Energy Resources and Technology
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Lecture - 28
Wind Electrical Conversion-II

Let us first briefly recapitulate what we said in the last class.

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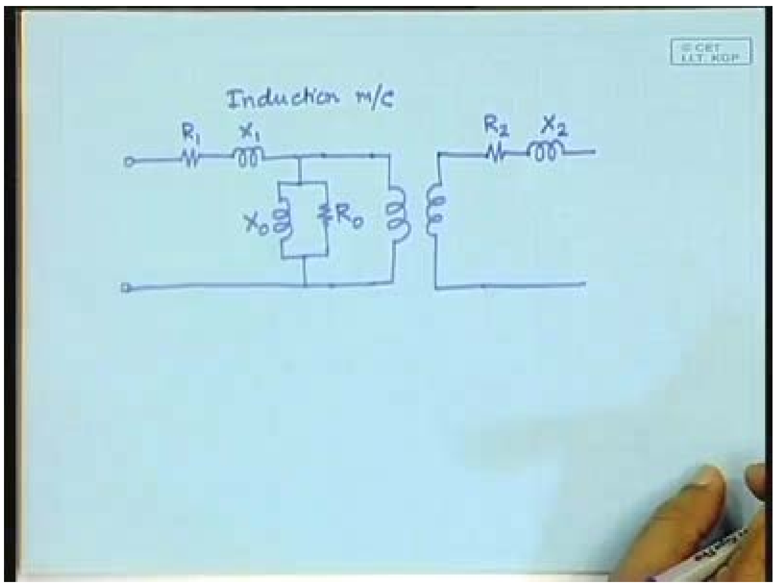

For the induction machine, we were developing the equivalent circuit and said that let this be the input side. There will of course be the stator resistance, there will be the stator leakage reactance and then there should be the magnetizing branch comprising of a magnetizing reactance and a loss component that is represented by a resistance. These represent the Eddy current loss and the hysteresis loss and then we said first that here after this has happened, there should logically be a transformer and that transformer here we will firstly represent the turns ratio between the stator side and the rotor side and secondly turns ratio will make the voltage different. But not only that, there will be a difference in the frequency in the rotor side also, because the rotor bars when it is rotating, see a different speed of rotation of the stator field.

So, there would be two things which we first represented as a transformer here and in this secondary side of the transformer there would be a resistance and a reactance, this resistance representing the rotor resistance, the rotor reactance, stator resistance, a stator reactance, the magnetizing reactance and the resistance due to the magnetizing branch. Then, we said that there are two conversions.

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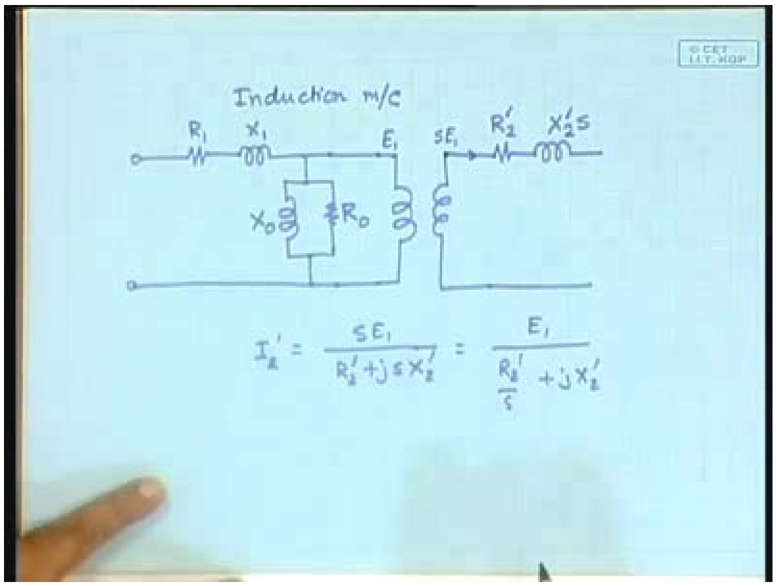

One, the one due to the turns ratio that can be taken care of simply by or the voltage here can be made equal to the voltage here simply by changing these, exactly by multiplying these by this square of the turns ratio and when we do that, we represent that or we signify that with the dash, with a prime. So, when we write this, you would assume that that transformation has already been done. So, here the voltage was E 1 and here also the voltage would be E 1 if they were rotating, if the secondary side were static, but then if it is rotating it would be SE 1.

S being a very small number the voltage induced here will be a small number, but at the same time the reactance here would be X 2 dash S, because the reactance is dependent, the value of the reactance would be dependent on the frequency which is then dependent on the slip and then we say that we can, if this is, this is the current, the current I 2 prime will be then SE 1 divided by R 2 prime plus jSX 2 prime and this is the same as E 1 by R 2 prime by S plus jX 2 prime.

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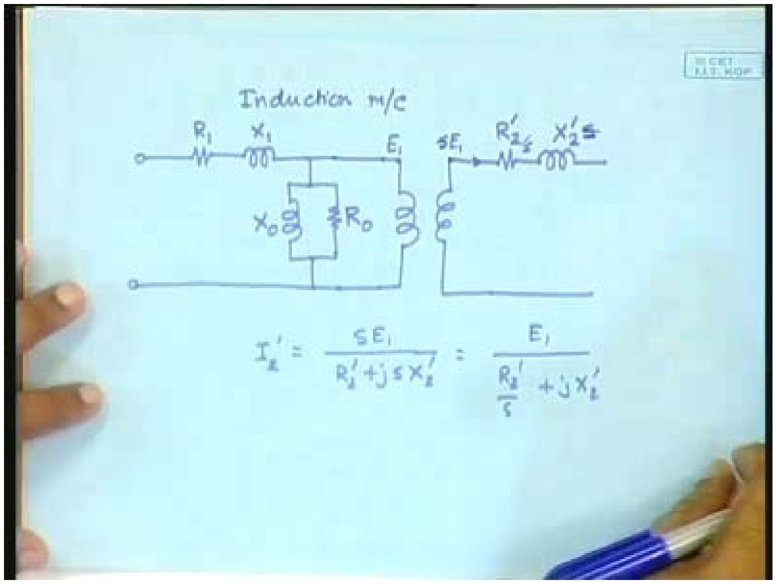

Since these are the same, we can say then that we will eliminate this transformer by dropping this and in that case this will have to be divided by S and this drops, this drops.

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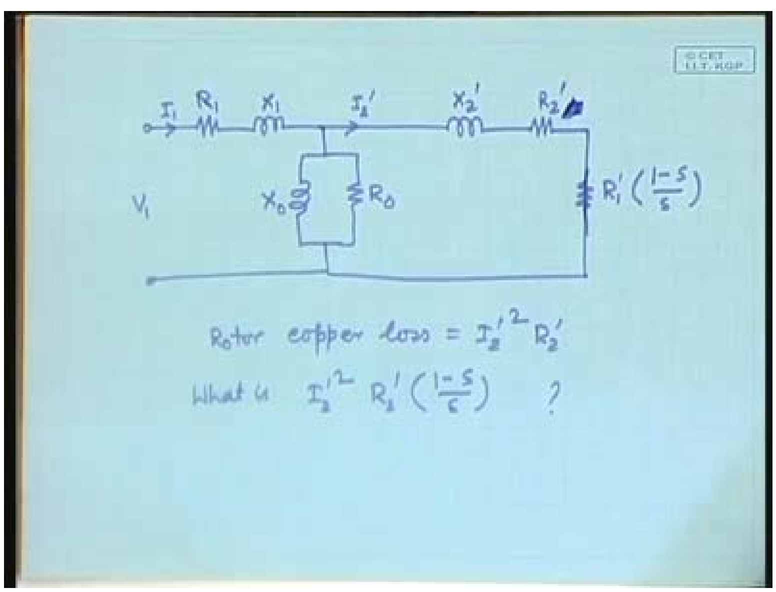

So, after that has been done, the final equivalent circuit is resistance, reactance, reactance here, a resistance here, a reactance here and a resistance here and this side is completely shorted, because the secondary of the induction machine is shorted. The rotor is a shorted rotor. So, let me give the names. This is R 1, this is X 1, this is X 2 prime, R 2 prime, X naught, R naught; this is by S. Now, notice; still we are talking about motors, we are not talking about generators. Here you have applied the voltage V 1. Now, what will be the stator copper loss? The current here I 1 square R 1, no problem.

How much will be the R n loss? You have to simply solve this circuit to find out how much is the current through this branch and that I square R naught. How much will be the rotor copper loss? You have to find this current I 2 prime. Why prime? Because, it is the equivalent referred whatever is the, is the current value in the rotor that is its referred value to these stator quantities that is what we are talking about. So, it is I 2 prime. You can easily find out from the circuit simply by solving these circuit equations what is I 2 prime? Then, I 2 prime times, times, well, wait; logically is it not true that I 2 prime times R 2 prime will be the rotor copper loss, I square R.

Where does the S come from? The S is, yes, we have already established conceptually that it should be there. But, we can say the rotor copper loss is I 2 prime square R 2 prime that is what conceptually it is; yes, it is true. The rotor copper loss is really this. Then, what about this? In order to take into account that issue what we will do is we will break it up into two parts. We will say that R 2 prime, let it be here, but ultimately we know that this thing was R 2 prime by S. So, we will add an additional resistance here, so that the total becomes R 2 prime by S.

What will that resistance be? R 2 prime into 1 minus S by S, so that these two added together will give …. Now, we have conceptually clarified that here this current square times this resistance will give you the rotor copper loss. Then, what is this? What is I 2 prime square times R 2 prime 1 minus S by S? After all, if the current is flowing through this resistance, there will be loss in this resistance. What is that? That is the mechanical power that is converted from the electrical domain to the mechanical domain. So, it is the electrical equivalent of the mechanical power that is converted, clear. So, you see in terms of the circuit, in terms of the equivalent circuit even the mechanical quantities become immediately, clear. This is the mechanical power that is ultimately available as, that is that will produce the torque, that will produce the actual motor force.

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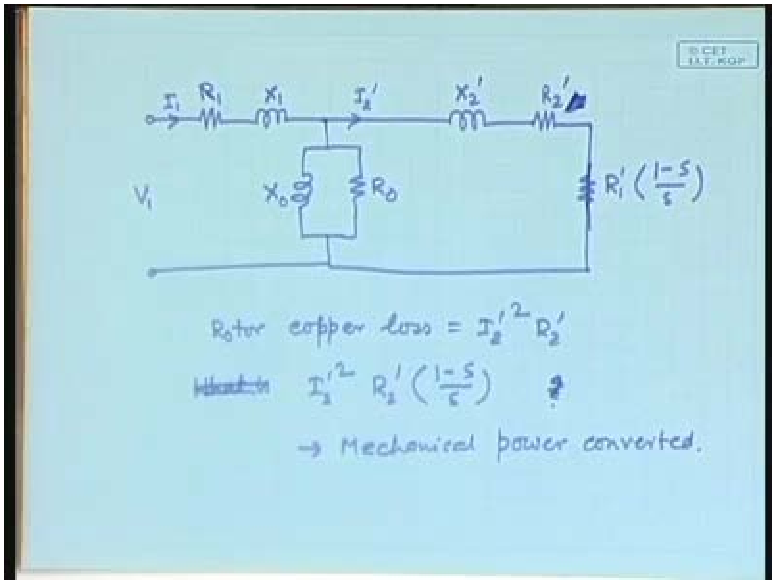

So, this is, this is the mechanical power, right. The moment you have the mechanical power it is trivial to obtain the torque. Why? Because the mechanical power is the torque times the angular speed.

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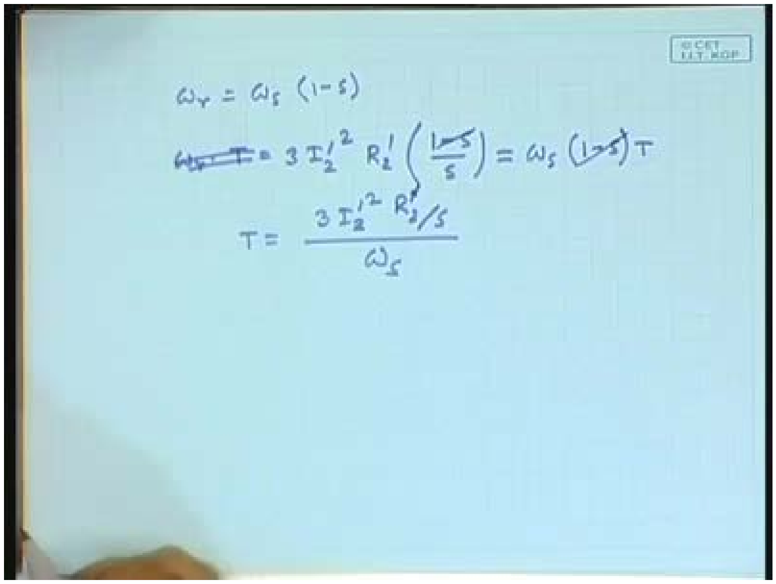

So, we can write, what is the angular speed? Omega r is omega s, this is the synchronous speed which we know because the field is rotating; the moment you have energized the magnetic circuit, the field is rotating and that speed is omega s and there was a slip. So, the omega r is given by … So, the rotational speed, angular velocity of the rotation, actual rotation, will be the angular velocity of the fields rotation times 1 minus S, S is a very small quantity like 0.03. So, the omega r is really close to omega S, but not really equal to it. If this is omega r, then we can write the omega r times the torque is equal to the power. That is I 2 dashed square R 2 dashed 1 minus S by S; no, not really true, because these were per phase quantities.

So, this is the per phase power and since there are three phases you have to multiply by three, because the torque is not per phase, the angular speed is not per phase. This is the total quantity, but the electrical quantities were per phase. When we said that this is the current, it is the phase current. So, these are all per phase quantities, so this has to be multiplied by three. Now substitute omega r. I will write in this side, I will write this in this side, so omega S 1 minus S into torque, right. So, you see, 1 minus S cancels off and you get T is equal to thrice I 2 dashed square R 2 dashed by S here by omega S, fine. Notice one interesting, very interesting thing. What is this?

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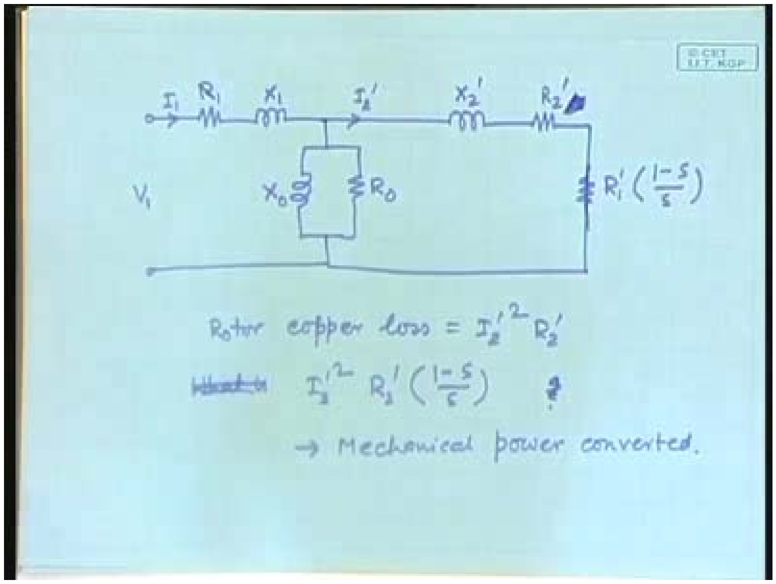

After all, when we had written this as R 2 dashed by S, it was R 2, this was the, we were musing about what is, what is the physical meaning of it, I 2 prime square R 2 prime by S? See, we have come back to it. So, what is it? This is the mechanical power and this is the rotor copper loss. So, if you take them together, what is it? The power that goes across the air gap, the power that is mechanically transferred that is electromagnetically transferred across the air gap, it is this power when you, when you multiply I 2 dashed square times R 2 dashed by S, which is the summation of these two and that is what is appearing here.

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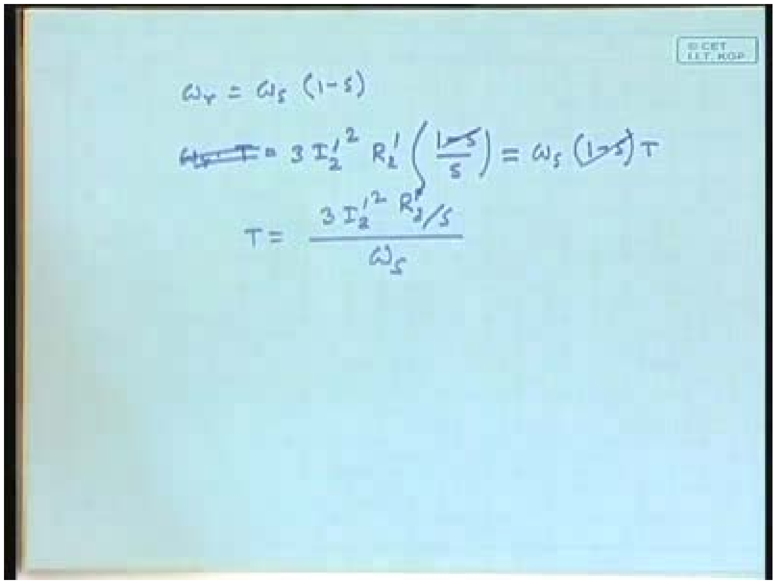

So, one way of visualizing the torque is that it is the rotor speed of rotation times, no, the torque is the actual mechanical power divided by the rotor speed of rotation. The other way of looking at it here is the power across the air gap divided by the synchronous speed, they are the same. That is something that makes things much simpler, because the power across the air gap is a very simple quantity and the omega S, you do not have to worry about many things, about the slip and all, it is just the speed that is produced by the rotating electromagnetic field, clear. So, that is the torque. But then, you have to find out I 2 dashed square.

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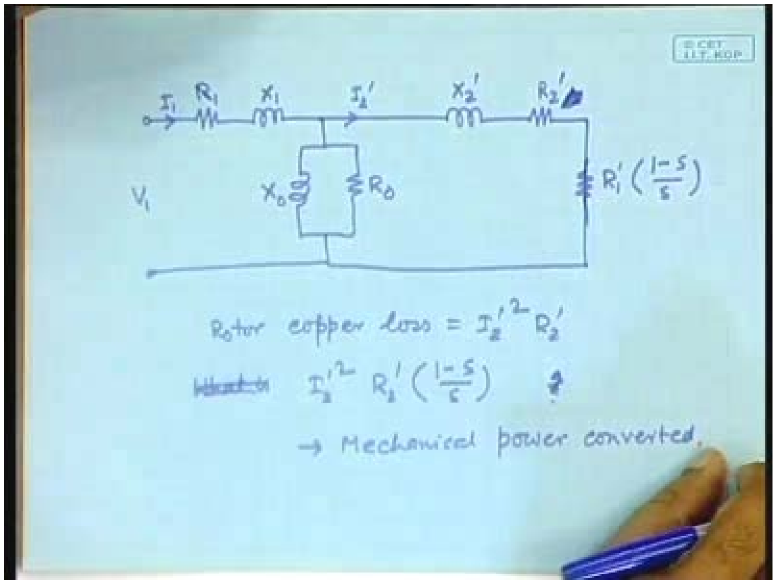

From this, can you not find out this? Yes, you can, not a difficult thing at all. All you need to do is to solve the circuit equation. So, here is the voltage applied and then you have to find out what is the current through this? You would notice that this would be a bit difficult to actually solve if we use this equivalent circuit because then, of course you can do it, you have learnt how to do it, all right, but it will take time. Why? Because you have applied here, so there will be a current, you have to make an equivalent circuit of these three branches, then you have to add this. Then V 1 by that equivalent resistance will give you this current and that can be divided into these two components and all that will have to be calculated and then only you finally obtain I 2 prime; obtainable of course, but a bit cumbersome.

So, what the electrical engineers do is to assume that it won’t, the sky will not fall on our heads if these two things are moved to this side. Yes, it will incur a bit of inaccuracy, but that inaccuracy is to the extent of 10% only, we will tolerate that.

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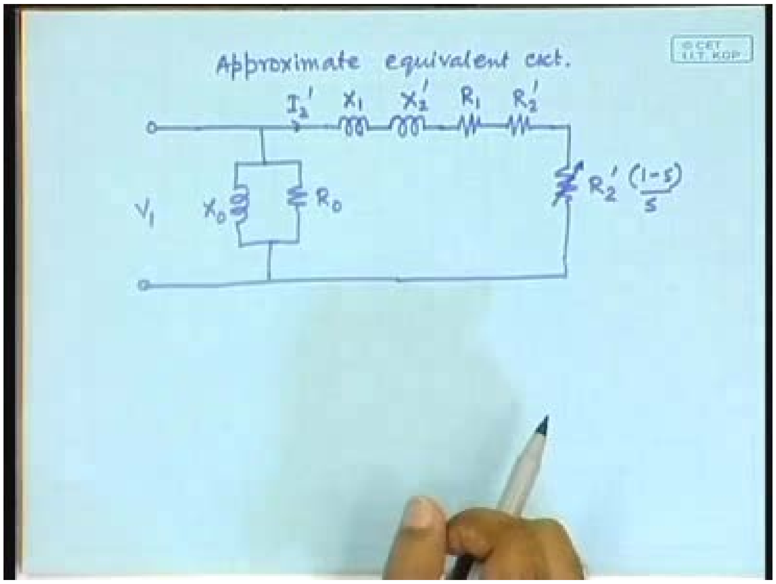

So, what we do is we move these two to this side and as a result the approximate equivalent circuit becomes, then it will be first the magnetizing branch, then it will be the X 1 X 2 prime, R 1 R 2 prime and then here there will be, that I will designate it as a variable resistance because it is variable quantity, R 2 prime 1 minus S. This is the approximate equivalent circuit. If you have it as an approximate equivalent circuit, you would immediately realize that calculating these things should be trivial. Why? Because how much is this?

This voltage is same as the input voltage and therefore all you need to do is add this all up, trivial of course, so it will be R 1 plus R 2 prime, because all this put together, R 1 plus R 2 prime plus j X 1 plus X 2 prime that is the total impedance of this fellow and V 1 with angle zero that is in the numerator divide that you get I 2 prime. So, you obtain the I 2 prime and you substitute it here. Then, you get a complete expression for the torque. In terms of what? In terms of all these quantities that appear in the equivalent circuit and then once you have obtained the torque, you can do this exercise yourself. You can see that now it has become almost a trivial exercise to actually write down the expression for I 2 prime and substitute it here. I will leave it to you to do this.

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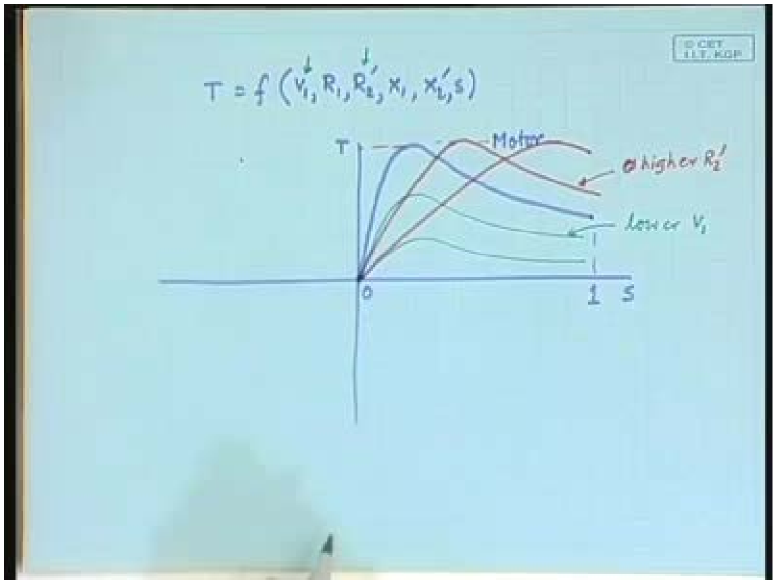

But then, once we have done that that means we have found torque as a function of all these quantities, what will be, will it be dependent on? It will be dependent on say V 1, it will be dependent on R 1 R 2 prime X 1 X 2 prime and all that. Out of all these V 1 is a variable quantity, right, V 1 is the input voltage. It could go up and down, it could vary. X 1 is the leakage inductance of the stator side which is not likely to vary. X 2 prime is the leakage inductance of the rotor side that is also not likely to vary. R 1 is the resistance of the stator winding that is also not likely to vary. But, for a special reason though R 2 prime is not a variable quantity really, but we will try to understand what its effect is; with some special reason, I will come to that.

If you now, it will also be dependent on slip of course most importantly. If we now draw the characteristic of slip versus torque, very important that is called the torque slip characteristics, then what does logic say? When the slip is zero what should be the torque? Slip is zero means the rotor is rotating at the synchronous speed, zero no current. So, it should be here and then depending on this function, depending on the function that you will obtain, please do obtain, today I do not want to drag it for a long time that is why I am leaving that exercise to you, but it is, it is trivial to obtain that, then the graph will be something like this, where this is zero and this is 1. 1 means standstill. Slip is 1 that means it is standstill. So, at standstill condition there is a torque, but then as the speed increases you go this way. As the speed increases the torque increases, but finally it goes like this. That is the motor ….. So, that is this side is the motor, clear.

Now, what is the effect of the input voltage? The input voltages effect is manifested something like this that, if you, it is proportional. So, this curve will go up and down depending on the input voltage. So, it will go something like this. For a smaller input voltage it will be like this. So, that is how it depends on the input voltage. How does it depend on, I am talking about the dependence on these two quantities, again with some good reason; I will tell you what? If you change R 2 prime that means if you increase the rotor resistance, then its shifts like this. The peak remains the same, the peak remains the same, so this is higher R 2 prime and this is lower.

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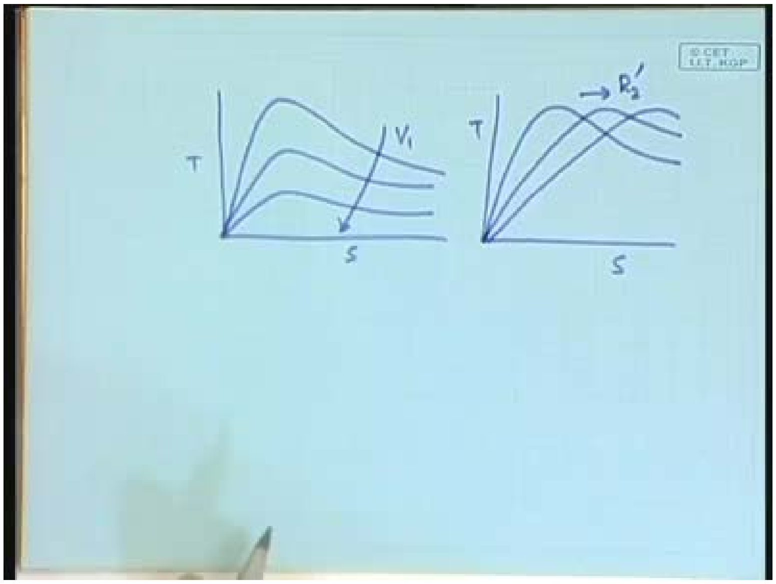

Just to drive the point home, if you vary the input voltage it will go from here to here to here. So, V 1 is being pushed down, slip versus torque and if you vary the rotor resistance, then it goes like this, clear. That is about all that we need to know from the motor side in order to go into the generator side. So, now we will discuss the generator.

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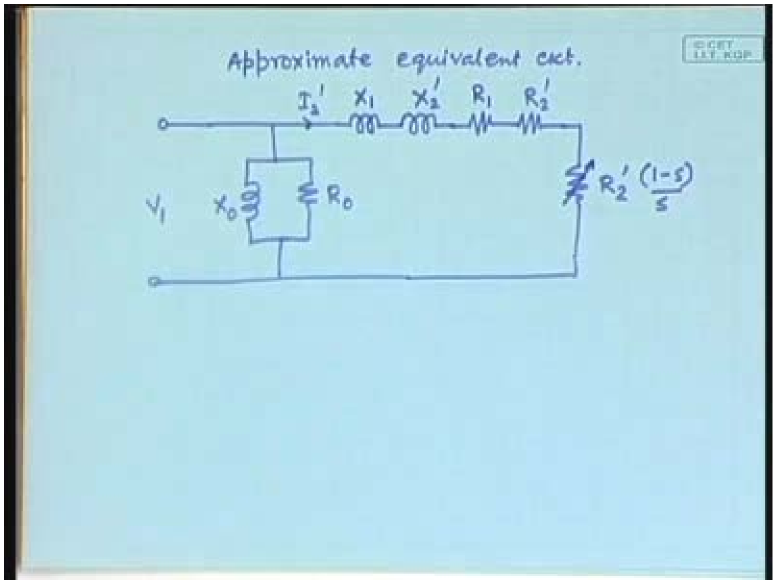

Let us get back to the equivalent circuit. In the generator, okay, what is happening?

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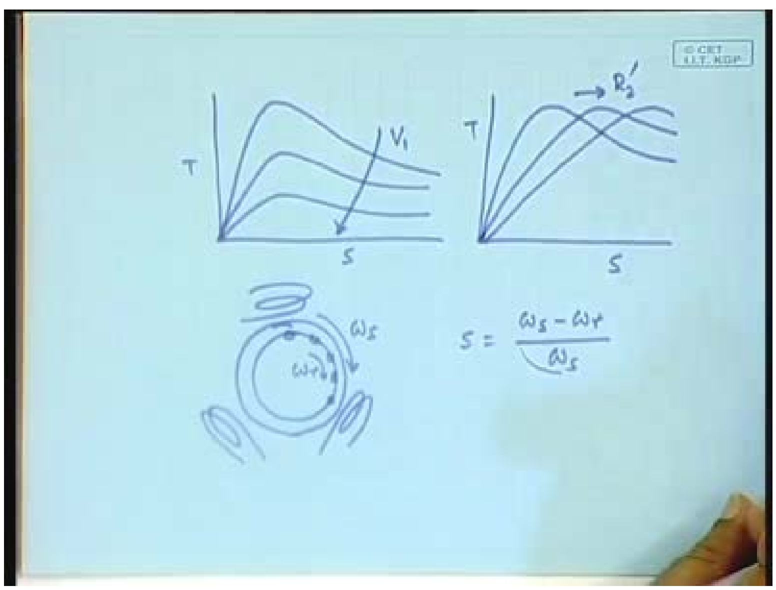

If you have the stator like this, the stator has windings like this which I drew schematically and I said that the stator field rotates with the speed omega S and there is a rotor which has conductors and the conductor fellows are rotating at omega r and so far we said that the slip is omega S minus omega R by … Now, you had energized the stator and as a result of that the rotor was rotating at a speed that was less than the synchronous speed and therefore S was a positive quantity. Now, suppose with something external to this thing, the rotor is speeded up to a speed exceeding the synchronous speed, then what happens?

Immediately you can see that the S becomes a negative quantity, S becomes a negative quantity. This fellow becomes larger than this one.

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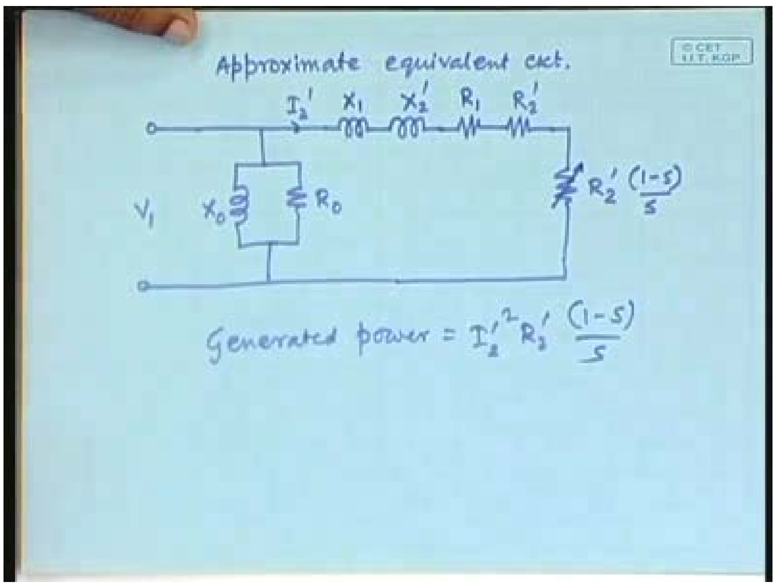

S becomes a negative quantity and as S becomes a negative quantity, in this equivalent circuit see what will happen? S becoming a negative quantity what is the meaning? Wait; this numerator remains positive quantity, all right, but this denominator becomes a negative quantity. So, the whole thing becomes a negative quantity means I square R loss, still it is I square R, right, but that I square R now becomes negative. I remains positive, but since this fellow has become negative the I square R becomes negative. What is the physical meaning of a power becoming negative? It is generated power. So, the quantity of the generated power is obtainable directly from the equivalent circuit as simple …..

So, we find that this amount of electrical power will be generated. The mechanical power will be converted to electrical power and this much of power will be generated and then that power will flow like this and that power, the amount of power that is generated will also supply the rotor copper loss, the stator copper loss, the iron loss and finally the remaining power will flow out, right. So, that is a concept of the induction generator. Notice one important thing. What will be the speed? What will be the slip? What is the sorry, what will be the frequency seen at the input terminals?

It is not given by the speed of rotation, because all that is given by the speed of rotation is a slip. The quantity of power generated will vary depending on the speed of rotation, but the frequency will remain the same as given by the grid frequency from where this supply is coming. So, here it is inherently a variable speed to constant frequency generator. That is what we needed for the wind turbine, right, because otherwise you cannot keep the, you cannot attain the maximum C P value. In order to attain the maximum C P value, the tip speed ratio has to be constant and therefore, as the wind speed changes you have to keep changing the rotational speed which means omega R which means S. So, all the time the S will vary but the frequency will not vary. So, it will still keep on pushing power into the grid. That is the main advantage of the induction machine in comparison to the synchronous machine.

Fine, now let us look at this. If I say that the frequency is given by the frequency of the supply that frequency is after all generating the magnetic field. That means this supply is generating the magnetic field. It is what is allowing this current to flow. Even if the slip is zero that means exactly synchronous speed, this still continues. At slip zero, what happens? It becomes open circuited, this whole route becomes open circuited, but still this continues which means that the magnetizing current comes from the supply, the grid, not from here and that is obvious because magnetizing current is what? It is a reactive current. It is not active power, it is reactive power, because this, this fellow is an inductance. This is only the loss component, but this is the essential component. This is producing the magnetic field and this is a reactive component. What does it mean?

It means that this whole generator, when it acts as a generator, it still continues to draw reactive power from the line, but pushes active power into the line. Do you understand this that there will be two different directions of the flow of active power and the reactive power? The active power will be generated here and will flow like this and the reactive power will have to come from the line and will flow like that. The induction generator does not generate reactive power and this is another important difference between the synchronous generator and the induction generator. When you studied a bit of synchronous generator you have understood that synchronous generator can vary its generation of reactive power by changing the field. Depending on the field it generates a different amount of reactive power, while the induction generator cannot generate a reactive power and the reactive power must be supplied from the field.

So, if this is supplied from the grid, fine, it takes reactive power. But then, the grid is, grid side will be loaded by the reactive power; the grid has to have the capacity of generating that much of reactive power. Well, how is the reactive power generated? Where is the reactive power generated? In a power system, active power we understand; the whole power plant is there for that, there is a turbine that rotates the generator, the generator gives the active power to the supply, all right, that is fine. Where does the reactive power come from?

The reactive powers are generated by capacitances and consumed by the inductances. So, here is an inductance that consumes the reactive power and so, the grid has to have some capacitance in order to generate that reactive power and so, if you have a wind farm or a large number of wind turbine generators at one place, it is a usual practice to place a big capacitor at that spot, so that the reactive power is generated right there and that is what gives the reactive power into this supply and the reactive power does not have to come from the actual transmission line. Because, if the reactive power has to come from the transmission line, even though you are not drawing active power or you are not pushing active power into it, if the reactive power has to be drawn from the line, it pushes up the current that goes through the line.

If it pushes up the current, I square R loss that is transmission and distribution loss of the line will also go up and so, it is desirable to have a capacitor at the end, at the terminals here.

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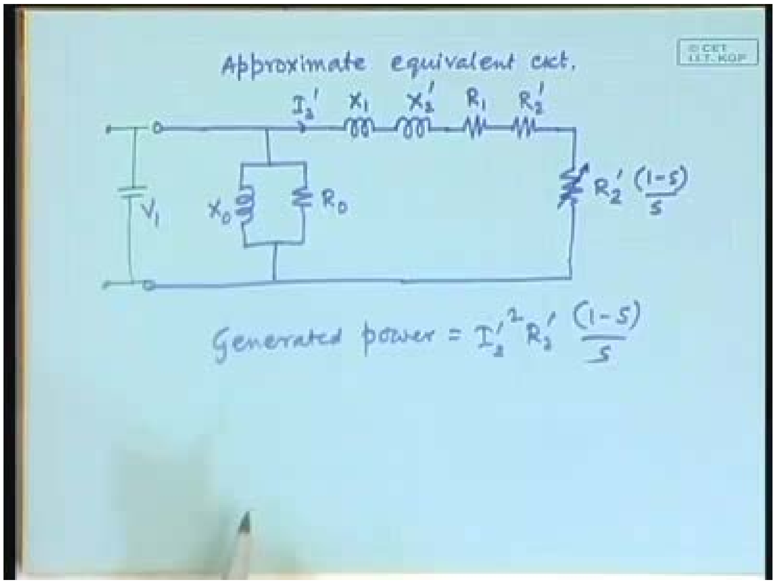

So, let me and then it is …. This is external capacitor. It is not really there inside the machine, externally you do apply or connect this capacitor. I have shown one, but this is actually three phase machine, so a capacitor bank has to be connected either at the end or in the start, finally supplying this reactive power into the system.

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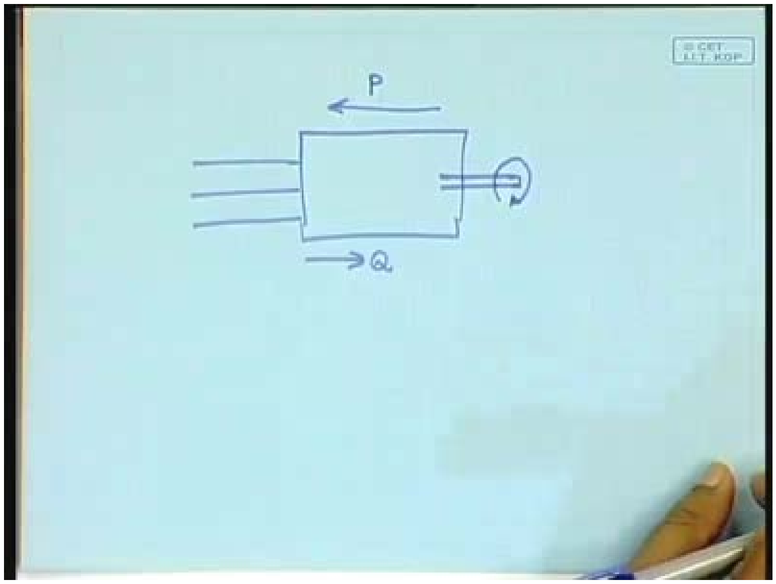

So, one important thing to remember is that if you, if you consider the induction machine as a black box connected to a three phase line and here is a shaft that is being rotated, then you have to, it is important to remember that the active power flows likes this and the reactive power flows like that. This is unique to the induction machine, induction generator, clear.

Well, now the problems that can come in induction generators can be simply solved by solving the circuit equations. So, they are rather trivial, but let us dwell at some length on the torque issue. If you have a some kind of a prime mover, say a turbine or wind turbine, whatever that is that is giving a torque to an electrical generator system and the electrical generator system is generating electrical energy and that is supplying to a load, what will be seen by the mechanical system or suppose you are changing the load, electrical load, you are connecting the load, you are putting lights on and fans on and then switching off, how will it be reflected to the mechanical side? It will be reflected by a back torque. That means the mechanical side is giving a torque and the electrical side will give a back torque and the amount of back torque will depend on how much is the load, electrical load.

If you do not put any load, there will be no back torque, really. If you put a load it will give a back torque. So, it is necessary for us to understand the character of that back torque and the character of the torque when we said it is in the motor mode, you have the torque produced and it is very easy to visualize that. In case of the generator mode you only have to think in same line. In case of the motor, we obtain that there will be a specific characteristic of the variation of the torque with slip and it was, I drew it somewhere, like this.

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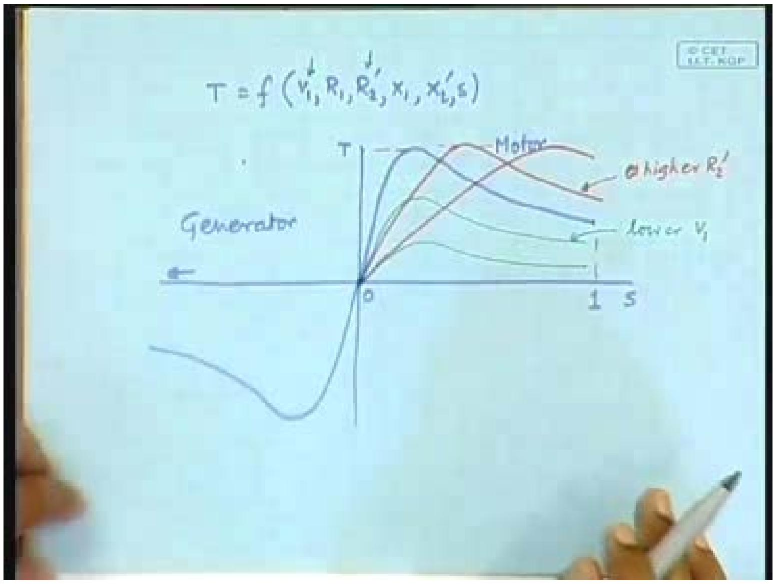

I drew it here, it was like that, but then here the slip was positive. If a slip is negative, if a slip is negative, it should be in this side, negative slip. So, this side will represent the generator mode. This side will represent the generator mode and if this side represents the generator mode then the torque will be back torque, will be in the opposite direction. So, this will be …., so it will be drawn in this quadrant, in this quadrant and it will actually be symmetrical. There is no difference actually between the motor and the generator, all the quantities remain the same. So, there is no reason it will be any different. So, if I draw, it will be a flipped mirror image that is it; follows from common sense and the common sense is right, you do not have to derive it all over again. Same characteristic works, so you have the characteristic like this.

Now, it would be rather inconvenient for us, since we will be spending more time discussing the induction generator, it will be inconvenient for us to draw it in this quadrant. That is why we normally put it in the first quadrant with the understanding that now S is negative. So, when we discuss any further, we will draw the torque slip characteristics like this.

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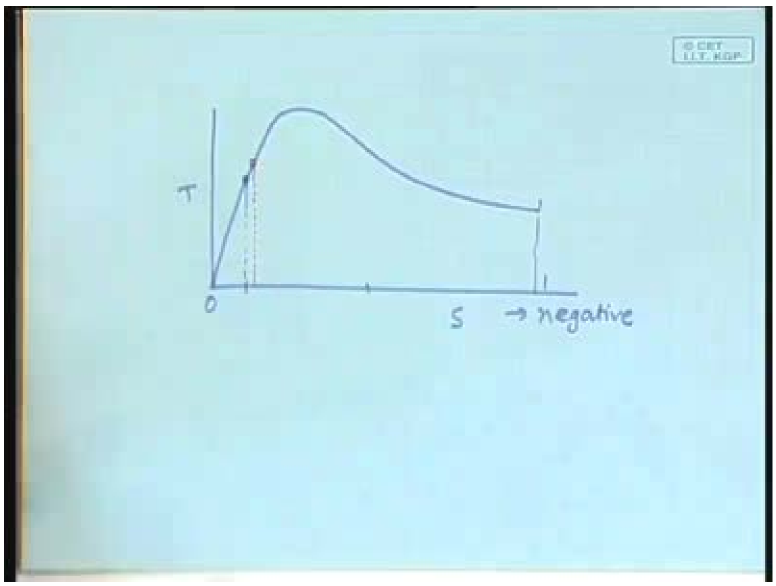

S, with S negative here and the torque is also the negative torque and here it will be, here it is zero, here it is 1 or actually minus 1. The slip being minus 1 means what? Means that the generator is being externally rotated at a slip, at a speed that is twice the synchronous speed. So, there is nothing holy about this value 1, while in case of the motor it was an important thing, because it means standstill condition. But, there is nothing so special about the value 1 for a generator. Now, few things are worth noting. First, suppose you are working say here.

Let us consider two things. One is working here, another is working here. That means this value of slip and for that value of the slip. Now, go up and it meets here. So, at this value of the slip that is the value of the torque and suppose now, due to some reason the slip increases, slip increases means it is rotated at a larger speed. So, then its corresponding value of the torque will be this. There was, the wind turbine was giving a certain amount of torque and due to some reason the slip increased and what has happened? The back torque has increased, right. A back torque increase means it will, it will slow down; it will slow it down. As a result, the slip will again come back to this value. Can you see that? There was a torque given by the wind turbine and when it is working here, if somehow the slip changes, is perturbed, then the torque is perturbed in the direction which will bring the slip back to its normal value. Is that statement clear? Which means, this is a stable mode of operation; this is a stable mode of operation.

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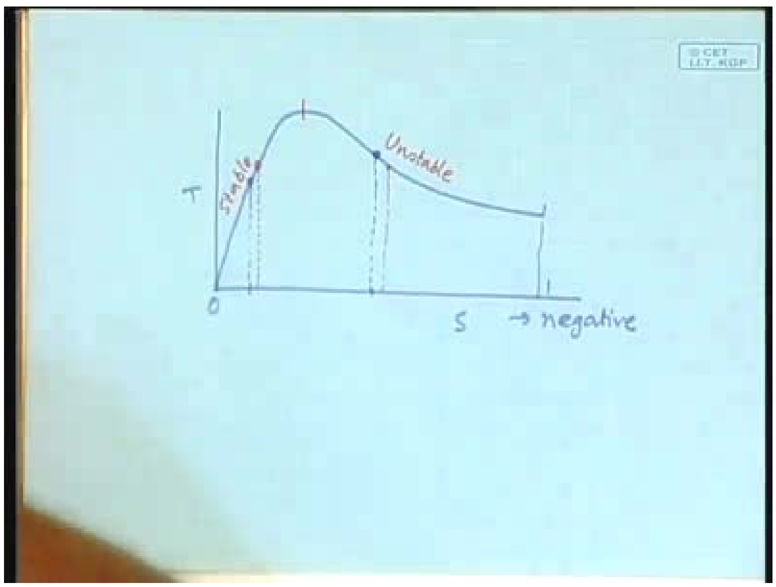

Just contrast it to the condition here. If the slip is here and the corresponding torque is like this, now you perturb the slip to this value that means it has, speed has somehow increased and you find the torque has, back torque has decreased, while the torque given by the mechanical system, suppose it is remaining the same, what will happen? It will further speed up. That means it goes here and then it will essentially run off, because wherever it goes, the generated torque that means the back torque is smaller and it is getting smaller and smaller in comparison to the mechanical torque. As a result, it will speed up; uncontrollably it will speed up which means that this zone is an unstable zone of operation. You cannot work here, you have to work only here all right. So, this is the stable zone and this is the unstable zone and here is the dividing line.

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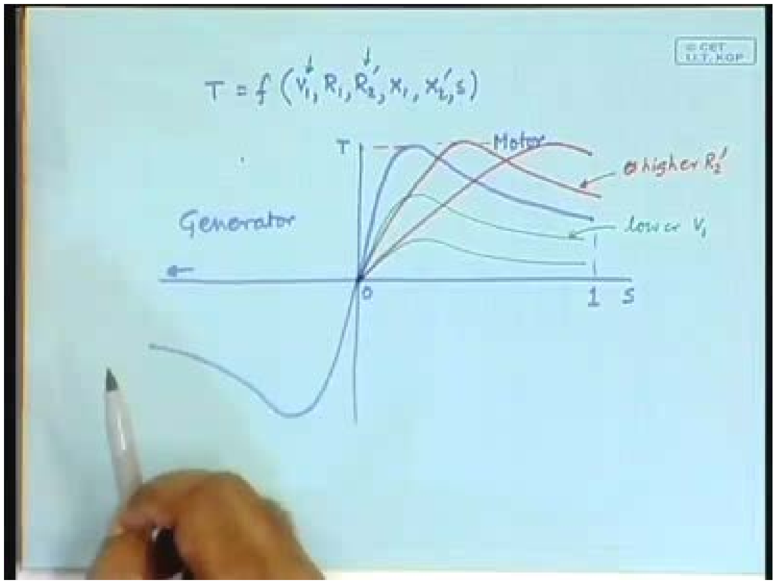

So, you have to work here and you would notice if you look at this that the lower the rotor resistance that means the better the machine, the more steeper this part is. Can you see that? The worse the machine, the lower the slope here, which means that you have a larger range of speed available for proper stable operation, while if it is a good machine, you have very narrow range.

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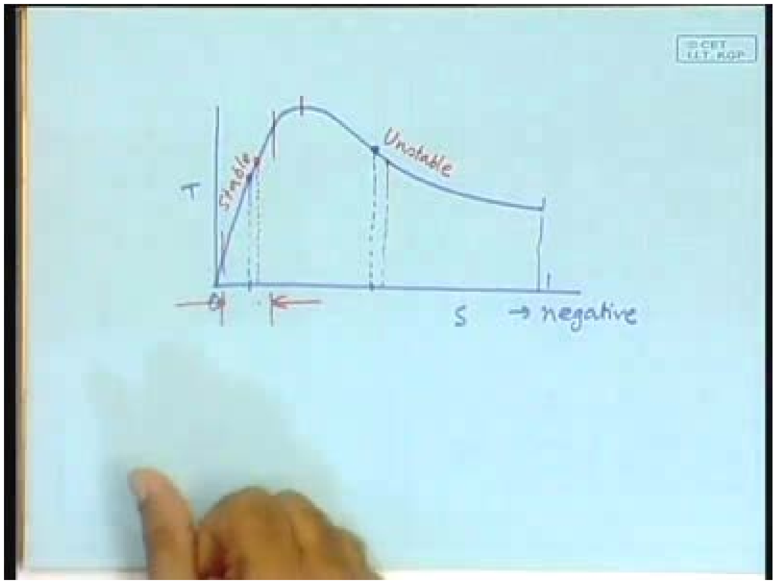

Obviously you will not make a bad machine, you will make a good machine and since if you make a good with a good efficiency, it has a very narrow range of available speed. Only this much, this much variation will be allowed and in fact, in very good machine this is even more steeper which means very little scope of speed variation.

So, I started by saying that the induction machine offers the advantage that it can operate at varying speeds, even though the frequency will remain constant. But it is not, not really so. Can you, can you begin to understand that it is not really so? Because, you effectively have a very narrow range in which you can vary this speed, beyond that it will become unstable. But still there are ways to overcome this, I will come to that. But still, at present time I am talking about 2007, India has about 3000 megawatts of wind electrical generation capacity in India. It is a large amount and almost all of them are simple squirrel cage induction generators connected to the grid which means they effectively have no variation of the speed really and that is actually maintained by variation of the pitch angle. Why? Because this is cheap; the squirrel cage induction generator is very inexpensive. So, if you are buying on the basis of the lowest quotation, obviously this wins, because this is cheap and very rugged, nothing really happens.

But the main disadvantage, as an engineer you will understand that it cannot vary, the slip, the speed above a certain very narrow range.

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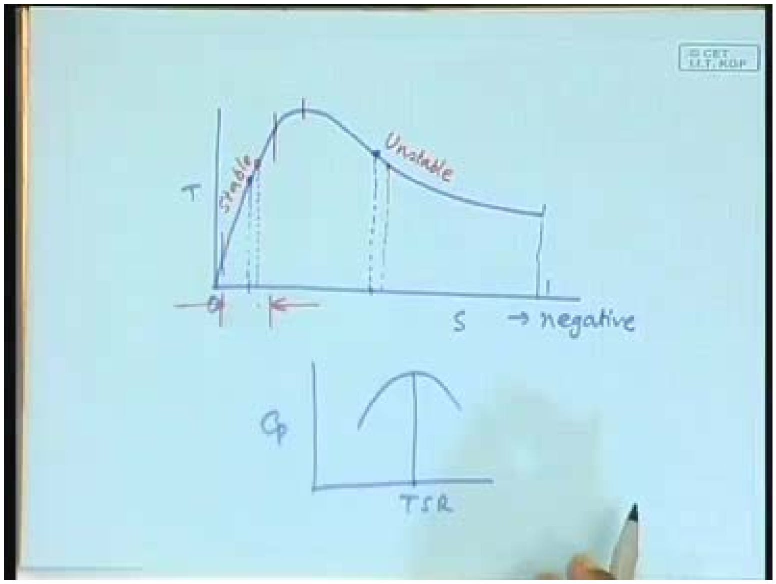

So, when we say that it is necessary for us to have a rather wide range of C p versus TSR characteristics, if this has to be maintained, then this fellow, as the wind speed varies between very, very wide ranges, the rotation speed also has to vary in very wide ranges. That cannot be done with this kind of efficiency. But still, these are the maximal installed machines that are available in India now. So, that immediately tells you that there is a huge scope of improvement.

How the improvements will or coming and other things those things will come in little later, but at least this much is understood. Here I was talking about the grid connected induction machine. You might naturally ask if you install a wind turbine in a remote location where there is no grid, what do you do? It is a natural question.

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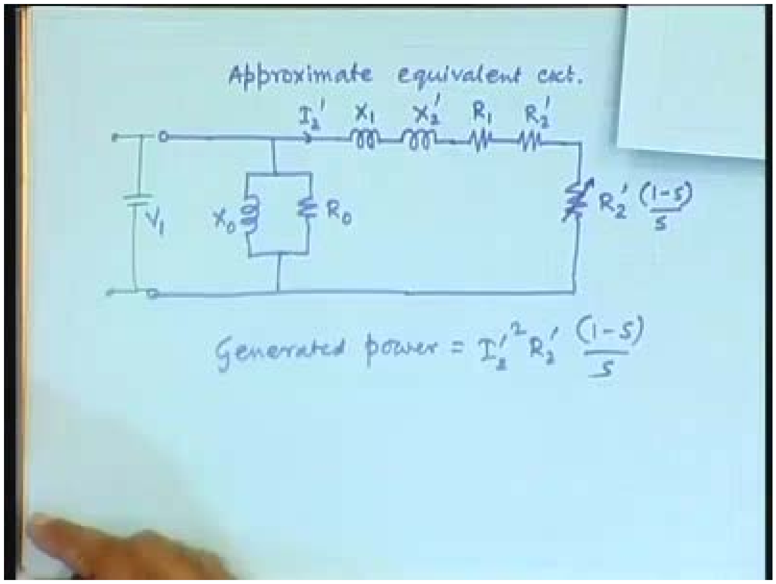

Then you do not have this supply side, then you do not have this supply side. Here you cannot connect to the grid. Then how do you do it? Well, there is still ways of doing it.

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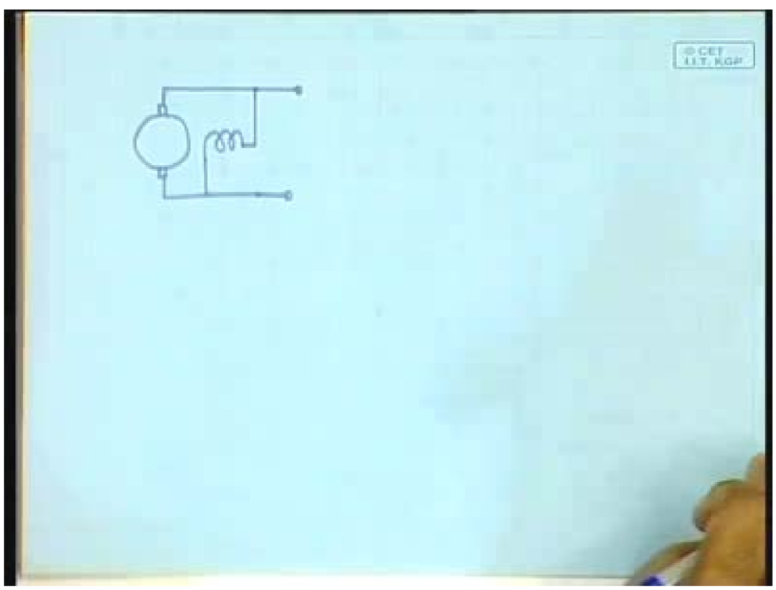

You remember, when you studied the DC machine, just let me draw the DC machine once, say you have a shunt machine and this had to be shunt connected and you have the supply. Normally you will have to give the supply to the field, rotate it and then the voltage is generated. But you have already learnt if you do not have the external supply to connect the field, it can still generate. Why? Because, there will be some amount of residual magnetism in the field, residual magnetism, it is a small amount that will generate a voltage here and because of that voltage a current will be flowing in this loop. As a result, the magnetism will be enhanced. A larger magnetism will produce a larger voltage, which will push another larger amount of current. As a result, the voltage will build up. This is called the process of self-excitation. In DC machine, this you have probably learnt in the first year. This is how the DC machine can self-excite. Similar thing can happen in the induction machine also.

What will happen? Well, in order to understand that you have to, you have to look at this.

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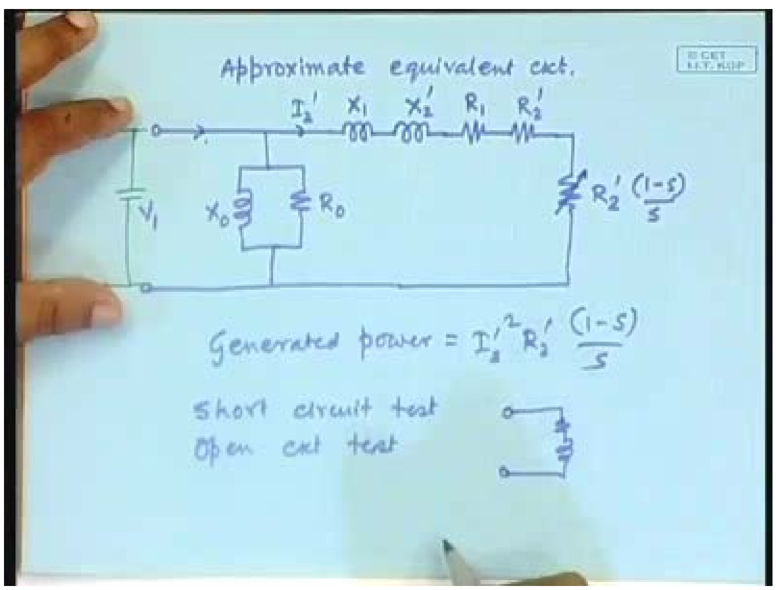

See, here is a, here is a component that produces a magnetic field normally, if you connect a voltage source here and where does the reactive power come from? Power comes from the grid. But supposing there is no grid, but you have connected a capacitor here as I have shown here, then if there is a little bit of residual magnetism as the rotor turns there will be some amount of voltage generated and that will generate some amount of, small amount of reactive power in the capacitor. The capacitor will produce some amount of reactive power that will be pushed into this line. As a result, the magnetism will be enhanced and in same way this machine can also self-excite. This machine can also self-excite.

But in order to understand how and in what way, let us go through this process. While testing the machine what we do is we perform two tests. One is called or if you want to obtain these parameters what do you do? Simple; we …. two tests. One is the short circuit test and the open circuit test. In the short circuit test, what we do is we give a supply, may be not the full voltage, but some voltage and hold it without that means not allowing the rotor to rotate which means the slip will be 1. The slip 1 means this fellow is zero. So, you have only this circuit and the reactance of this one is much lower than the reactance of this one.

So, effectively you can forget in that situation most of this current that is coming from this side will be flowing like this, not like that. So, you can say that here is my voltage which you can measure, here is my current which I can measure and if I place a watt meter, I can measure the wattage and as a result, it is nothing but a circuit like this. You have got two terminals and you have got an effective resistance and effective inductance.
You have measured the voltage, you have measured the current. Can't you? No, you cannot, unless you obtain the active power, you cannot really measure these things individually. So, you measure the active power also. That way you can measure the X 1 plus X 2 prime together, remember not separately and R 1 plus R 2 prime together. That is what you need really here.

They can be separated out. By a DC test you measure the resistance of the stator R 1. If you have measured the R 1 plus R 2 prime and separately measure R 1, you can find the R 2 prime. In order to find this, what do you do? You then do the open circuit test. What is an open circuit test? There you run it free, you run it free, so that there is no, if you run it, run it free, the slip is very little. As a result, what happens? This becomes small number, the whole thing becomes a very large number. As a result, this becomes effectively open circuited. That is why it is called open circuit test. No current almost flows through this line and the current mainly flows through this line. So, if you can do the same thing, measure the voltage, measure the current, measure the active power, you can find these two. That is what we do, but we go a little bit further.

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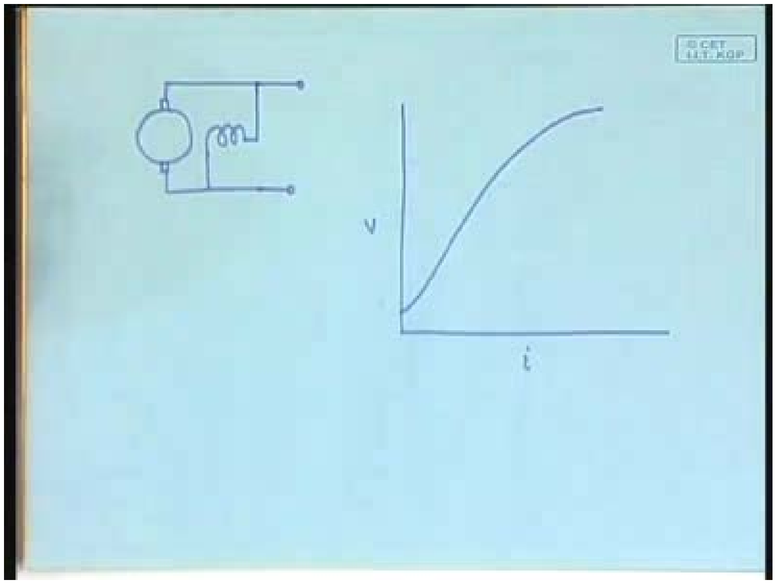

Suppose in that open circuit test we are measuring the current that goes through and measuring the voltage, so the current here and the voltage here and plot a graph, what kind of a graph you would expect? Remember, what is happening here. Here this thing is rotating, this thing is rotating and you are, you are changing this current and you are measuring the voltage and you are plotting like this. Effectively current will be ampere turns. The turns ratio is fixed, so this will be the n i. V is proportional to the flux; the voltage that is induced is proportional to the flux. So, effectively this will be the B-H characteristics and the B-H characteristics, as you know, is something like this. This can be measured. Normally, if you are trying to run a machine as self-excited induction machine, this has to be measured.

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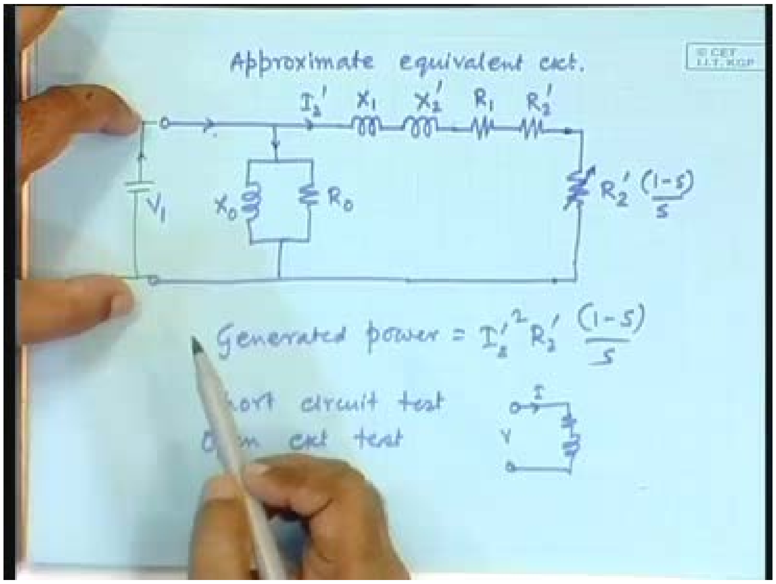

So, once you have, you have obtained this, this says that if there is this much of current flowing through the field, this will be the voltage induced in the, voltage is appearing here. Now, you have connected a capacitor here. As a result of that what will happen? The capacitor whatever is the current that is generated by the capacitor will flow through this, because this side is open …., this side is open. So, this will be the loop. So, the current that is generated by the, by the capacitor will flow through the field and so, these two currents will be the same and the current through the capacitor, the capacitor also has a voltage versus current characteristics, right. A resistor has a voltage versus current characteristics, capacitor has a same characteristic. What will be the characteristic like?

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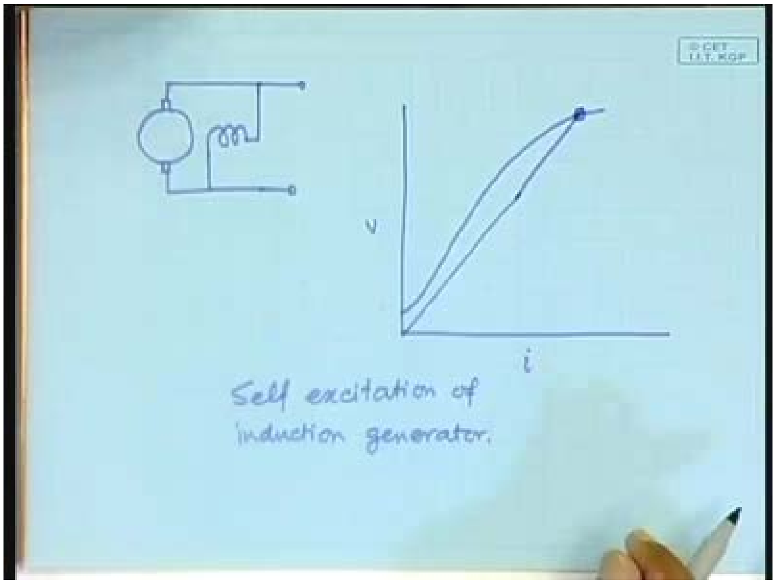

It will be a straight line. So, it will be a straight line, the capacitor line. For this value of the current this will be the voltage, for this value of the current this will be the voltage. But since these two are connected just one to the other, where will it work? Where these two graphs will meet; this will be the voltage generated. So, that will be the voltage generated. This is the process of self-excitation of induction generator. Let us end the class here and we will continue with this in the next class.