Energy Resources and Technology
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Lecture - 27
Wind Electrical Conversion - I

In the last class, we had given you a brief idea about how to go about choosing a specific site for wind turbine installation.

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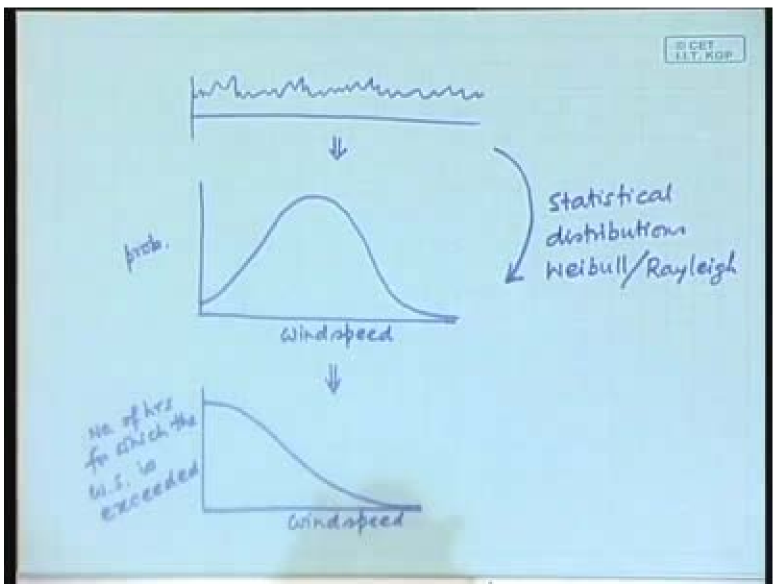

The method was that first you would record the data which will yield a very ugly graph something like this and from there you would obtain a relatively neater graph for the wind speed distribution characteristics. That is your wind speed here and in this axis it would be what? There are two possibilities. Either it could be the probability or it could be the number of hours in a year for which this wind speed was prevailing. So, let us go ahead with the probability as the y-axis. Now, from there where do we go? We go to the wind speed duration characteristic, which would be like this and in this case, here it is wind speed and here it is number of hours for which the wind speed is exceeded.

So, this is essentially how we had proceeded and we had also said that there are other ways of circumventing this step, where we normally use the statistical distribution characteristics that are known to be valid for wind speed distribution, the Rayleigh distribution and the Weibull distribution, for which if you know the average velocity, then you can obtain, you can draw at least approximately this characteristics and from there you can obtain this. So, there are two possibilities, either from the actual that you obtain this or from statistical distributions, mainly Weibull or Rayleigh.

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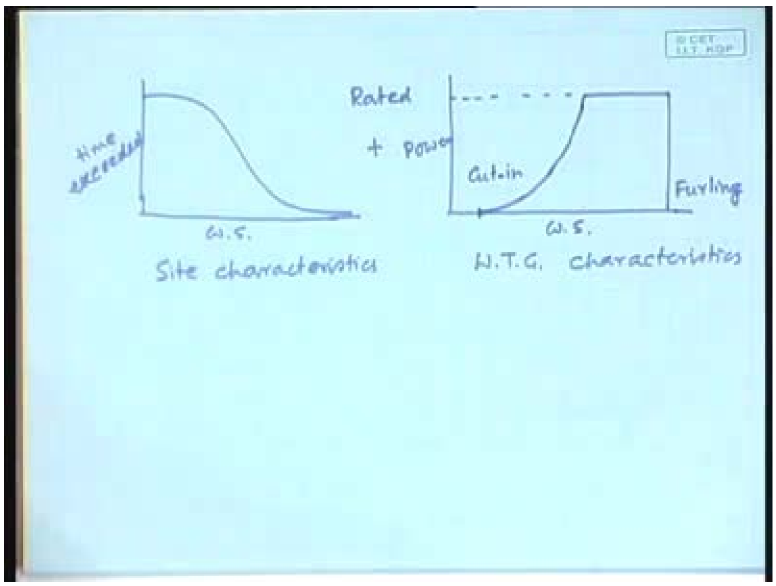

So, we had come here and then we said that first we have this characteristics representing the character of the site, this characteristic representing the character of the site. So, this is the wind speed distribution characteristic and we have to add the characteristic of the wind turbine. So, this is the site characteristics and this is the wind turbine generator characteristics. So, the site characteristics would be represented by the wind speed duration curve. So, here is the wind speed and here it is the, the time exceeded. Please settle down fast, please settle down fast. So, this is the time exceeded and this is the wind speed. So, you have the duration characteristics as representing the site and you have to have the wind turbine generator characteristics represented by the wind speed versus power and this characteristic, as I told you, starts from the cut-in speed goes up as a cube of the wind speed for some range and then, when it reaches, this is the rated power of the turbine. This is the rated power. When it reaches the rated power it is made flat till the furling wind speed. So, this is the cut-in and this is the furling; this is the furling. Why don't you settle fast? So, these are the two characteristics that we are trying to match.

I have to break for some time. See, this has to be eliminated from the video any way. Tou have to be mature enough to understand while a recording is on, if you do come in, please do come in and settle fast. Two, should not walk across the room. Three, you please go to the toilet before coming in. I do not want in the middle of the class somebody asking to go to the toilet; got it, is that clear and when you walk in there, please do not talk, it gets recorded, you get it?

So, we have this characteristic representing the site and this characteristic representing the generator.

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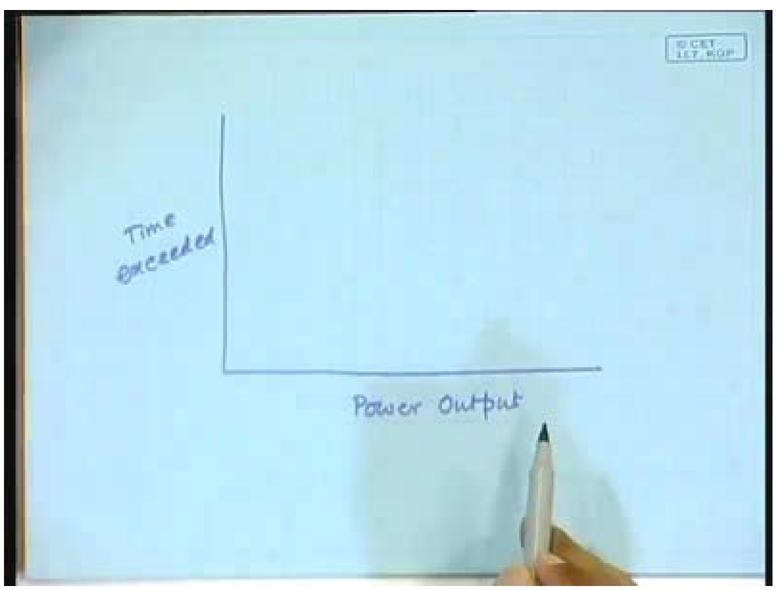

These two have to be matched and that we said has to be done by obtaining the power duration characteristics which would be, where you draw the power output here and in the y-axis you should draw, what will be the y-axis? Again time exceeded. How do you draw this?

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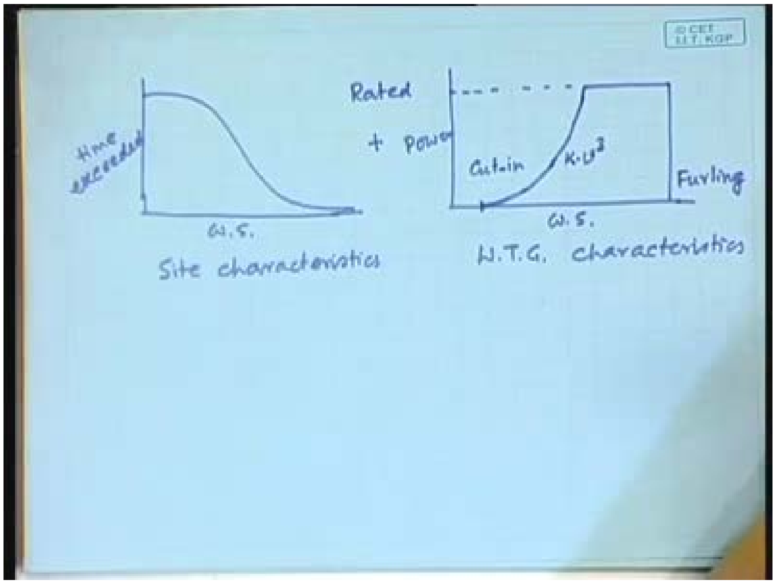

The power output for any value of the wind speed, wind speed was here, wind speed was here, but the power output for any value of the wind speed would be given by this characteristic. But then, let us first follow this cube characteristics. Then at this, at this time it is sometimes K times the v cube, right. The K is essentially half rho A C p and all that, whatever it is, there is a constant times v cube. So, this characteristic, if you want to put that here what will you do? For every value of wind speed, the power output would be K times v cube, right. So, you draw a characteristic similar to this.

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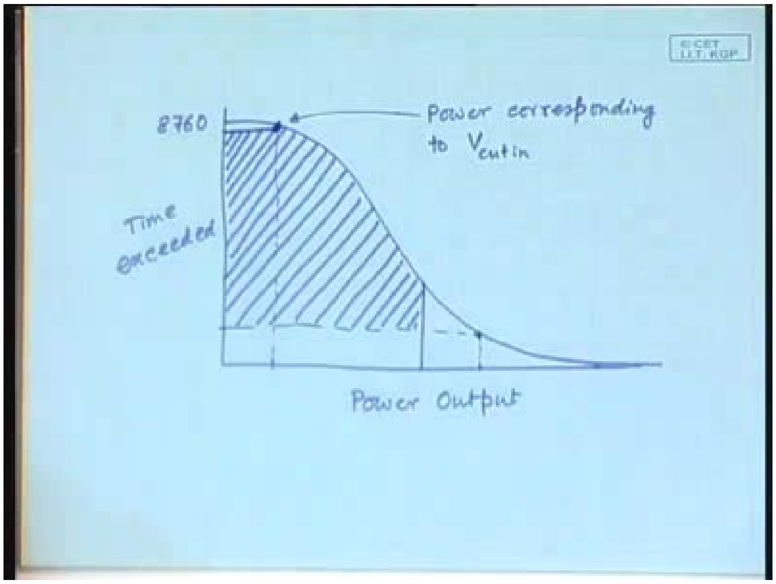

But here the wind speed, this axis, will be replaced by K times v cube, which will lead to a curve which is similar to this curve, similar. But remember, the difference is that now the x-axis are all powers which means it has been, the velocity has been cubed to plot each of these. So, it is actually elongated. What is this point? The total number of hours in a year. Why? Because zero power is obviously exceeded for that power, for that time, 8760; so, 8760 appears there and it goes to zero. Now, out of this whole time you would see that the power generation is zero, really zero, below this wind speed, right. So, some part will be chopped off, you will not get the power output and that is corresponding to a low value of power output.

So, this is essentially the characteristic, where you have cubed the velocity, but a small velocity when cubed will give you this particular point, below that you are generating nothing, so just go up and here you are not generating anything. So, this part gets chopped off. You are not generating in this part, then you are generating in this part and its characteristic is cubically proportional to, so it continuous till what point? Till you obtain this rated power. Even if the wind speed is larger, you do not really generate beyond the rated power, right. So, that gets a hard chopping off, beyond that you are not generating. So, you are not generating beyond this rated power output. So, it is a hard chopper. Then what?

So, you have represented this, you have represented that and you need to represent this and this is essentially a very high wind speed at which you do not even generate this. So, it will be represented by a very high power output level here say, but you are not generating at that power. It is only, this point represents that value of the wind speed whose cube is being plotted here. Then you draw the horizontal line and this part is also chopped off. So, ultimately you would say that I will be able to generate power only for this range, this area. The power generation or energy generation will be proportional to this area; the energy generation will be proportional to this area.

So, what does this point represent? The power corresponding to V cut-in. Power means not the power, electrical power output, the power contained in the wind that is represented here. Here, it is the power corresponding to cut-out or furling and here is the rated power, good. So, it will not be difficult for you to appreciate the fact that all these points are different for the different wind turbines. Different wind turbines are manufactured with different values of rated power, different values of the cut-out speed, different values of the cut-in speed. As a result, this area that represents the amount of power that you are getting, amount of energy that you generating out of that particular site, will be different for different wind turbines and remember that a wind turbine can be big or small. A big wind turbine will obviously produce more energy, all right and smaller wind turbine will obviously produce less energy, all right. But then, if you simply say that which one is better, which one is generating more power, obviously it is a bigger one. That should not be your criterion.

The criterion should be how much area am I being able to use in comparison to something. In comparison to what? In comparison to the install capacity, right. So, the bigger the wind turbine, there will be something in the denominator with which you compare. So, that denominator is the energy that you would generate if ideally the wind turbine is operated at its rated power for the whole year. Which area is this? It is this area, right.

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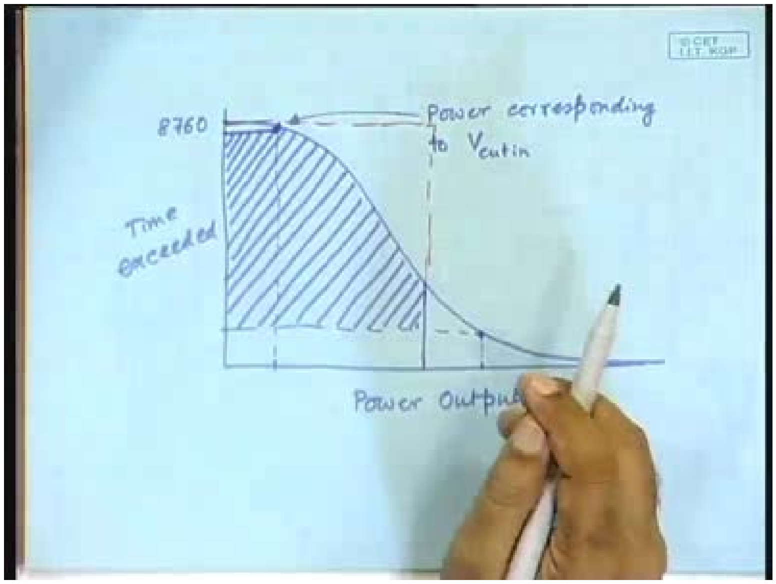

It is this area for the whole year, 8760 hours, right. How much power? This is the rated power. So, this box represents the amount of power you would have generated if you ran the wind turbine at a full rating for the whole year. So, this is the area that goes as the denominator, while this area that is the actual energy generation over the year goes as numerator to keep some kind of a suitability estimate for that wind turbine, for that particular site. So, it is not just this area, not just this area, because the larger the wind turbine, the larger will be this area. Unless you compare with something, compare with the install capacity, you will never know how good, how well is it performing in that particular site. So, that leads us to some kind of a factor.

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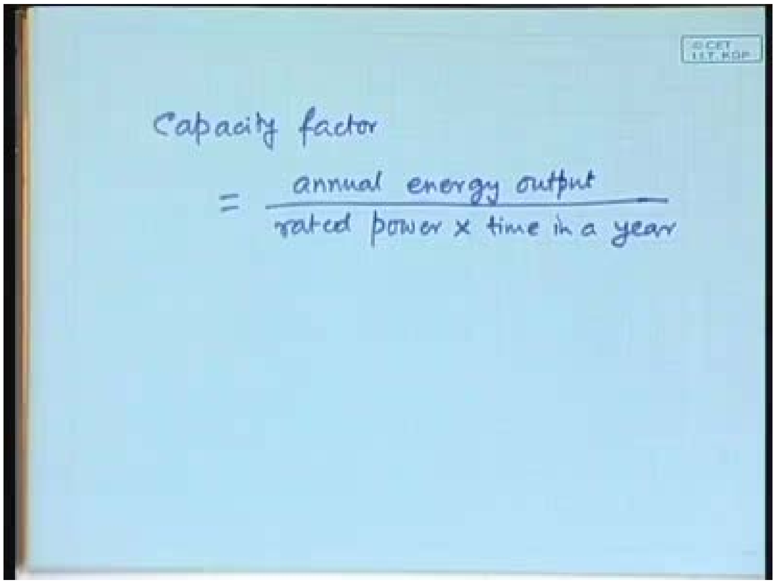

It is called capacity factor. The capacity factor is given by, it is a ratio of the annual energy output to the rated power times … So, it is a ratio between energy and energy power times, times this energy. So, you have energy by energy and this is called the capacity factor. You may have heard of the term load factor, in case of power plants. What is a load factor? It is essentially the similar concept. Out of the whole capacity that is available how much is being utilized? So, a thermal power plant, supposing it is rated at 200 megawatts, so if you had produced power at this 200 megawatt level all through the year, then you get some amount of energy. Now, that being in the denominator, in the numerator is how much energy you have actually generated out that the plant that is the plant load factor.

In case of the wind turbine, a more used definition is the capacity factor, which is similar in concept to the load factor. But here, the difference is that a thermal power plant you can ideally operate it at full load all through the year, at least theoretically. I mean you just assume that the shutdown periods are at least theoretically brought down to zero, maintenance is not required. If you assume that, you can theoretically, but you cannot for a wind turbine. Why? Because wind is not coming, so while the difference between, conceptual difference between a thermal power plant and the wind power plant is that ideally a thermal power plant can be operated at full load all through the year, while a wind turbine cannot be and that is exactly why this statistical distribution of wind speed in that particular site is very important.

You would immediately realize that different large and small wind turbines will have different capacity factor and the one that gives the maximum capacity factor for a particular site is the right choice for the, right choice of wind turbine for that site. You got the point? So, the wind turbines choice is site dependent. The wind turbine which will be very suitable for say, the Eastern Ghats will may not be the most suitable for the Western Ghats. Why? Because of this characteristic, clear. This is something that many people do not understand. Simply they, when they talk about wind power availability or even wind power installation, they talk about so many megawatts of wind powers are installed; no, it does not really make sense, because it all depends on which site, how much is the statistical distribution and ultimately out of that how much energy you are generating all through the year.

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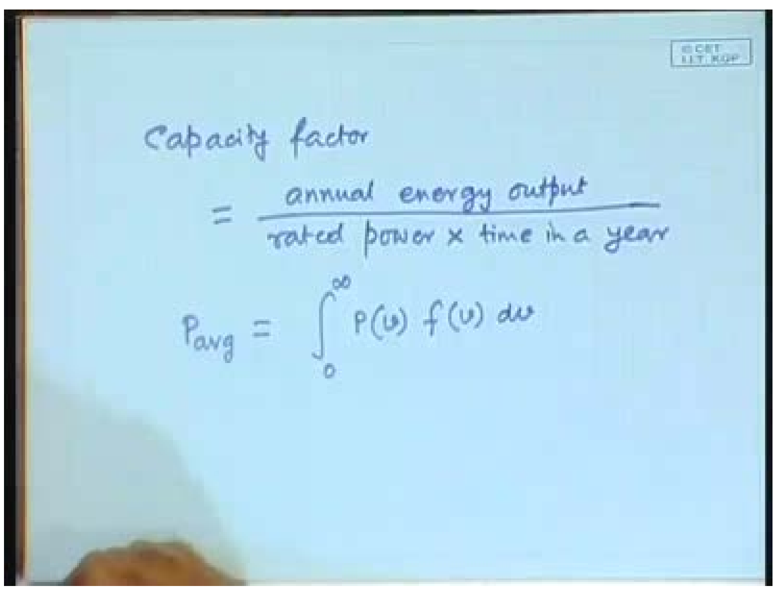

Now, this it will not be difficult to see that the numerator, the average power that is generated, so P average, will be the integral of, integral of power as a function of the wind speed times the probability distribution of wind speed, right. This integral normally is to be obtained graphically as I showed, but under the assumption that the characteristic is exactly of this type.

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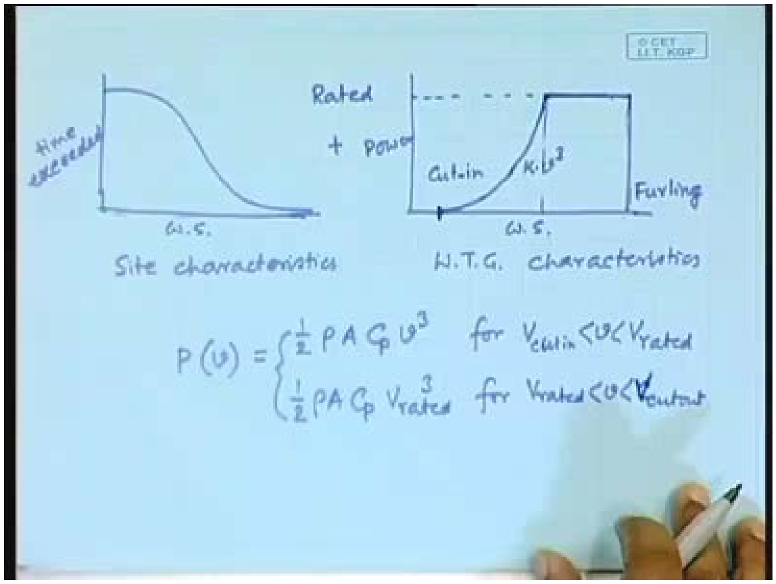

That means below a certain thing there is no generation of power, after that it is exactly cubic and after that it is exactly flat; if you assume that, then it can be somewhat analytically obtained, because if you have this characteristic, if you have this characteristic, how much will be the P as a function of v? You can easily see that that is, it will be half rho area C p times small v cube, small v is two third of infinity. This is for which value of wind speed? V cut-in. No, not the cut-out, rated and this will be two things, half rho A C p what cube?

Yes, this is the amount of power at this value and that is being flat. So, for V rated, sorry, V cut-out. Can you see or it got chopped off?

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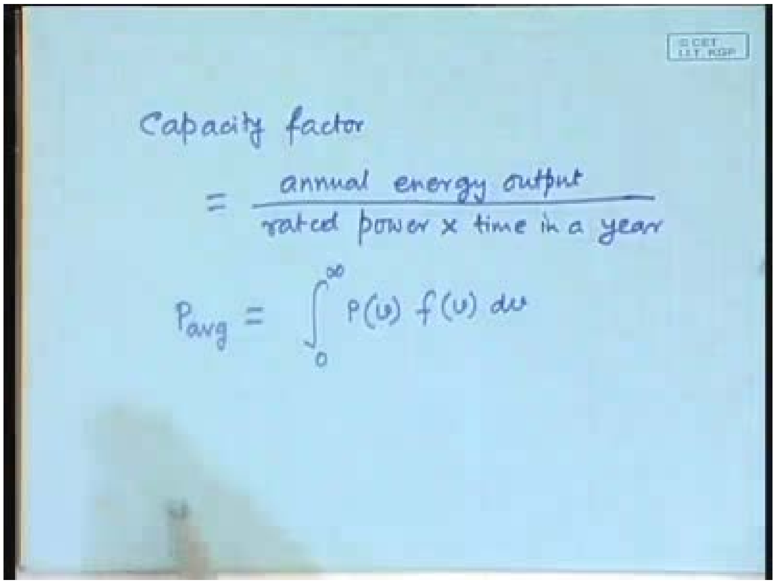

Yes; so, if you use these expressions, then it will not be difficult for you to analytically express this.

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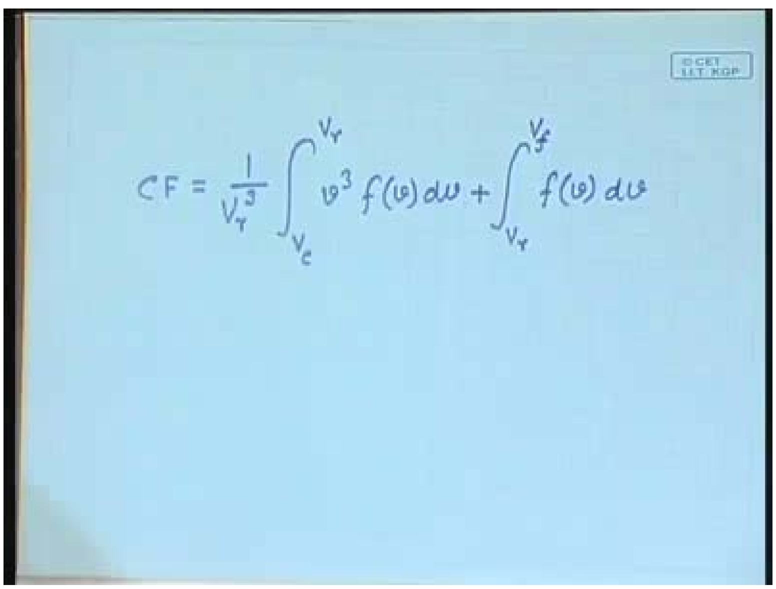

So, analytically if you express this, your capacity factor expression will be CF, capacity factor, it will have two components, one, you will have to once integrate over this range and again integrate over this range and so, it will translate to 1 by V, let me shorten the subscript, V rated cube integral V cut-in to V rated, remember, I am just shortening this cut-in, it will be v cube fv dv plus V rated to, yeah, V, let me, let me give another subscript furling, f, so this will be fv dv where fv is the statistical distribution of the current. You can do it this way, good.

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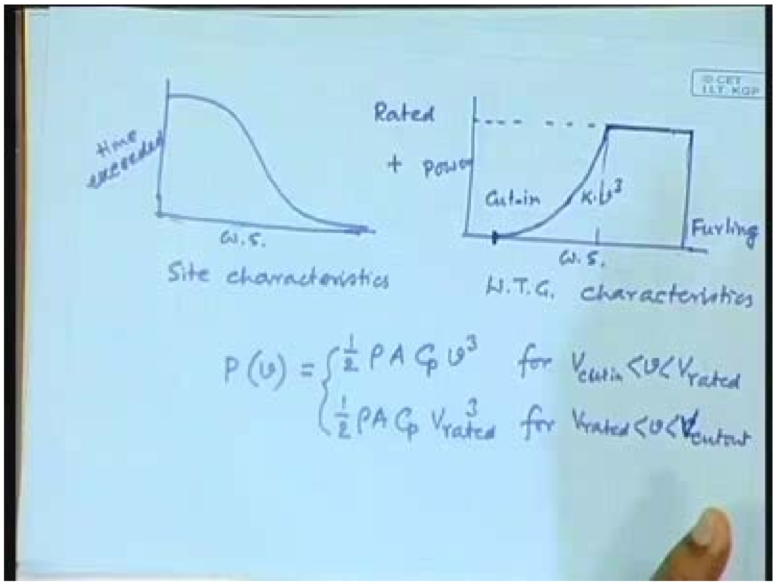

So, this can be integrated, but actually things are done mostly by graphical means, the reason being that you will never have this characteristic exactly cubically proportional or this characteristic exactly flat. That is given by the manufacturer's specifications and so, normally this job is done graphically, clear. So, if you are having the task of installing a wind farm in a particular spot and there are say, 20 different vendors coming to you trying to sell their wind turbines, how will you do that choice? How will you go about it?

Number 1, first measure the characteristic there. From there, obtain the statistical distribution, find out which characteristic is it most closely matching. That means in the Weibull distribution, the variable parameters set them properly. Then, you can approximate it by the Weibull distribution. From there, obtain the duration curve.

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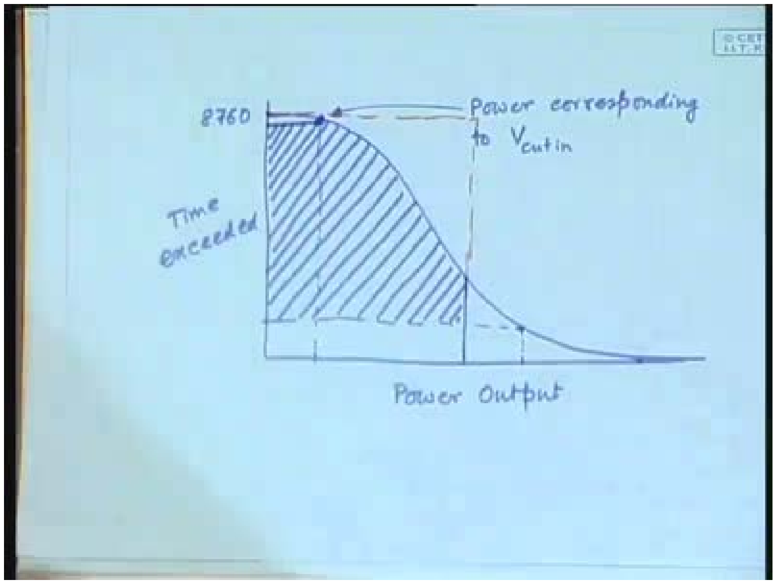

Ask the manufacturers for their wind speed versus power characteristics; match them to obtain this for all the wind turbines. From there obtain the capacity factor for each one and the one that gives the maximum capacity factor is the choice, clear. Unfortunately nobody does it, but nevertheless you should know how to do it. So, you have learnt how to construct, how to choose wind turbines from the mechanical side. What about the electrical conversion? Electrical conversion means there is a mechanical energy coming in the shaft and that has to be converted in electrical energy, has to be converted by some kind of a generator.

The natural next question is what generator will you choose for this purpose? Now, you have learnt in the first year the characteristic of some different types of electrical machines and as you know, all motors are the same as the generator depending on which side is being energized; magnetic side being energized it gives electrical power, electrical side being energized there is mechanical power. So, there is no fundamental distinction between a motor and generator but what are the different types of such rotating electrical machines you have learnt of?

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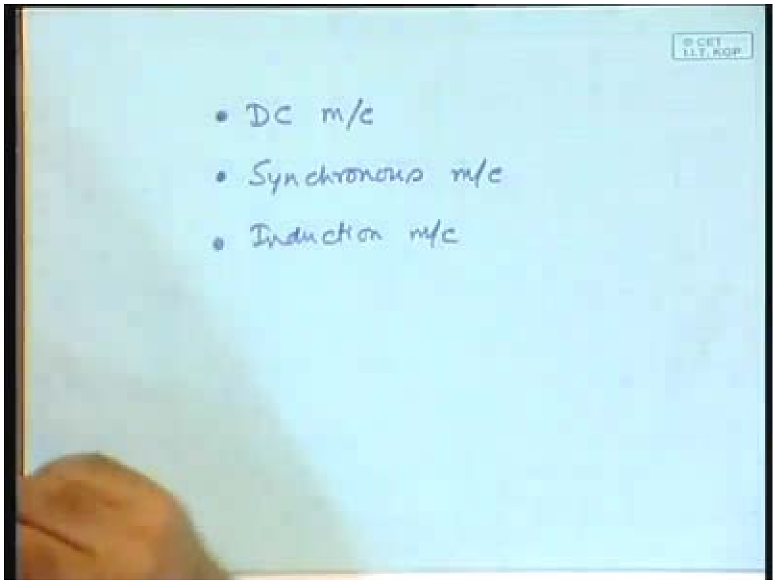

One, you have learnt of the DC machines. You have learnt of the synchronous machines and you have learnt of the induction machines. Out of this, which one will you choose or what are the comparisons between the characteristics of each one? DC machine, you have learnt about the DC machine in reasonable details I guess, right. One thing you may have understood that the DC machine is a very cumbersome machine. Why? Because, it has to have windings both in the stator and the rotor and the rotor winding have to be energized. So, something, rotating steel you have to give connections. So, you have to have brushes, so there has to be brushes and there has to be carbon contacts; so, these are somewhat cumbersome and these are prone to difficulty. There are flashings, sparking in the brushes, they have to be replaced, maintenance requirement.

Due to all these, unless you specifically require a DC machine nobody uses a DC machine and where would you specifically require a DC machine? Where normally the AC machines, I mean, are not used that is the traction machine. That means your railway trains, they run on DC machines. Why? Because, they have certain very important desirable characteristics, but other than that, DC machines we will never use, never as a generator. So, we will exclude the DC machine from our discussion. So, let us not spend time on discussing and after one hour decide that it is not good. Let us decide it is not good, so let us not discuss.

Synchronous machines, what is a synchronous machine?

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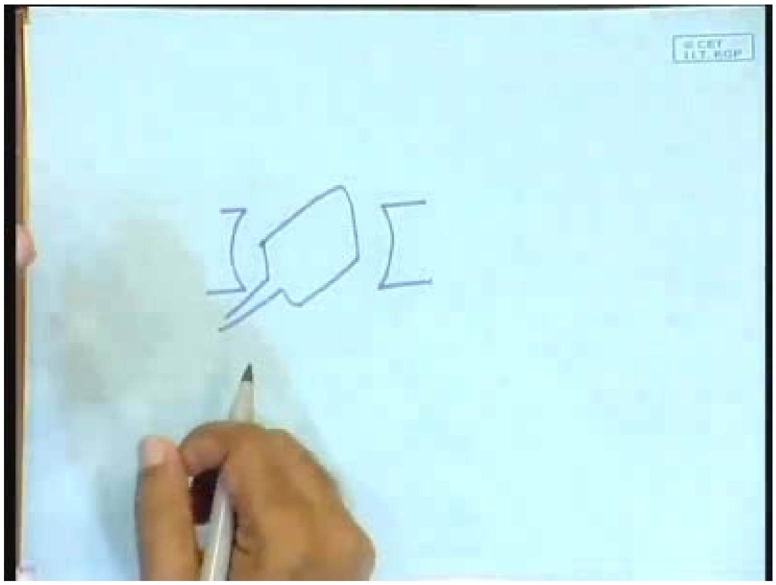

Essentially a synchronous machine is where you have, when in the school you studied about the generation of power, the kind of construction that you saw, like there would be North and South poles and there would be a solenoid rotating and thereby it is exactly the same. Only, then it was a school days representation, but now you would have to understand how it is actually made and then it is worthwhile to tell you that the field is not really static and the armature rotating; it is the opposite, the armature static, the field rotating. Why? Because, the armature has to carry the bulk power and the current, so the conductors are thick and so, it is far more convenient to put that in the stator and put the field in the rotor.

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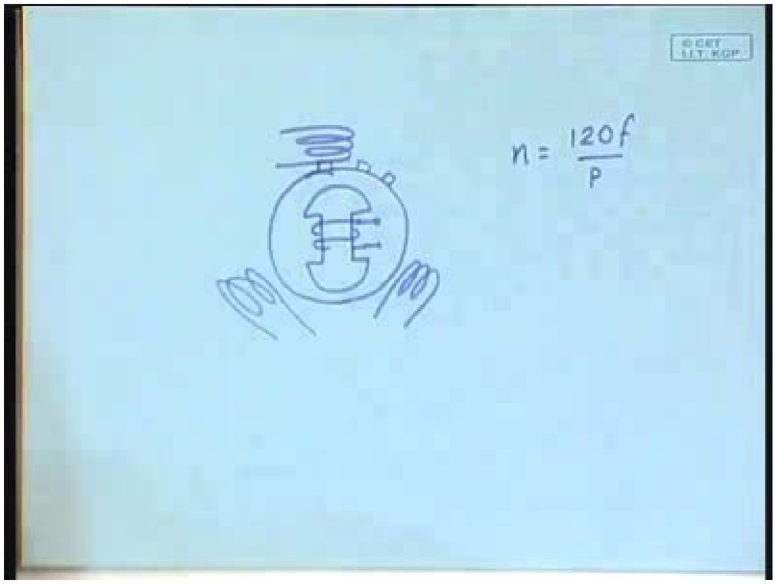

So, nowadays the construction would be, you might imagine the stator. I am schematically drawing. There would be windings like this, three phase always and they would be connected in three phase and there would be the field that will be rotated. That is the normal structure or construction of a synchronous machine. Here, I have shown it as sort of a solenoid. It is not put as a solenoid of course. These are put in such slots; these are put as winding that go into the slots. So, effectively they produce a solenoidal winding, clear. So, these are windings that go like this through the slots and effectively they produce, such windings that can be schematically represented by this.

Now, the specialty of this machine is that the voltage that will be generated in each of these, they will be sinusoidal. Why? Because, the North Pole is rotating and it is passing by. While it is just under this that it has the largest rate of change of flux. As a result, it will produce and then when it comes in between then it sees the least. So, the whole thing will vary sinusoidaly and after sometimes, this South pole goes there and does the same thing. So, you will see a sinusoidal voltage generator. What will be the speed or frequency of that sinusoidal voltage? It will be exactly proportional to the speed. So, it will have to be rotated at a speed that will be able to generate for example our supply is 50 hertz, it will be able generate 50 hertz.

Now, there is no reason to assume that there are exactly three windings. There can be windings here also, right. So, there can be 6 windings. So, in that case, it will be having a larger number of poles. There is no reason to assume that these have exactly two, there can be further poles here also. So, depending on that you can say that the frequency is not exactly the same as the speed of rotation; it is proportional to the speed of rotation. So, the actual relationship is that speed is 120 f by P; P is the number of poles, but that is not our concern here.

What is the concern is, in that case, in order to generate a constant frequency I need to rotate it at a constant speed and our supply is constant at 50 hertz. So, if anything is to be hooked up to the power supply grid, then it must generate 50 hertz which means the synchronous machine should, not should, must rotate at a single specific constant speed, right. Let us see does this character match with the character or required character of a wind turbine?

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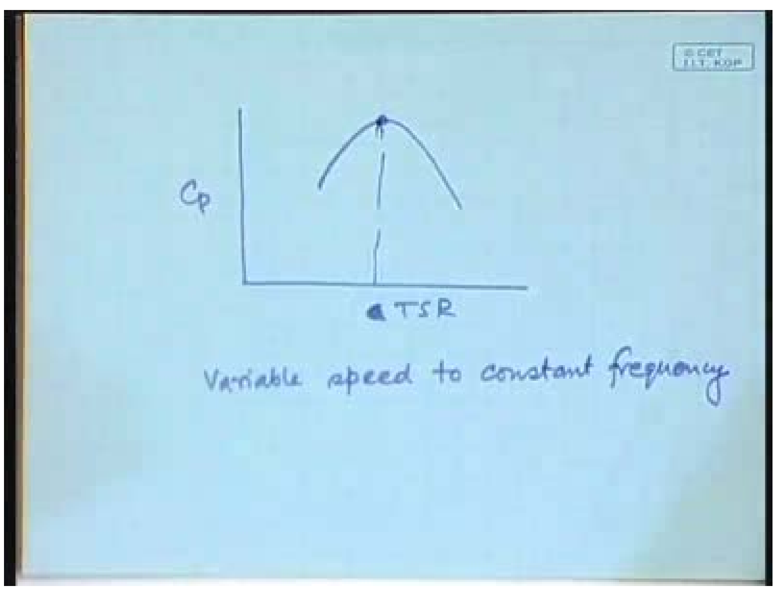

In a wind turbine you have seen that the tip speed ratio versus C p characteristics is something like this. What means, what does it mean? You want to achieve the maximum power coefficient, but for that you have to operate at a constant TSR, tip speed ratio.

What does it mean? As the wind speed changes you have to keep the rotation of speed proportional to the wind speed at a value which corresponds to this maximum power point which means as the wind speed changes, you have to change the rotational speed, else you cannot really track this point, which means that this characteristic actually contradicts the requirement of the wind turbine. A wind turbine should be a variable speed to constant frequency generation system.

Nevertheless, what happens in a thermal power plant? In a thermal power plant, the steam is regulated, so that the turbine produces a certain amount of power and turbine rotates at exactly 50 hertz or 3000 RPM. So, you may notice that if there are, the number of poles is 2, then it will be 3000 RPM. So, in that case, if say the amount of wind, no, amount of steam that is going into the turbine say it goes up, what happens? The turbine tries to rotate faster, but it is connected to the grid that means to this. It itself does not allow it to go away from synchronism that means it still continues to rotate at the synchronous speed. So, what happens actually is something like this that it gets sort of locked to the grid and its frequency and so long as the locking is maintained, it cannot really rotate at a different speed. So, even if the amount of power that is going into the turbine changes, it still remains locked till a critical point is reached when the synchronism is lost and that is very undesirable for a normal power plant.

So, there is a question of this locking and the locking ensures that even if the power input changes, this fellow will still continue to rotate at the same speed. You might argue why not do the same thing for the wind turbine? Well, note that it cannot be done. The issue is that suppose you have connected a wind turbine to such a synchronous machine which is connected to the grid, yes, it will lock and after that it will keep on rotating at the same speed, but in that case as the wind speed changes, it will be going up and down this curve, because it is locked at single speed. So, it will not be a desirable way of operating this wind turbine. But still, you might argue that supposing my objective is not to supply the grid, rather my objective is to run it as a standalone system.

For example, there are islands in the Sunderbans, where you have such wind turbines just catering to that island, not connected to the grid, because the grid cannot be brought in there, it is so remote. In that case what? Yes, you can use that. In that case, you can use synchronous machines, but nevertheless since you have to go back with some message, let me tell you that synchronous machines are very seldom used with wind turbines, very seldom used. So, what is actually used are, okay where they are used and how, I will come to that later, are the induction machines.

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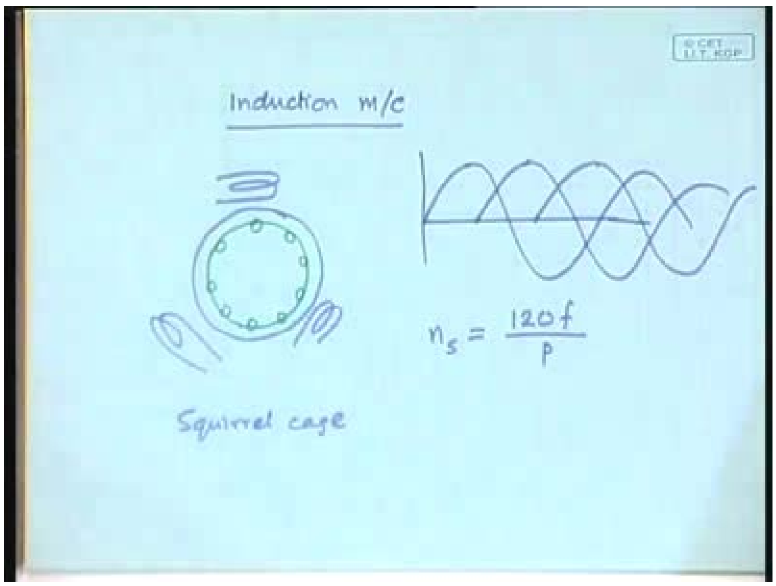

So, I will dwell a little deeper into this issue of induction machines. Now, what is an induction machine? Here, let us first understand it from the point of view of a motor and then we will understand the generator, because generator is little more, comes a stage later after understanding the motor. Here also you have the stator structure that is …. and imagine that you have somehow produced the windings like this. Probably you have learnt, let us not get into the details at the stage, probably you have learnt that if you have three phase supply and three windings 180 degree out of phase that means there is a three phase supply, where the three phases are 180 degree, 120 degree out of phase like this. So, from here to here it is 120 degree, from here to here is 120 degree.

If the three phases are separated like this and if the windings are also separated physically at 120 degree apart, then a rotating magnetic field is produced. So, there will be a magnetic field that will actually go rotating like this at a speed 120 f by P. So, the speed of rotation is called as synchronous speed is 120 f by P; P is number of poles. Now, you have the rotor in this case as, let me draw in a different colour, it will be easier to see; it has conductors like this and this conductors, I have shown that they go into the paper like that, so it is going like this and at the two ends they are simply shorted. This is the structure of the squirrel cage generator, the squirrel cage generator.

So, in case of squirrel cage machine, it is called a cage because these conductors are made of not wires, they are simply aluminum bars that are shorted at the two ends and the whole thing looks like a cage. That is why it is called a cage machine. So, what I was saying, if you shorten, imagine that the field is rotating at the synchronous speed, so each of these windings will see as if a North Pole is passing by, right, as if a North Pole is passing by. When it is passing by, it will see a varying magnetic field. If it sees a varying magnetic field, there would be voltage induced in that, each of these wires and these wires are shorted. What does it mean?

The voltage will immediately induce current, right, if they are shorted. So, voltage being induced means immediately current will flow and the current flowing means what? The moment the current flows there is a magnetic field produced by that current. So, there was a magnetic field which produced a voltage which produced a current which produced a magnetic field. You might say then I am, I am finding it difficult to imagine what will be the direction of that magnetic field. Yes, you might find it difficult and that is exactly where Lenz’s law comes into, comes very handy, because then you would say that Lenz's law says that the effect will oppose the cause.

What was the cause? There was a rotating magnetic field and the cause was not only the rotating magnetic field, cause was the relative velocity between the conductors and that magnetic field. That is why the whole thing happened. The magnetic field that will be produced will oppose that and therefore, therefore this fellow will, there will be a magnetic field that will produce a torque which will make it rotate in the same direction as the original magnetic field, so that the cause is opposed. The cause was the relative velocity; that will reduce.

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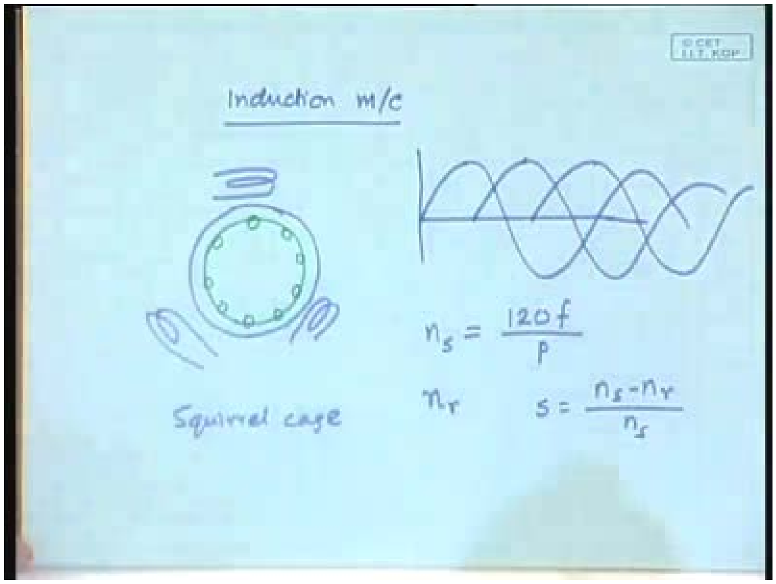

As a result, this fellow will start rotating and suppose it rotates at a speed n r, this is synchronous speed, this is rotor speed, this n r will be less than the synchronous speed. Why? Because, if it becomes equal to the synchronous speed, then the cause is gone. No longer it will have the cause and therefore no longer there will be any magnetic field. So, it will be slightly less than and that is why we define a factor called slip, which is n s minus n r by ns and slip is normally a very small quantity something like 0.03, 0.04. So, actually the rotational speed is very close to the synchronous speed, but not exactly the same. So, that is why this fellow starts rotating.

Your fan is like that, your motors are like that, your pump machines are like that, so every machine that you see around you are all induction machines, because they are very rugged. They are very simple to construct, they do not go out of order easily. So, all these machines that you see around you are induction machines. There is no connection to the rotor, can you see? There is no external connection to the rotor. Power goes into the rotor through magnetic field and that is a major advantage of it, because you do not have to give any electrical connection to the rotor and that is why they are so simple and they are so rugged.

There are of course induction machines, where the rotors are also wound with wires and you do give a supply. Those things are there, but presently let us understand this squirrel cage induction machine. So, you have a squirrel cage induction machine constructed like this. Now, if you, we are ultimately aiming at going into generators, so all the expositions should be, should be aiming at later I have to understand the generators, while in normal induction machine expositions in the books, we will find motor is treated mostly as motor and generator is practically not discussed. So, there will be a little bit difference between the way I am talking about it and the way you will find in text books.

As you know, whenever we electrical engineers encounter something, we always like to represent that as an electrical equivalent circuit. While we were dealing with the photovoltaic panels, we still brought it down to the level of the electrical equivalent circuit, because that is why we are very comfortable. We can do anything we like; we can predict, we can, we can analyze using the electrical equivalent circuit, so here also would like to obtain an electrical equivalent circuit. Now in doing so, first realize, suppose this fellow is static, suppose this fellow is not rotating. You are somehow holding it and you are energizing the stator and there is a rotating magnetic field. What actually will happen?

What will happen is that, because of the varying magnetic field, there will be a voltage induced, there will be a current and all that will happen and that is in no way different from what happens in a transformer, right.

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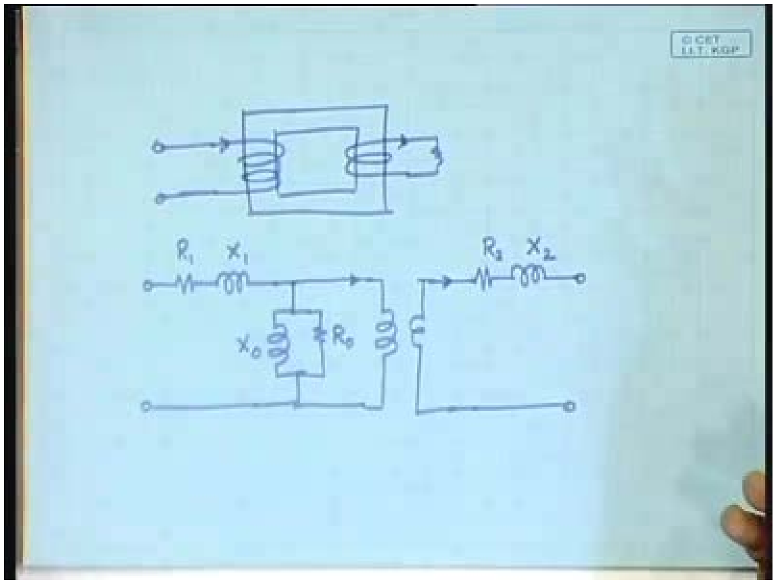

In a transformer we have, we have a … Here, this fellow because of this current produces a magnetic field that induces a voltage here and if you have some kind of a path here, it pushes the current, right. So, that situation is in no way different from this situation. If it is so, then in developing the equivalent circuit, we can easily take cue from the way we understand the transformer. So, what was the equivalent circuit of a transformer? Probably you have done that, right. So, in putting in the equivalent circuit of a transformer, we simply say that I give the supply from this side and what will I see if I look it from this end?

We will see first there is some kind of a resistance in this winding, there is some kind of an inductance in this winding; in fact, this leakage inductance in this winding and then, so we will have to start from this supply side. We will have to put in the resistance, we will have to put in the inductance of the stator. So, R 1 X 1 and then there is a magnetic circuit. What does the magnetic circuit do? The magnetic circuit, of course in order to establish the magnetic field, you have to, you have to spend and in what way you should spend? There has to be some kind of a, there has to be some kind of an impedance that is seen by this stator side. It is represented here and it is like this. So, there is an impedance that is seen through this. Whatever the current is flowing that is representative of the component of the input current that produces the magnetic field.

Now, if you energize a magnetic circuit that will produce also some losses. Why? Because, there will be some Eddy current loss, there will be hysteresis loss, you know that and the losses will also have to be supplied by these two terminals. So, that is represented by a resistance here and then would say that now it goes to the secondary side and then we have represented all the known idealities and then we would say that here let there be an ideal transformer now and in this side there would be, in this side there would be a resistance and there would be an inductance to finally give the output. That is how we develop the equivalent circuit of the transformer.

The only thing is that here it is R 2 X 2 and this is called, some books call it R n and X m, magnetizing, some books call it R naught X naught, so let us, you can call them any of these. Then, at the next stage, we say that we do not really need this ideal transformer. We have extracted all the non-idealities and they are all here, so we do not need this. But, just saying that will not suffice. Why? Because here there was a, there was a turns ratio and because of the turns ratio, the current that was going in was not the same as the current that was going here. As a result, if the current is different, then the amount of power loss that was here will also be different. That has to be made the same if you want to eliminate this.

Yes, in order to do that what we do is a simple trick. We say that let the same current flow through this and as a result we will need to change these and since the power loss is proportional to i square R, therefore what we do is we multiply by the turns ratio square and by doing that, we say that now my equivalent circuit is something like this.

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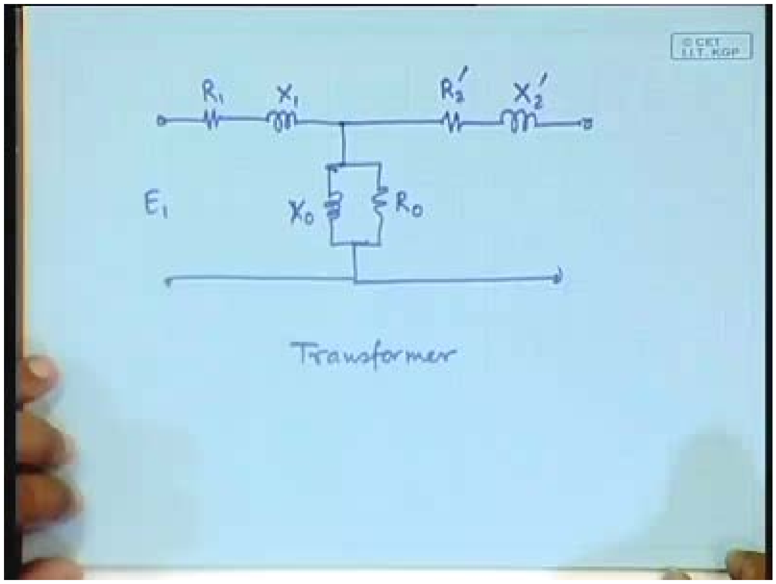

Resistance, inductance, then this side inductance and then there is a resistance and there is a inductance, but then you say that here it is R 2 dash X 2 dash. The dash means that it has already been multiplied by the turns ratio square. Here is R 1, here is X 1, X naught R naught. So, this is the transformer, so here it is your supply voltage. Now, here it is not really the secondary voltage, because we have eliminated the transformer. So, here it is the secondary voltage as referred to the primary side. Now, we are not really trying to understand the transformer, we are trying to understand the induction machine.

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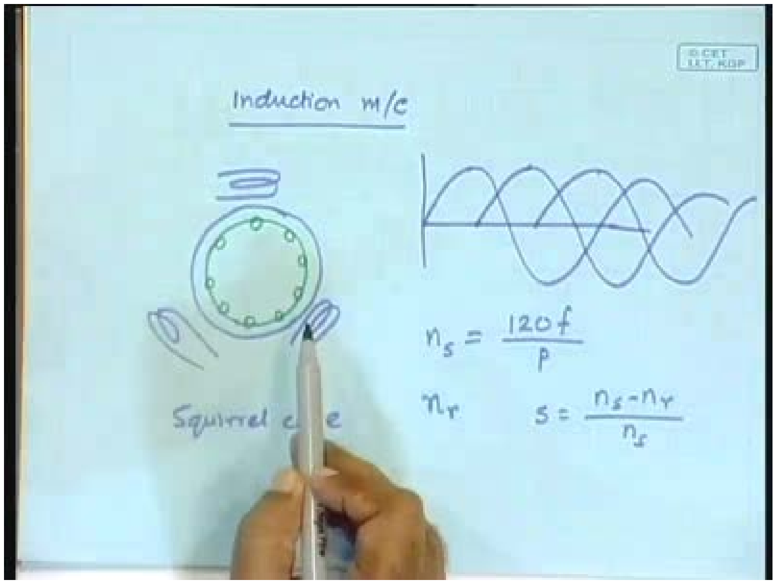

In what way will the induction machine be different from the transformer? One, if it is held static, this is the same thing. But if is allowed to rotate, then something more happens. What is that? One, the frequency, the speed seen by the rotor conductors will not be the synchronous speed. So, whatever frequency was here, here it will see or induce a different frequency and that frequency is the slip frequency that is this frequency times the slip. It is a very low frequency that is ….. So, not only the voltage is different like a transformer, but also the frequency is different. That is the only difference.

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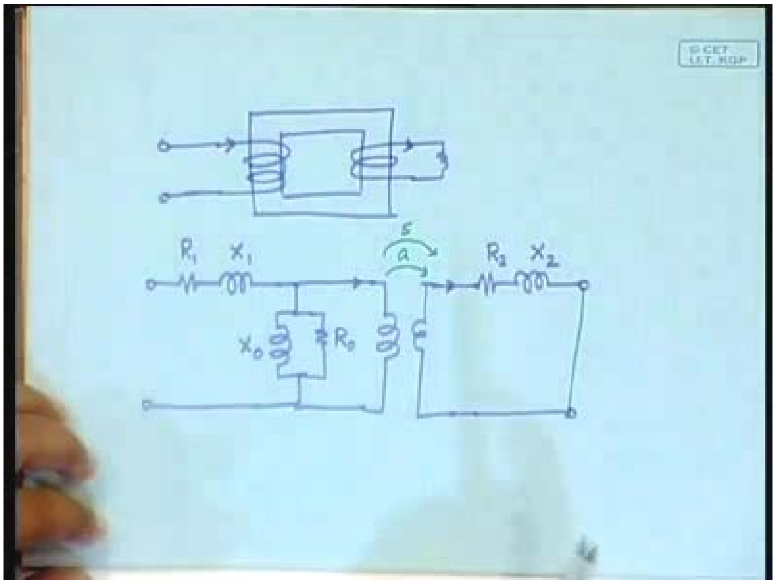

So, if you have, so if you have this representation, then in addition to that we will say that this transformer is not only a voltage transformation device, but also a frequency transformation device, clear. In the next step we try to eliminate this. In order to eliminate this, oh, the other thing is that here the secondary side is shorted. There is nothing coming out of secondary side. Unlike the transformer you are not connecting something else to the secondary, it is shorted. So, this side will be shorted. So, let us take care of these two things. One is a, that is, the conversion of the, because the turns ratio and this another conversion because of the slip, there are two conversions here.

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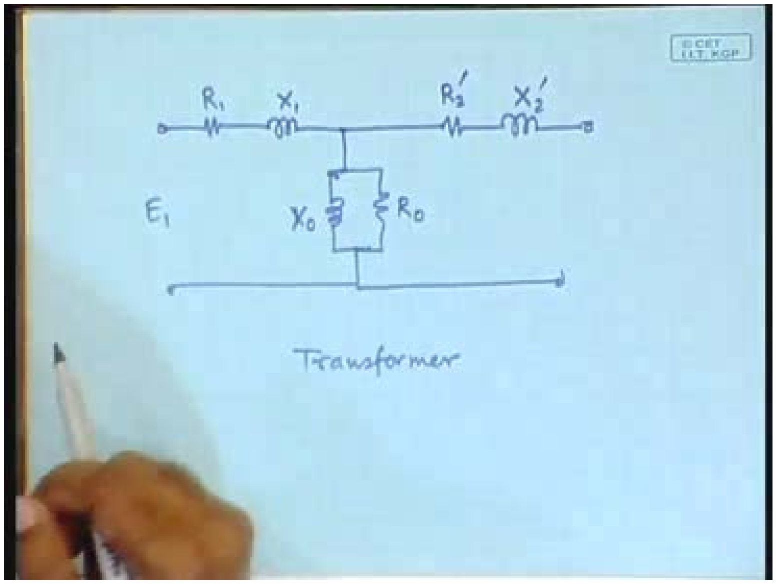

The first one is the same thing as this. You cannot take care of that by the same way you did it for the transformer. All you say is that now I will not say R 2 and X 2, I will say R 2 prime and X 2 prime meaning that I have already multiplied the R 2 and X 2 by the tans ratio square. What about the frequency business? The rotor has a different frequency. Now, there also we will go by the same kind of logic. Notice one thing. If there is a coil with some inductance what will be the inductive reactance? It will be proportional to the frequency, right. So, whatever this fellow's value was, whatever this fellows value was if it is connected directly to the 50 hertz supply, it will not be the same value, because now it is experiencing a far lower frequency.

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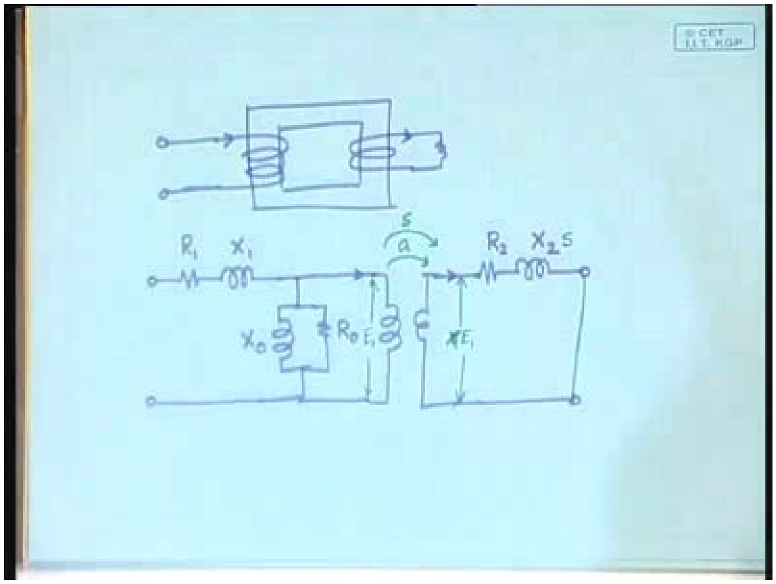

So, this fellow will be X 2 times S, this fellow. But, R 2 will not be affected, because it is a specialty of the inductance that the inductance value is proportional to the frequency. So, it will see the frequency difference here. We have taken care of this one by writing it like this. But now, we have to go by the same logic. What is it seen from the stator terminals, seen from the input terminals, I should be able to make no difference. Whether it is this equivalent circuit or that equivalent circuit that is the logic and because of that logic, when we eliminated this transformer with the turns ratio a, we said that we will multiply this, because then whatever is seen by the input side will remain the same.

So, in order to do that, what is done is that here there was supposing the voltage here is E 1 and voltage here is, if you now do not consider the turns ratio, then it will be SE 1. So, the SE 1 is the voltage that allows the current to flow, SE 1 is voltage that allows the current to flow and how much is the current? How much is the current i? This SE 1 divided by this. So, it is that amount of current.

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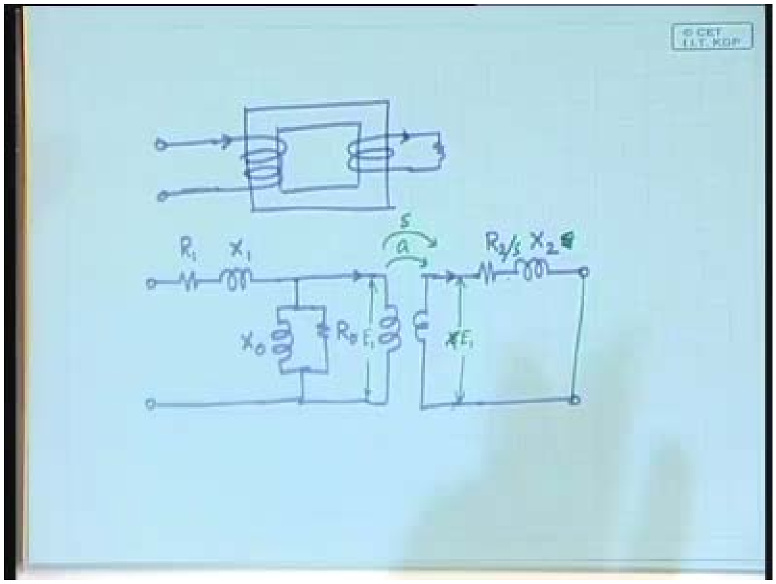

Now, in order to keep the power dissipation seen by this one constant, what we can do is we can say SE 1 by this or we can say then, no, no, it will be the same if you drop this, but in that case we will divide these by S, same thing. The current with SE 1 as the voltage and this as the impedance is the same as E 1 as the voltage and these as the impedance. So, if you do this, then here is E 1, here is E 1, so I do not need the transformer anymore, clear.

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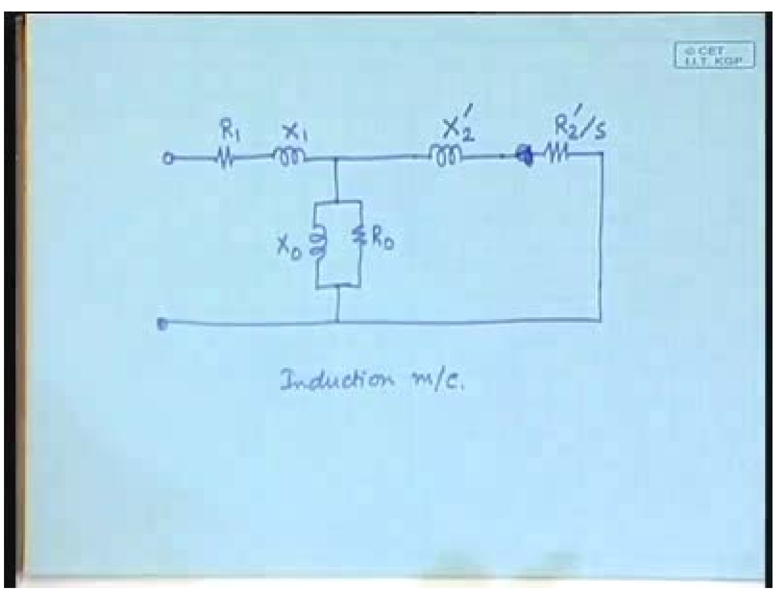

That makes it a very simple representation of the equivalent circuit, where the equivalent circuit would be R 1 X 1, this is X naught R naught, this is the primary side and in the secondary side you will have this is X 2 prime and then, sorry R 2 prime by S. That is additional thing that is necessary, but this side is shorted. So, this is the equivalent circuit of the induction machine, fine. From the next day, we will start form this point and then we will develop an understanding about how the induction machine performs as a generator.

Thank you very much.