Energy Resources and Technology
Prof. S. Banerjee
Department of Electrical Engineering
Indian Institute of Technology – Kharagpur

Lecture - 29
Wind Electrical Conversion – III

In the last class when we ended, we were talking about the stand alone induction machine that means an induction machine connected to a wind turbine which is supplying a separate load that is not connected to the grid.

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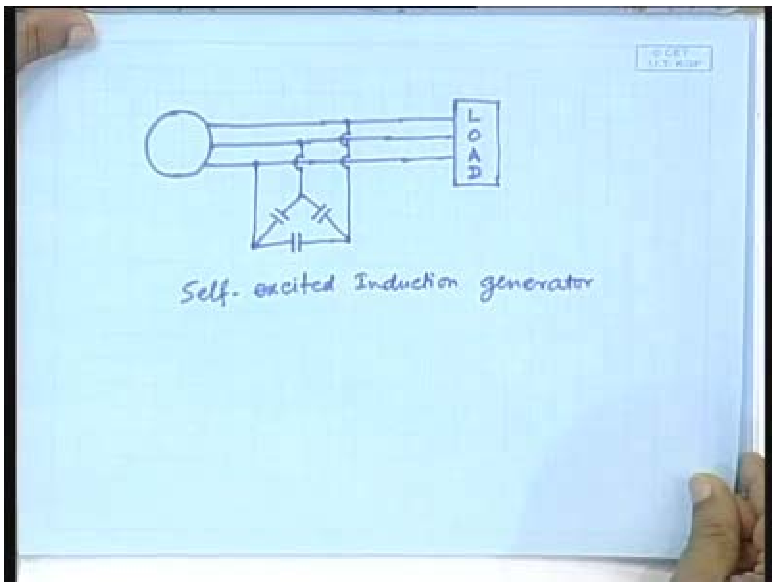

In that case you might represent the induction machine as schematically as this with three lines coming out and as I showed there will have to be a capacitor bank connected across this, otherwise you will not get the supply of the reactive power. So, this can be a delta connected capacitor bank like so, which will be then connected to the line and these lines will be connected to some kind of a load. This could be lighting load in which we can logically assume that to be more or less resistive. It could also be motor kind of load in which it will be a resistance plus inductance kind of load. So, this is the general arrangement for the situation where it is a stand alone system. So, it is a self-excited induction generator.

Now, in that case if you have the arrangement somewhat like this, then in that case the process of buildup of the voltage which I stopped with in the last class, can be obtained conceptually as follows.

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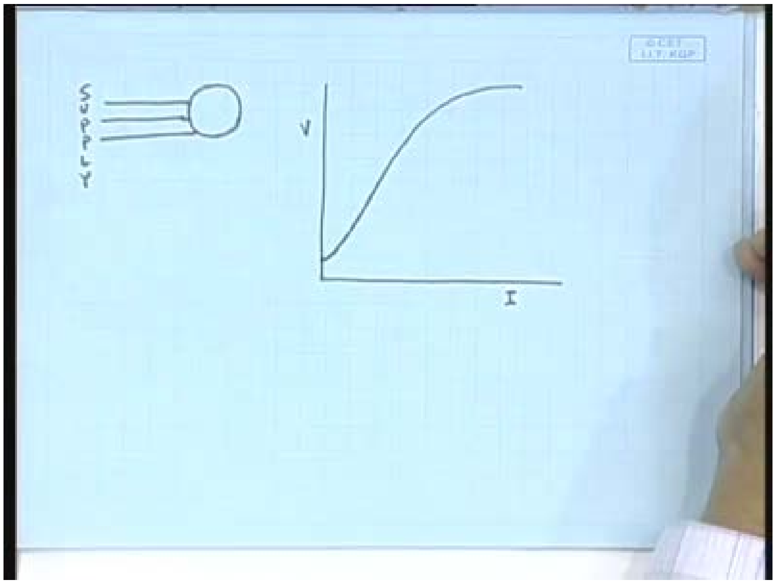

That supposing you have taken the machine separately, say the machine here, I am drawing the machine schematically just as a circle and you have supplied it from a three phase source with the supply side here, as a motor not as a generator and run it free in the no load condition, in that case you will have, you will be able to obtain, if you place voltmeters here, ammeters here and watt meters here, you would be able to obtain the magnetization characteristics of it in the form of the motor current. This is a common mistake that in this case we will have to draw the current here versus voltage there.

Why? Because we are trying to obtain something similar to the B-H characteristics of the magnetizing part and in the B-H characteristics the B, the H, H is the ampere turns, turns times the amperes and so, the current has to be in the x-axis and B will be proportional to the voltage induced and so, the voltage will be in the y-axis. So, if you, if you do that and do the test, you will get the open circuit characteristics something like this. So, this tells that if the magnetizing current is this much the voltage induced will be that much. So, when we did the test you did it in the opposite direction. You applied a voltage and there was a magnetizing current flowing.

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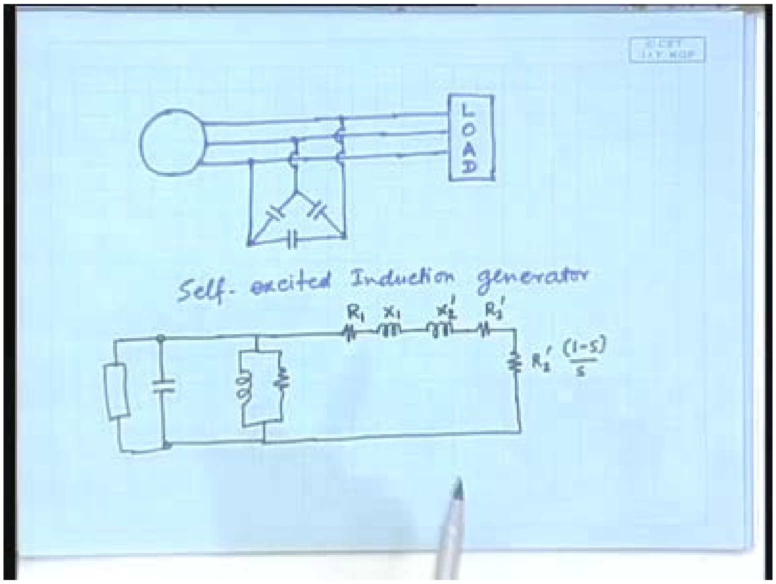

But in this case, you can logically infer that if the magnetizing current is this much the voltage will be that much and then here at the terminal of the machine there is a capacitor bank and suppose this part is now disconnected, you are talking about the open circuit condition no load, so in that case the capacitor bank is connected and if you recall the structure of the induction machine equivalent circuit, it will be this is the magnetizing branch and this magnetizing branch will only be seen because the other part will be open, both in the case of the test where you are performing in no load because in that case the rest of the part, let me draw anyway.

So, it will be a resistance which is R 1 and inductance which is X 1, another inductance which is X 2 prime, another inductance, another resistance which is R 2 prime and then there is a variable resistance connected to it which is R 2 prime 1 minus S by s and here at this terminal, we had connected the capacitor. Remember, this is a power phase equivalent circuit while this thing is actually three phase and it is here that you are connecting the load later, not at this stage. At this stage we are talking about the rest of the machine operated at open circuit that means the load is not connected.

Now, in that situation, in that situation when the, since there is no load the amount of current flowing through this circuit is very small. So, you have only this circuit to be considered and the amount of reactive power being consumed by the magnetizing branch will be the same as the reactive power generated by the capacitor and in that situation, if the machine is rotated because of the residual magnetism there will be some voltage induced here, because of that voltage induced there will be a current flowing through this capacitor and by the nature of the capacitor it will be a leading wire. That means it is a, it will generate reactive power and that reactive power will circulate through this.

Naturally the magnetism will build up and ultimately the whole thing will settle in a specific voltage. That means a specific voltage will be generated in the process of self-excitation. What is that voltage? In order to see that, here is the characteristic, V-I characteristic of the magnetizing branch. What is the V-I characteristics of the capacitor? It is the linear characteristics.

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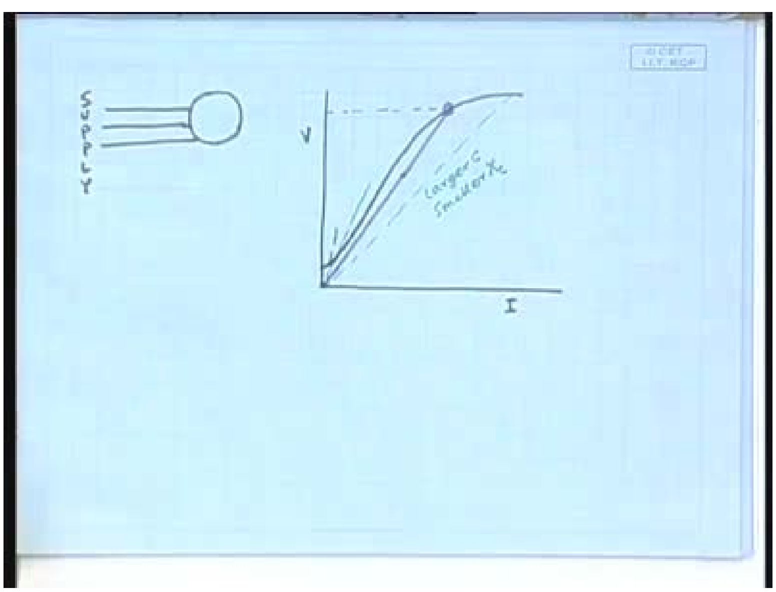

So, it is a, it is a linear characteristics like this. So, for a specific value of the current, if you, if you pass a specific value of the current through the capacitor, a specific value of the voltage will be across that. So, that is the, that is the characteristics, it is a linear characteristics. Capacitor is a linear element. So, if you extend it, these two will meet at a point and this point means that now the voltage across the capacitor is same as the voltage across the magnetizing branch, the current through the capacitor is same as the current through the magnetizing branch. So, this will be the operating point and naturally you would infer that this will be the generated voltage.

If you actually do this on an induction machine you will find that there is a capacitor connected across the induction machine and you have by some external means rotated it, in your laboratory we do this experiment with a DC machine being run as a motor to mimic the behavior of the wind turbine and in that case, as the speed of the DC machine, of the drive increases, you will find beyond a certain speed suddenly the voltage will shoot up to this point. What is the point of this, beyond a certain speed? Why does it happen only beyond a certain speed?

That is because if the speed is low, the characteristic will, the capacitor characteristic will be like this, if the speed is low. Why? Because the capacitors depends on the frequency; when it is rotated, yes, it generates a voltage, but that voltage is the frequency and the amount, the value of the capacitance, capacitive impedance depends on the frequency, right. So, if the speed of rotation is low, the capacitance line is here, it will intersect this characteristic here and naturally it will not build up. Only beyond the certain speed, as you increase the speed, as you increase the frequency it goes like this and you can easily see that there is a critical value of the speed beyond which it will self-excite, clear. Otherwise, you will see a very small voltage corresponding to the residual magnetism existing there.

How does it depend on the value of the capacitance? The larger the capacitance, the more inclined will be the line. So, for the larger capacitance or smaller X C, the capacitive impedance. That is 1 by J omega C, so the larger the C, the smaller the X C, then it will be here, so which means that for larger value of capacitance it will self-excite to a larger voltage and for a smaller value of capacitance you can see that again it will not self-excite beyond a very small voltage. So, the capacitance value has to be, capacitance value has to be beyond a certain value. That is one point and for every capacitance value there will be a critical speed beyond which it will self-excite. Is that clear? Because, see, ultimately what matters is the X C; X C is 1 by J omega C. So, C larger means smaller X C and also the omega larger means a smaller X C, so you have to, this will, this capacitor line will keep moving depending on the value of C and depending on the value of speed. So, only beyond a certain, certain value it will self-excite. So, so much about the process of self-excitation.

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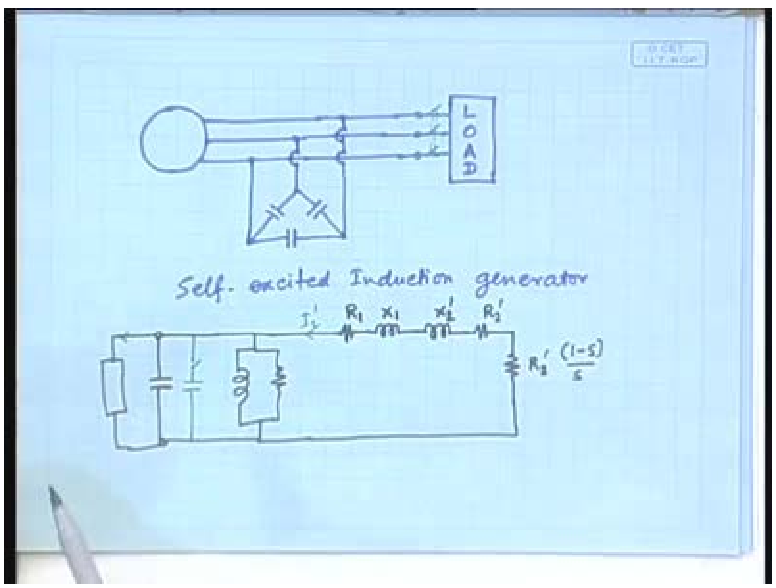

So, ultimately what you have achieved is there will be a voltage induced at these terminals and now you have got a switch which would switch on, which is switched on. Now, if you switch on that the load comes into the picture. The moment the load comes into the picture, notice that even if it is a resistive load, so that has to be supplied, so the resistive load has to be supplied. So, there has to be a current drawn by this. A current drawn, a power drawn means the power has to be generated here. Can you see that? This is the point at which the power is generated, so the power will be generated here and the power is I 2 prime square. So, here is the I 2 prime, I 2 prime square this, so I 2 prime has to flow. If I 2 prime has to flow, then these two fellows will produce, will consume reactive power.

So long as this current is small, the reactive power consumed by these two fellows will be small. But the moment I 2 prime becomes significant, there will be significant amount of reactive power consumed by these two and where is the source of reactive power? Only one. So, so far when it is not loaded, the capacitor had to supply only this, but now the capacitor is having to supply also these. So, the capacitive …. generated will have to supply the magnetizing as well as these components. So, the amount of capacitive …. now available for supplying the magnetism branch will be less, clear, will be less. The moment it becomes less, what will happen is effectively that this line will move and the voltage will drop. So, depending on the load the voltage will actually drop; that should be intuitively clear.

The moment you have some current flowing here, the current has to be generated, comes from here and the current will produce reactive power consumption here and it will become somewhat worse if the load is of the inductive type, say another pump or fan is running there, which means it is also inductive load and that inductive load again will consume reactive power and the reactive power comes, can come only from one source, only from one source. Since it can come only from one source, therefore the amount of reactive power then available for the magnetizing current is again smaller, the voltage will be drop further.

So, this means that immediately leads you to the conclusion that in case of the self-excited induction generator the terminal voltage will drastically vary depending on the load. That is one drawback of the self-excited induction generator and the way to overcome this problem is to have a couple of capacitor banks connected and the second branch you bring into action only when the load, you have put the load which means additional amount of reactive power needs to supplied. So, the capacitor bank, the additional capacitor bank can be put into service. So, that means that self-excited induction generator would need, you know, a few separate capacitor banks which can be switched on or off depending on the load, otherwise the voltage will collapse.

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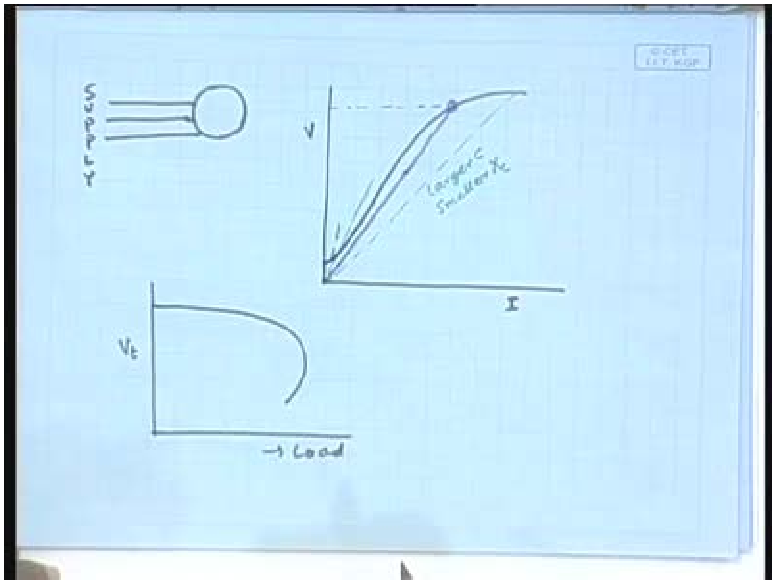

In fact, if you draw the load, this is the load versus the open circuit voltage, terminal voltage, then the characteristics looks something like this. So, it drops very fast beyond a certain value which is not a desirable characteristic. So, that has to be overcome by connecting additional capacitances.

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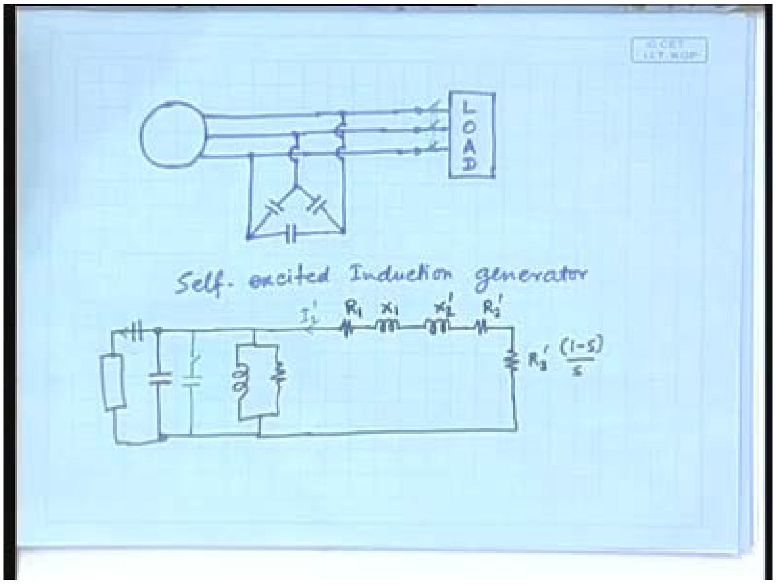

In some cases people also connect series capacitances here to overcome this problem. Series capacitances means the amount of reactive power generated by that capacitance will be dependent on the load current, because it is connected in series. So, if you connect a load and if you draw power through that, this load current will increase means the amount of capacitive …. generated will also increase. So, that will sort of counteract the effect of loading. Yes, that is used and that is good for this kind of machine. So, not only a shunt branch of capacitances, but also a series capacitance is sometimes used in order to counteract this problem.

So, we have learnt to, briefly recapitulate, the main advantage of connecting an induction machine instead of a synchronous machine was that the induction machine is able to operate at variable speed while maintaining the constant frequency. That was the main and the second advantage is that the induction machine is cheaper, far cheaper than the synchronous machine; it is rugged, it is very strong, so its durability is higher.

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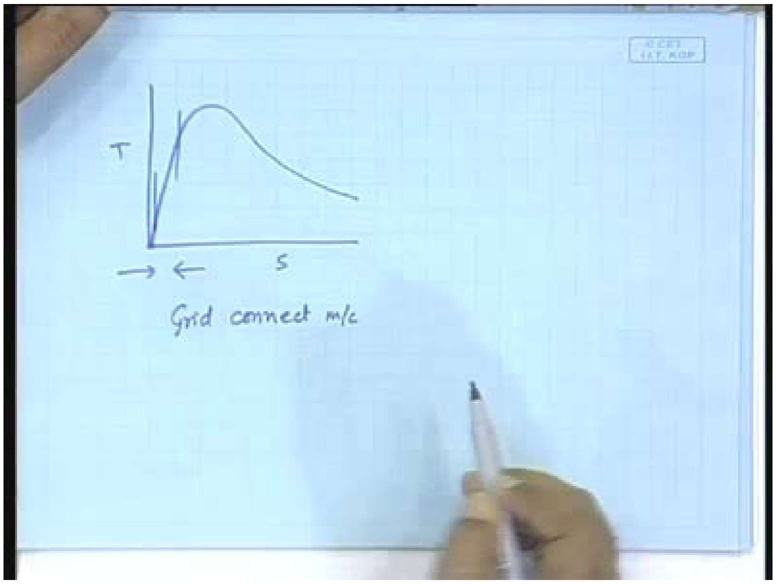

But, the disadvantage is firstly if you connect it directly to the grid, then, yes at least logically, theoretically it does supply a constant frequency though it can rotate, but actually it cannot; because of the torque slip characteristics of the machine, it will be like this and because it can operate only in the small range, so it will have only a very small range of the slip that is feasible and since slip is given by the speed, so only a small range of speed will be feasible. So, the machine will be able to operate only within a very small range of the speed variation. So, that is for the grid connected.

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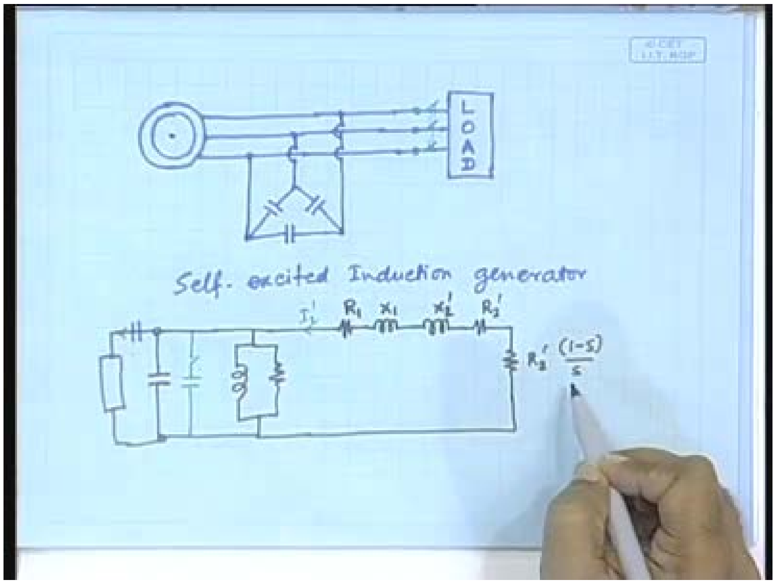

For the self-excited machine, as I told you, in this case you do not have a grid connection and so, you are not really concerned about maintaining a constant frequency that is at the grid, but yes, still the problem comes. What will be the slip? After all, the amount of power generation will be dependent on slip and you are externally rotating at a certain speed and you are getting some power output which means that there are two things here. One is the rotation of the magnetic field and other is the rotation of the rotor and there must be a difference in the speed. You are externally rotating this rotor, but what will be the speed of rotation of the magnetic field? Obviously that will be different given by the slip, right.

Now, in this case, the slip is not a constant quantity. It will be a varying quantity, something that will constantly change depending on the load that you are taking and the speed of rotation of the rotor and to determine the slip is a very a complicated affair. Only for those who are specializing on this, this will be justified to teach. That is why for this course we are excluding that how to obtain the slip in this case. But, only remember that still there is a slip, still that slip and the rotational speed will give you the frequency generated and in this case the frequency will not remain constant, it will be dependent on the speed of rotation.

So, what will be the effect of that varying frequency on the load? If you are using an incandescent lamp, you will not feel it really but if you are using a fan or if you are using a motor you will immediately feel it, because depending on the wind speed that motor speed will also keep on varying. For a larger wind speed you can feel that frequency is larger and therefore, the speed of the motor should be varying all the time.

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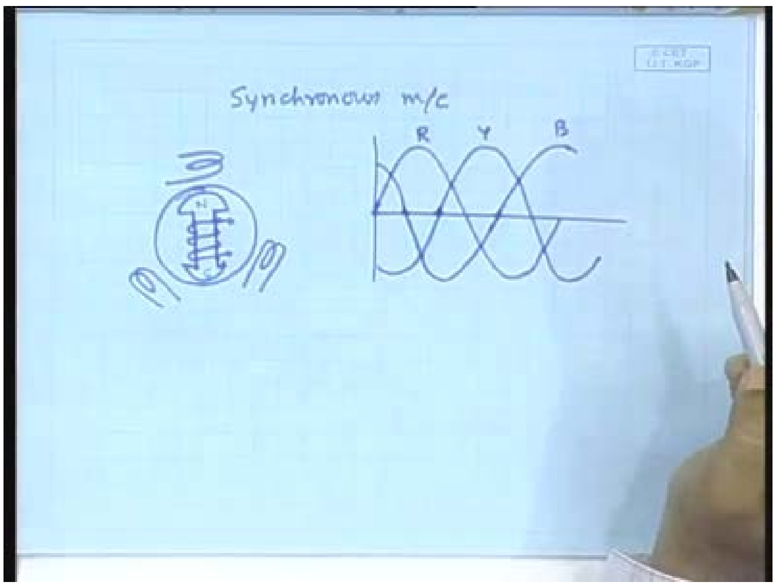

One subject I had somewhat, now I jumped, that is the synchronous machine and you had informed me that you did not have the synchronous machine covered adequately in the first year level, so let me just give a brief idea about this machine. So, in this machine you have, I am, I am actually drawing the way it is done. Your stator is almost the same as we have drawn earlier, but the rotor is a magnet something like this and you have got a … So it is not, it is not difficult to see that as the rotor is rotated, it will pass, suppose this is our North Pole and this is our South Pole, the north pole will pass below this solenoid, this winding and the winding will see a maximum, the rate of change of the flux when it is just passing by. So, at that point, it will induce a positive voltage. When it is, again the same thing is happening on the South Pole, it will have a, induce a maximum negative voltage; in between it will vary. So, it is not difficult to see that it will generate a voltage that is sinusoidal.

The next one, this North Pole, when it is under this one, after 120 degrees it comes to this winding and so that will induce a 120 degree apart, but the same kind of voltage, so it will induce a voltage like this and the third one will induce a voltage that will be again 120 degree apart of that, so it will be like this. So, the first one will phase R, will be phase R, the second one will be phase Y and the third one will be phase B. They are 120 degree apart. That will how the, that will be how the voltage would be generated.

Now, this voltage as it is generated by this mechanism will be something like the open circuit voltage. If you do not connect a load, then that will be the voltage that will be seen and as you know that such sinusoidal voltages, now, from now onwards we will treat things in single phase, but we will always remember the thing is in three phase, because always the circuit diagram, the equivalent circuit, the phasor diagram, things are drawn always in the single phase.

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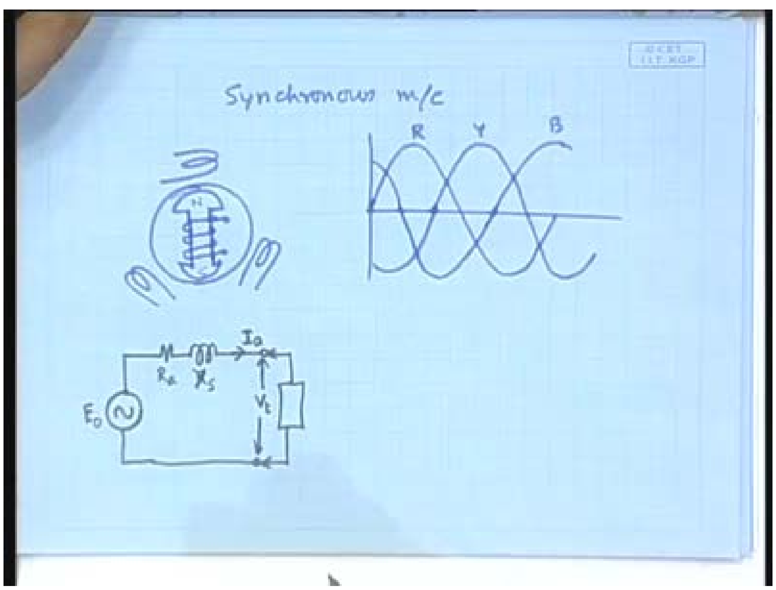

So, if you, if you just schematically draw the circuit diagram it will be a voltage generated, a voltage source, sinusoidal voltage source that will have, invariably it will have the, when the current will flow then you have connected some kind of a load to these windings, right. These windings will have some small resistance and some amount of inductance and then that will be connected to a load. So, very simply speaking, you can imagine the circuit to be like this. So, when you have a load connected, there will be armature current flowing. The voltage induced here is say, let us call it the open circuit voltage or E naught and the voltage here, the terminal voltage V t. The current flowing through the load is the I a, same as the armature current. So, this is the, this is called the synchronous, oh sorry, reactance.

Now, with this if you draw the phasor diagram, then you can see that the phasor diagram will depend on the load, because the load could be an inductive load, it could be a capacitive load, all the things are possible. So, let us draw these two types, then you will be able to understand how things are working. First, let us draw the inductive load.

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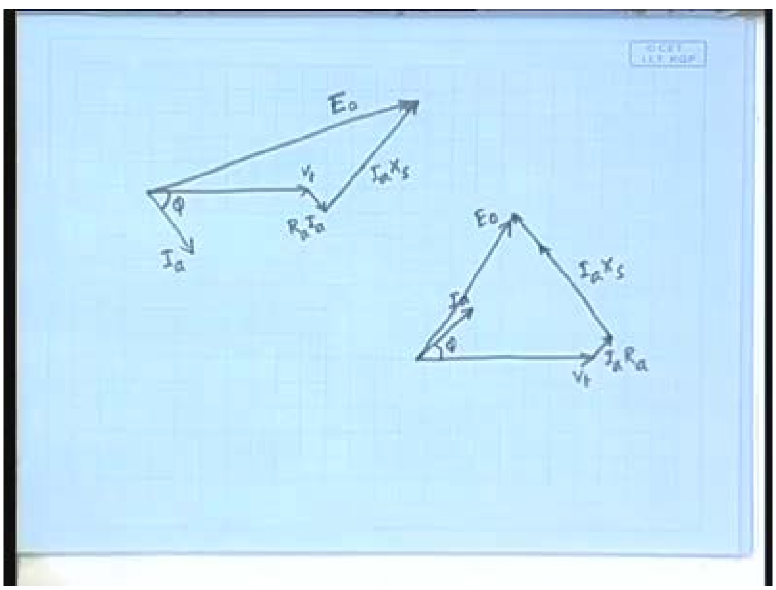

So, here is your terminal voltage V t, which we will take as the reference and since it is an inductive load, your current will be lagging. Now, notice there will be two drops one through the R a and other through the X S. So, the drop across R a will be in phase with the I a. So, you can, you can, so V t plus these two drops will give you the E naught. Let us do it graphically. So, there will be a R a, R a I a drop and there will be another drop that is I aX S. Now, this drop, this drop will be orthogonal, perpendicular to this drop, vectorially. So, you will draw it like this. Remember, this amount I a X S will be far larger than the I a R a, because resistance is generally very small. So, you can see that this will be the drop, so here. So, this voltage plus this voltage plus this voltage added together, this voltage plus this voltage plus this voltage added together will give me the …, so this will be the … You can easily see that the generated voltage will be larger than the terminal voltage and what is the generated voltage?

The generated voltage will depend on the flux, generated voltage will depend on the speed of rotation, right and the speed of rotation. In this case it is constant, because you have to generate 50 hertz, in case of a normal synchronous machine connected to the grid. So, it will effectively, this voltage will effectively be dependent on the, on the flux and that is generated by this winding, right. So, the flux is being produced by the magnetizing winding and by varying this current you can vary the flux generated. So, you can vary this quantity. So, depending on the character of the load you can always generate the required amount of generator voltage. So, you can easily see that this mechanism is, by this mechanism, the synchronous machine is able to supply a reactive volt ampere. You do not need a capacitor here, right. The machine itself is generating the reactive power that is being consumed by this fellow, clear.

Now notice, if in case your load is capacitive, then what? This is V t, here is your capacitor, capacitive I a that is leading. This is your phi, so now the phi will be like this; it is a leading power factor load. If it is a leading power factor load, you have the I a R a in the same direction and the I a X S will be like this. I will, I will draw it little longer, because then it will not intersect with this and then what will be the generated voltage? It will be this. So, you see, in this case the generated voltage can be less than the terminal voltage, right because of this mechanism. So, all you need to do is to reduce the field, so that the generated voltage is less, then it is able to supply the required amount of, you know, lagging bar.

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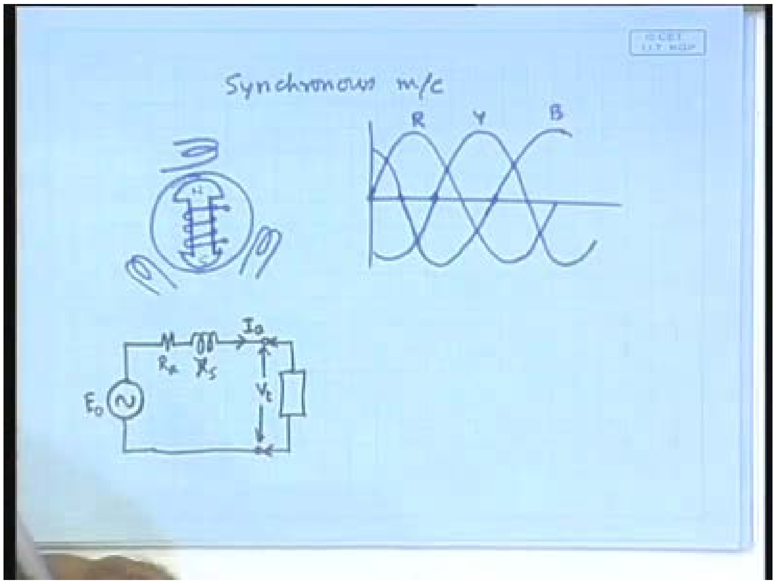

So, here also this one, the load, its …. was changing, its reactive power was changing and simply the synchronous machine is able to supply the varying amount of reactive power just by varying the field, by varying the excitation. That is the strength of the synchronous machine, something that is not available for the induction machine, because induction machine cannot generate the reactive power. That is one major difference.

So, if this point is understood, then you might argue that why not use a synchronous machine? The reason that we cannot use synchronous machine is that in that case the speed of rotation should be hard at, in a hard way given by the grid frequency.

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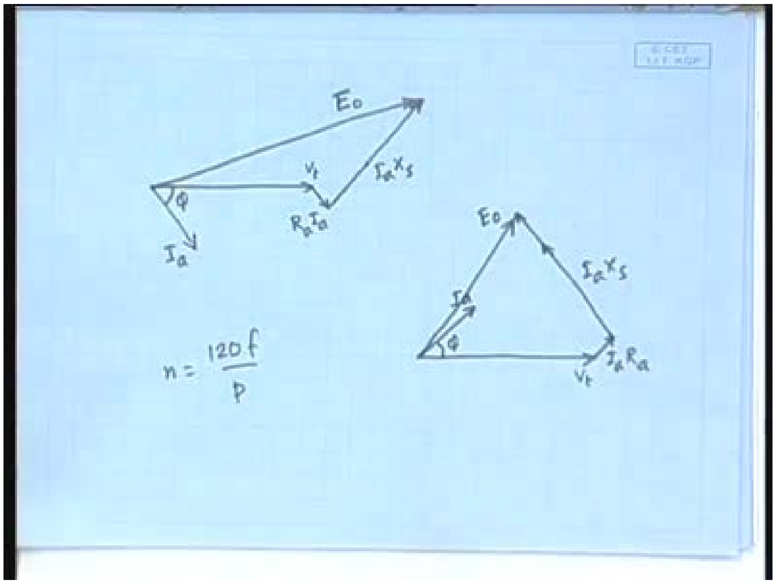

The grid is a 50 hertz and therefore, the speed of rotation is n is 120 f by p, p is the number of poles here. So, the speed of rotation will be hard that amount. In case of the induction machine it could at least be varied by some extent, here that scope also does not exist. But still nowadays, some people are preferring this machine, because now we have another scope.

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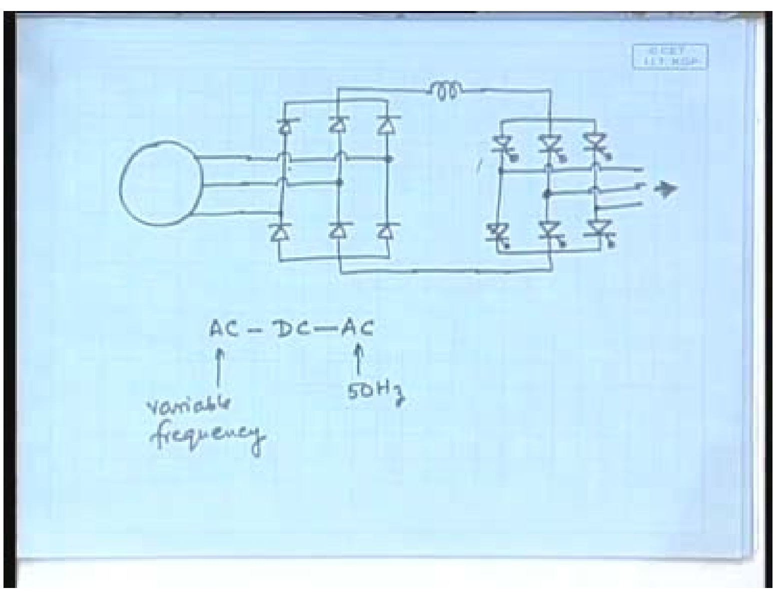

The scope is that after you have generated the voltage and the power, say it is coming out of this, it is possible to then rectify it to a DC and then regenerate the AC at 50 hertz, so that its frequency will not really matter. The arrangement will be something like this. Here I will draw. So, you have a DC generator at this point by this rectifier arrangement and that DC will have the ripples. So, in order to smoothen it out, one generally connects an inductor here and then at this point here, you have DC, but since all the loads are AC, therefore that has to be reconverted to AC, but at 50 hertz. Now, that can be done by an arrangement something like this, a very similar arrangement though. This is to the load. Now, these will have to be controlled switches. Earlier these were realized by thyristors, but now other devices are coming like IGBTs with which you can do this, but in this course let us not get into the details of this.

The basic idea is that you can convert it in the form of AC to DC to AC system and this AC is at 50 hertz and this is at variable frequency. So, this is what goes into the load or to the power line. In this way, it is then possible to vary this speed by any extent, right and that is why this is sometimes being preferred, because here there is no restriction on the speed that you have - the AC-DC-AC system and in that case, you can use a synchronous machine. In some cases, people are also considering permanent magnet machines, permanent magnet means where the field is constant, because as I told you in a power plant, in a thermal power plant, the machines are not permanent magnet machines, because in order to supply a varying amount of reactive power you need to vary this and the way to vary this is by varying the field, right.

If you have a constant field that is not possible, but here in this case because there is a DC link in between, the amount of reactive power consumed by the load is not being supplied by the machine. There is no way for the, for the machine to supply that and therefore you can effectively use a permanent magnetic machine here. Where does the reactive power of the load come from? They can come from capacitor banks connected here or it is nowadays possible by properly firing these thyristors to generate the reactive power here itself. That means by this arrangement it is possible to generate the electric power.

There is another arrangement of the induction machine that is nowadays becoming popular, so because it can also vary the speed over a very large extent. So, how can this be done in induction machine?

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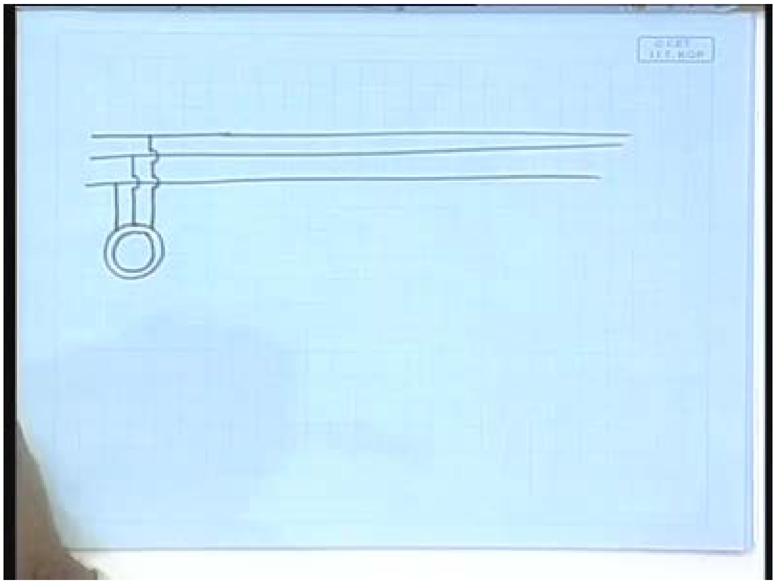

In an induction machine, as I told you already, suppose there is a line, this is a power line say and the induction machine has a stator supplied by the power line and there is a rotor and you are rotating this rotor. So far you have learnt that this rotor as it is rotated, if the speed of rotation is bigger than the synchronous speed, then it will generate power and that is what will be pushed into the grid. But then, that can go on only till you have reached the rated speed. That means you have, it is then pushing out a rated value of the power. If you, if you increase the speed any further what will happen?

If you increase the speed any further what will happen? Firstly, the machine will over heat because a large amount of current will flow. The machine may burn.

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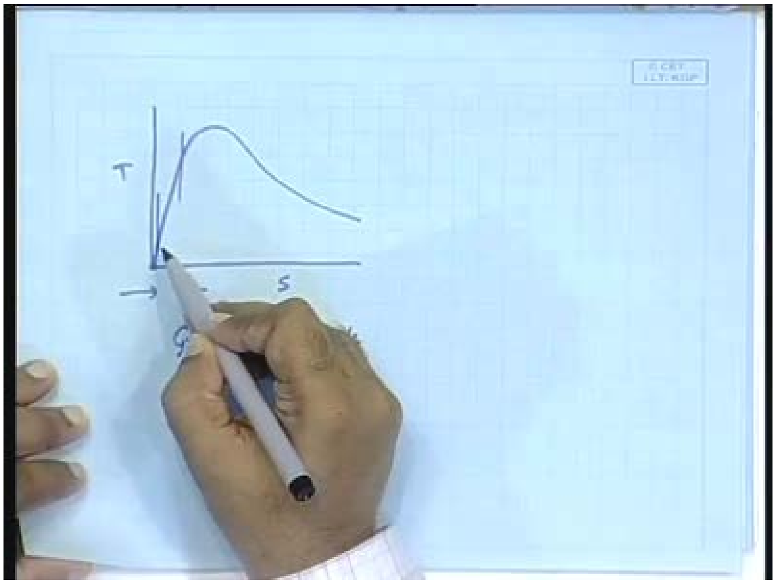

Number two, this problem will, this problem will set in that you cannot vary the speed beyond a certain range. In order to avoid this problem, what is done is so far we were considering squirrel cage machine. That means the rotor is self-contained and shorted by itself. Now in the alternative arrangement, the rotor they are also wound that means you have actual windings which are taken out. That means you can, you can imagine it something like this. I will draw it in separate page.

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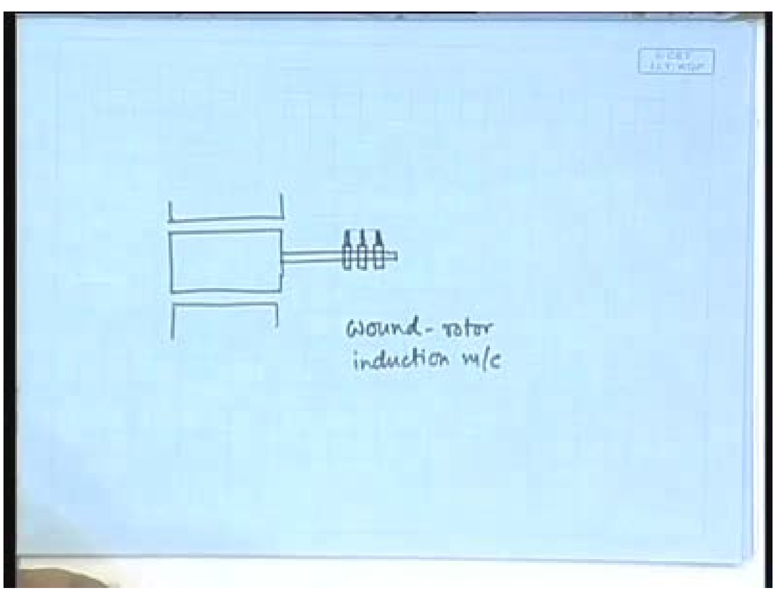

So, in the rotor also you have, so this is the stator side and the rotor has a shaft and in that shaft there are rings like this, called slip rings and there is a, there is a contact to this slip ring. So, there is a contact like this. That means this is not permanently connected. This fellow is rotating, this fellow is static, but this is making contact as it rotates and these are connected to the windings. So, in that case you will have access to the rotor conductors, rotor windings. This is called the wound rotor induction machine, but in that case normally these terminals would be shorted.

Why? Because, you need the rotor to be shorted. But, notice that you still have the option of connecting something there. For other reasons this is used right now in industry, but this can be, this can come in very handy for our purpose.

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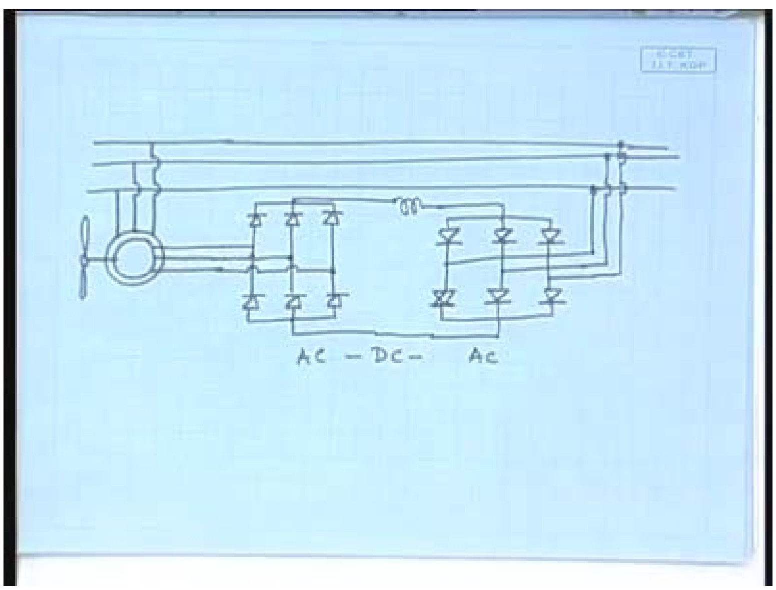

So, imagine that this is physically connected, this is physically connected, to our wind turbine. I am just schematically drawing it. So, here you have, how do I draw? In an arrangement something like this, through an arrangement something like this, you have the rotor terminals available to you. So, you have the stator terminal connected directly to the grid, but the rotor terminals are available to you. So, what do you do with them? Here firstly we convert them into a DC, any question and then the DC is, then you put a filter and then that is converted into AC. That means it will be, sorry, so you see in the, in the rotor, in the rotor there is a AC-DC-AC arrangement, AC-DC-AC arrangement, but that rotor output is then connected to the grid.

You might say what is the difference between this arrangement and this arrangement?

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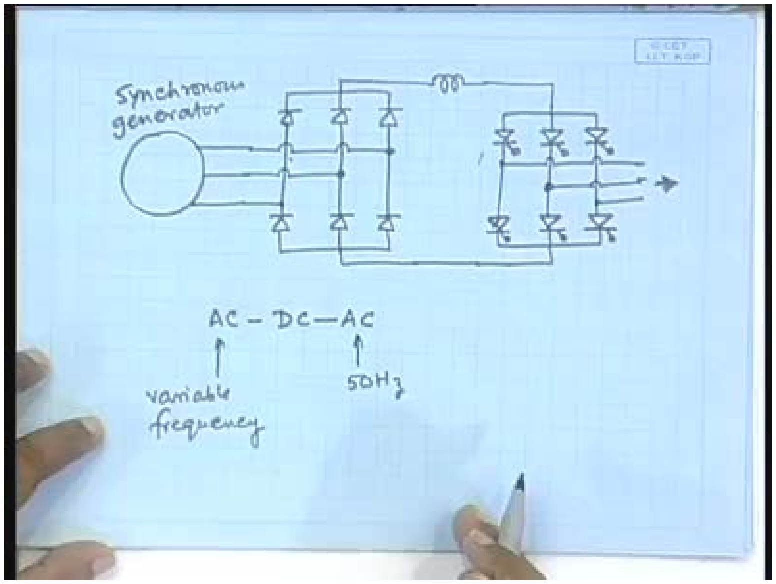

Here the arrangement was it is a synchronous generator. It was a synchronous generator, which is somewhat more expensive than the induction, induction machine, but the whole power is going through this AC-DC arrangement, AC-DC-AC arrangement to the grid.

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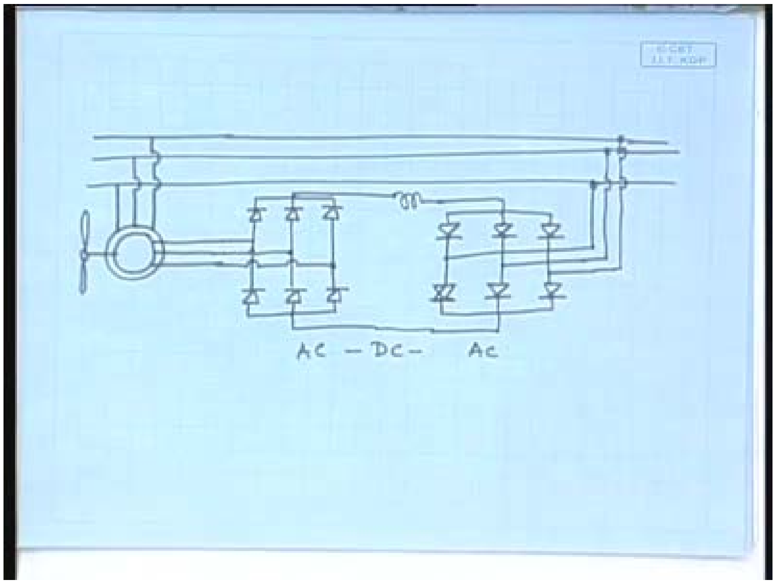

While in this case, much of the power is going directly to the grid and only a part of the power that is generated by the rotor is going through the AC-DC-AC arrangement to the grid, right. So, this arrangement will actually carry less power, so it will be less expensive. That is one advantage. The other advantage is even more important. That is notice the, where is equivalent circuit, I drew somewhere? Yeah, notice the equivalent circuit.

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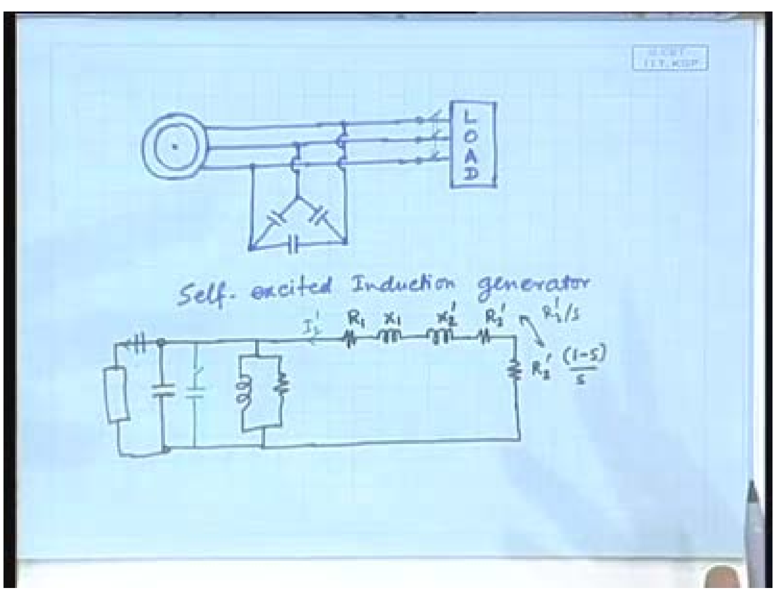

When the speed becomes too high, where is there a overloading? That is because the I 2 prime becomes too high. Why does it become too high? Because, this term becomes low and therefore, the current flowing through this, this line becomes large. What if we keep this resistance constant, this whole resistance that is seen by this side? What is the whole resistance seen by this side? R 2 prime by S these two put together is R two prime by S. If we keep these resistances the same, the current will not go out. How can you do that? Notice the basic idea.

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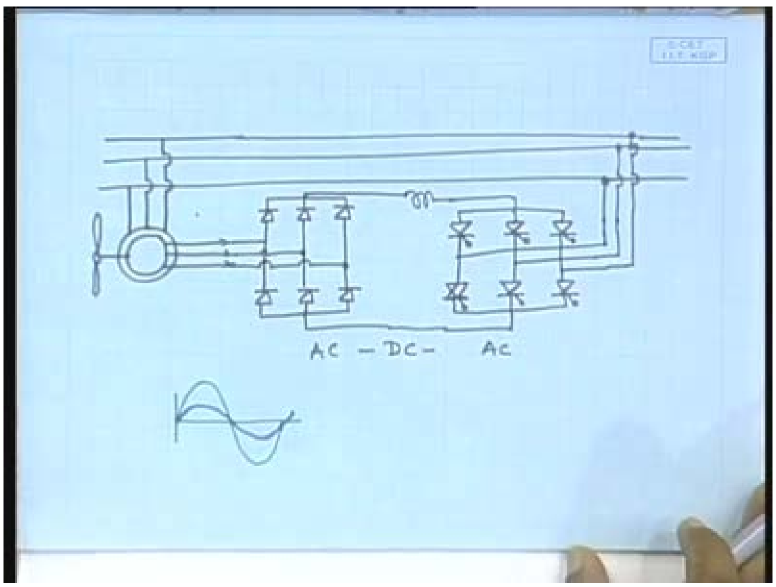

Here there is, at this point there is a sinusoidal voltage in the rotor conductors and that is fed into a rectifier. A rectifier means if there is a voltage, there will be a current through. That is the character of the rectifier. If there is a positive voltage then there will be a current through, if there is a negative voltage no current will flow. What will be the phase of the current? In this side it is DC. Here it is DC, here it is AC. I am talking about these currents. What will be phase of the current? They will be in phase with the voltage, because whenever there is a voltage the current will flow. So, the currents wave form will be like this.

So, this one will see this current, ultimately this will see a DC, because when the current here is positive it will flow through this. When the voltage in the next phase is positive it will flow through that, when the voltage in the next phase is positive it will flow through this and so on and so forth. Ultimately, it will see a voltage, all the time a DC voltage.

Student: …

Separated in three component means…

Student: …

Three phases …

Student:

Here, at this point, oh, well, well, well, then, I did not draw it correctly. This will be, these are all controlled. So, there switching is controlled. For sometime you want this voltage to become the positive one. At that point, when you want that at that point you turn this one on, when you want the next, this one to be positive, you turn this off and turn this on and so and so forth. It is basically choosing the time sequence properly that a AC generator, three phase AC is generated here. But really, I cannot go into the details of it, there is a lot of theory to it. When you attend a course on power electronics, this will be dealt with in detail.

Only presently it will suffice to understand that it turns the DC into a AC by, actually does not turn it into a sinusoidal AC, it turns into a sort of square wave kind of AC, but it does so, does that by simply switching it in the proper sequence; that is all. So, there will be sometimes when the voltage you want in this point to be the peak AC voltage, so at that point of time this will be switched on; at another time this voltage should be the peak AC, at that time this will be switched on and so on and so forth and this will provide the return path.

The point that I was making is that, as far as these terminals are concerned, if you imagine yourself sitting at this terminal looking at this side, what will you see? You will see a sinusoidal voltage and the current flowing in phase with it, right. Which means what will this fellow see? It will see as if a resistance is connected. Even though this is not a resistance, it is completely different affair, but effectively these terminals will see a resistance. Why because, it is an uncontrolled rectifier and so, the current will flow in phase with the AC and therefore it will see a resistance.

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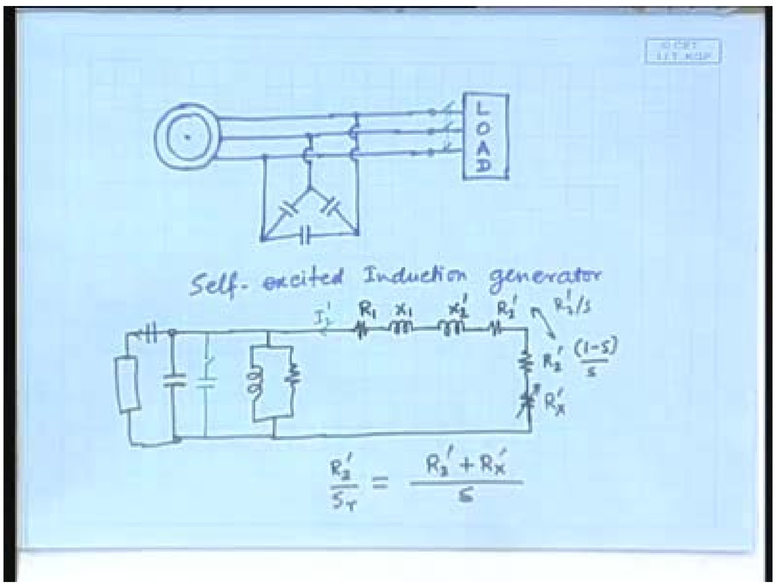

It will see a resistance means effectively it will see as if an additional resistance has been connected to it, say let us call it R x. Since all the terms in the secondary side are dashed, we will also call it R x dashed. That means it is being represented as referred to the primary side. Now, as the R 2 prime by S becomes smaller, with S becomes larger, becoming larger that is you are afraid that because this is becoming smaller, this current will be will become too high, you can stop it by adding these resistors. So, all your strategy will be that this plus this should now, should now become the same, remain the same. That means whatever was your R 2 prime by S, when it was rotating at the rated speed, generally in the rated amount of power, whatever was this, even if it is ….. or more, we will keep it the same and it can be done. Because the amount of resistance seen by it depends on the amount of current flowing through it and the amount of current flowing through it depends on the amount of current being pushed into the, into this side and that can be controlled by controlling these firings.

So, by controlling these firings it is possible to vary the amount, amount of current that flows here and to vary the amount of current that comes from here and therefore the resistance seen by that. So, effectively what will happen is that this resistance will vary, it will be a variable resistance and the strategy, control strategy will be to keep the total resistance here constant. So, the strategy will be that if at the rated speed my resistance here was R 2 prime by, is it visible, yes, slip at the rated, then, after this mechanism comes into action, so long as it has not reached the rated speed, so long as it has not reached the rated speed, it will be the same. So, this part will not be, will not be done. That means it will, it will be effectively shorted. The moment it exceeds the rated speed, then the strategy will be that R 2 prime plus R x dash by S, this should be the same. Effectively what will happen? Effectively the current will remain the same. If the current here remains the same there will be no overheating. Here also the current will remain the same, because additionally there is only the magnetizing branch, so there will be no overheating.

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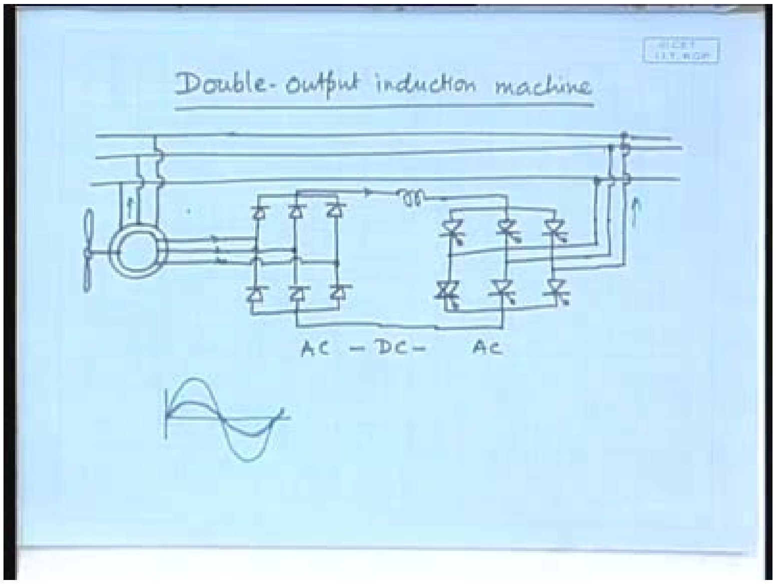

But, you would notice that it will now generate a larger amount of power and where will that larger amount of power go? It will goes through this line. So, there will be, like there was a power generated by this term, now there will be a power generated by this term and this will be going through this path into the grid. So, in this case, an induction machine, single induction machine has two outputs. One output is going this way; so, one output is going this way and the other output is going this way. That is why this kind of machine is called the double output induction.

These machines are now considered one of the major things that are, that will come into the market in near future. You can easily see that, because this is far smaller than what you would have to have if you use a synchronous machine, AC-DC synchronous machine, because this is only handling the amount of power that is generated by the rotor, not by the stator. A stator is connected directly. Therefore it is, it does not require this mechanism. Its cost is less than what you would need for the synchronous machine and so, this is the basic idea.

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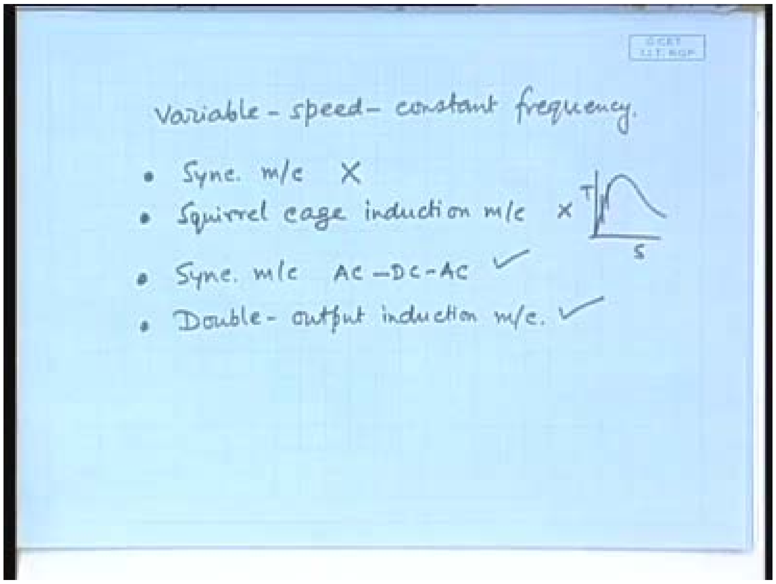

You would notice that out of various options that you have now, for an energy engineer it is important to remember that you have to have a variable speed to constant frequency. Our options were, 1 - which is not a variable speed machine; options were a squirrel cage induction machine, this is also not in true sense a variable speed machine, because the torque slip characteristic has very narrow range available to you. Third option was synchronous machine and then AC-DC-AC system, which is a variable speed and the, which is also a variable, a variable speed system. So, presently the things that are being considered are mainly these two options.

However, you should remember that at present in the year 2007 many of the machines that are actually installed are of this type, squirrel cage induction machine that is directly connected. So, actually they are not variable speed machines and as a result, your conclusion should be that they do generate sub optimally presently and that is why there is a lot of room for improvement. Fine, with that we will end this lecture. In the next lecture, we will take up a new topic.

Thank you!