationary observer will conclude, the angle between them, although they are rotating but angle will remain fixed in phase. And therefore, see without doing any maths we are trying to physically understand ok, can we understand what is going to happen that is my intention is. So, at t equal to 0 plus, there is a stator field of supply frequency f, electrical speed is f, rotor also the same speed.

Mind you the number of poles of stator and rotor windings must be same, because we know that you cannot have a machine, you have wound this stator for 4 poles and rotor you have wound for 2 poles, it, it is not going to work that we have seen earlier. So, some basic conditions to be fulfilled by for the torque production is that the number of stator poles and number of rotor poles must be same. If the stator, you have wound for 4 poles rotor is to be also wound for 4 poles.

Therefore, at t equal to 0 plus, we find two fields are there now. Here also when the rotor was opened as I told you there were two pole 2 poles there, even if rotor was not carrying current, there were induced pole on the rotor, but this B S and this so called induced rotor poles, they will be along the same line they cannot produce any torque.

Perhaps in this case when you close the switch, there will be a rotating field produced by rotor. And frequency of the rotor current at t equal to 0 plus is also f. And it is f the frequency of the balanced 3 phase current which decides the speed of this field, and with respect to whom with respect to the structure. What is the structure now, rotor, but rotor is not moving at t equal to 0 plus. Therefore, a, a stationary observer will say both the stator field are there, rotor field are there, they are moving with same speed. And therefore, it is expected it is produce a torque and machine will start moving.

Now, just physically to tell in which direction rotor will start moving. The Lenz's law tells us that the induced voltage or induced current in a coils will be such that it will try to oppose the very cause for which it is due. What is the reason for current in the rotor conductors here, it is because of the induced voltage. And induced voltage as we have seen depends upon the relative speed n s and n r, which was equal to n s at the instant we are considering that was the cause of the induced voltage. In simple terms, because there is a relative speed that is why there is an induced voltage in the rotor coils. And because of that induced voltage the current is flowing.

Now, the question is there are two options on the rotor. We have now understood rotor may rotate, because there is stator field separately created B R rotor fields separately created. But the question is in which direction it will? Either it will move in the same direction as that of B s in the clockwise direction or in the opposite direction, which one do you think it will move, so that induced voltage becomes lesser and lesser because that is the cause. So, cause it should start moving in such a direction such that the relative velocity decreases with time, then only Lenz's law will be satisfied.

Of course, in later lecture we will apply left hand rule and decide about the direction of rotation that is there, but you also start thinking in this way that there is a stator field, there is a rotor field, that t equal to 0 plus, they are moving at same speed. So, it satisfies that condition the angle between these two fields, perhaps is going to remain same at least at t equal to 0 plus. And therefore, we expect some torque is developed. And the question is in which direction clockwise or anticlockwise, it is decided by in which direction stator field is moving, it is moving in the clockwise direction. And you may be rest assured that rotor will start moving in the clockwise direction as well that is the important and interesting part ok.

Now, this is at t equal to 0 plus, so we have now understood there will be stator field, there will be rotor field, and hopefully this B s and B R are not along the same line. We will examine those things, but it is likely they will have some angle separation between them, and that will cause rotation and rotor will start moving. And rotor will start move, so some electromagnetic torque is developed and that is causing acceleration.

Now, after t equal to 0 plus goes machine will slowly pick up speed. Now, I want to accepting ok, rotor will start moving, now the question is it, it will speed up 0 rpm it was, it will be 5 rpm, 10 rpm most probably that way speed will go up. And at what rate it will go up it depends upon its inertia if it is a very large motor, it will slowly slowly move up; if it is a small motor, it will very quickly pick up those things are there.

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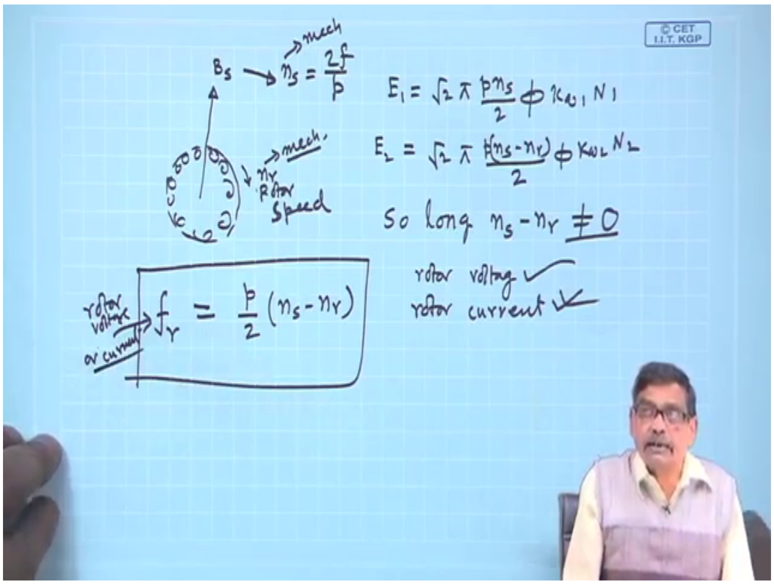

Now, the question is let so rotor will start moving. Let us argue like this. I will not draw all these details thing now, we have now understood this is B s, n s this ns is 2 f by p so much rps. And here is now rotor; rotor I will simply draw like this. So, rotor coils are there. And we have now learned if rotor has to rotate, it has to rotate in the same direction, rotor speed, all are mechanical speed, mechanical, this is also mechanical. It cannot rotate in the opposite direction, because then it will violate Lenz's law relative speed must go on decreasing.

So, so the induced voltage in the rotor E 1 we have written several times nonetheless let me repeat that it is p n s by 2 plus per pole kw 1 N 1; E 2 will be root 2 pi p n s minus n r suppose rotor is root rotating at some speed in the same direction so it must be then this phi kw 2 N 2. This is the rotor speed, rotor speed not rotor field speed rotor speed; n r is mechanical speed you connect a tachometer whatever reading it shows, it will be like this. So, there is now n s minus n r, and nr is going on moving.

Now, the question is that t 0 plus business has gone now sufficient time has elapsed rotor is rotating stator supply, you have given Bs is there. Now, the question is what is the frequency of the rotor current? Because it is the frequency of the rotor current that will decide what will be the speed of the rotating field. So, long, so long n s minus n r not equal to 0, there will be rotor induced voltage, rotor voltage will be there as well as rotor current will be there, because rotor current will be also present, because I have kept the switch closed done nothing else.

Therefore, both these things will be present. And I know if rotor current is present, rotor will produce a rotating magnetic field. What will be the speed of that field, it depends upon the frequency of the rotor current. What is the frequency of the rotor voltage and rotor current it will be p by 2 n s minus n r. This is the frequency; frequency of rotor voltage or current or current, anyway we will continue this in next lecture.

Thank you.