Energy Resources and Technology
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Lecture - 25
Wind Energy – V

A wind turbine obviously has to be controlled. Why does it have to be controlled, because at some point of time it has to be started depending on the velocity of wind and then your objective would be to extract the maximum power from it that requires certain control strategy and then if the wind becomes too gusty, too high a wind speed, then obviously the wind turbine has to be protected and this will call for certain measures. For example, if it is too high a wind speed and you are extracting the full amount of energy out of it, obviously the gear box, the generator, will be overloaded and they might burn and so that has to be protected and finally in situations like cyclones, so high a wind speed, obviously it has to be protected. So, that will require certain strategies, certain measures for controlling the wind turbine. So, today we will mainly discuss that. Now, the strategies for controlling the wind turbine becomes clear if we, if we draw or make a plan for how do we plan to extract the power as the wind speed varies. As a function of the wind speed, what is your planned way of extracting the power?

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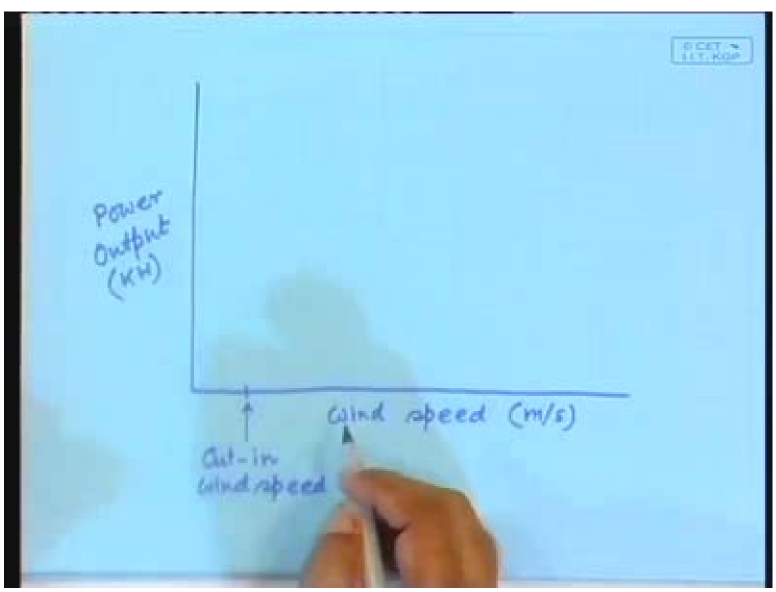

Following common sense, we can draw a graph like this. In this case, it will be wind speed in the x-axis, meters per second in the x-axis and in the y-axis it will be the power output. The power output will be in the y-axis, say it will be in kilowatt or megawatt or something like that. Now, what will the curve look? Obviously, at very low wind speeds will you be able to extract any power? No, obviously not. So, it should be starting at a specific wind speed, right and this wind speed is called the cut-in wind speed, the cut-in wind speed. Below that it might not rotate or it might also rotate in the, in the case that it attains certain amount of torque, so that it can rotate freely, but no power is extracted from it. It is allowed to rotate freely. So, it can be both. In some wind turbines there is sufficient starting torque, so that it can start to rotate, but you do not extract any power out of it.

In many modern and large sized wind turbines, the starting torque is very small, so that it will not start at all by itself. So, at this point of time, you start extracting the power. When you decide that okay, my cut-in speed has been reached that means the wind speed is now sufficient to extract power. Beyond that, obviously there will be no power output before that. Beyond that what happens? What should be the characteristic like? Beyond that there will be a range when the wind speed is moderate. If you extract the full amount of power out of it, as much as you can within the limits of the Betz theory, then at least the generator, the gear box, these things will not be overloaded. So, what will be the strategy? Obviously to extract maximum power.

Now, if you extract the maximum power of it, power out of it, then what should be the characteristic like, as you vary the wind speed? It will vary in proportion to the power contained in the wind and the power contained in the wind varies cubically with the wind speed, right.

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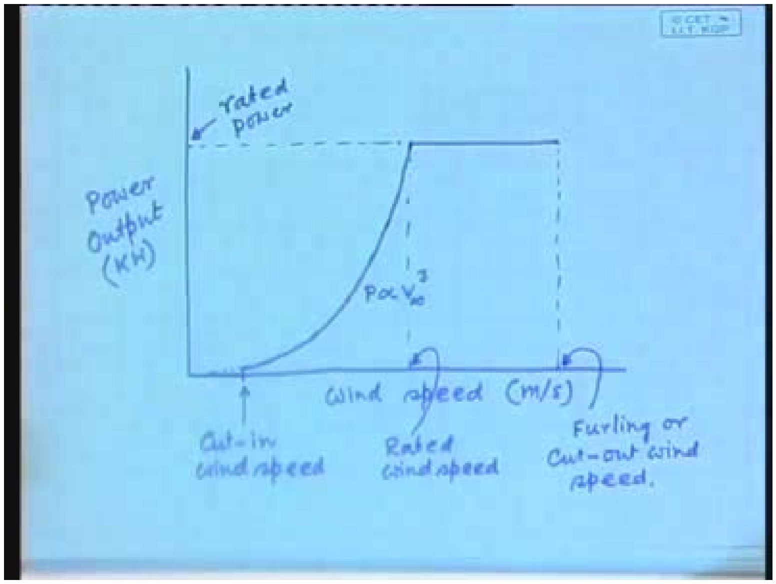

So, obviously the amount of power output will vary like this and it will be cubic characteristics, fine. At this point, if you extrapolate, it should go to zero at zero velocity. So, here it is P proportional to V cube or V infinity cube. So, that is the characteristic and what we will have to do in order to attain this characteristic, we will discuss that. But, as the wind speed increases, there comes a particular state, when if you extract the maximum possible power output that is the rated power of the generator. Every generator has a rated power, every motor has a rated power, everything has a rated power, so it has reached at this point where it is the rated power and it is reached at a wind speed that is the rated wind speed. So, that means when you construct a wind turbine, you construct in such a way that if the wind speed is this much, the power of the output will be that much and that is the rating for the machine.

When you did your laboratory experiments, you would have found that every machine has a name plate and on that name plate a rated power is written. What does it mean? Can't it produce less than that? Yes, of course, it can produce less than that, but if it produces more than that, then the wires overheat; they may burn, the insulation may go. So, overheating will not be desirable. So, that is the concept of the rated power. It comfortably works at that particular speed and particular power. What should you do as the wind speed increases further? Obviously, you should not exceed the rated power or even if you do, you can do only by 10% or more, not more than that.

So, what should be the strategy ideally? Ideally it should be to flatten the characteristics. That means at this point it should be a flat characteristic. Even if the wind speed increases, power does not increase and it becomes level at the rated power output till a certain wind speed, till a certain wind speed and at this particular wind speed, the wind speed is now too high for the protection of the wind turbine itself. If it is too high, then what happens? At some point of time you have to, you have to engage your protection mechanism. That means it cannot allow the wind turbine to rotate any further. You have to stop it. Why? Because, if it does not, then the stresses will be so high, that the wind turbine blades may break. So, at this point it has to be stopped. This wind speed is called the furling wind speed or cut-out wind speed. So, this is your rated wind speed.

You will find that normally the wind turbines are rated to work at that speed producing the rated amount of power. At that point, at this point, you will find that this is still working at the maximum power level, maximum power level is at the maximum efficiency, maximum C P, power coefficient and it is producing its maximum possible power output. So, this is the optimal operating point of the turbine, clear. So, that is the rated wind speed. In the specifications of a wind turbine, normally the rated power is specified and the rated wind speed is specified. One energetically illiterate person will assume that if I have installed a wind turbine there with a rated power say 1 megawatt, then I have, I am through; I am producing 1 megawatt. No, because ultimately what you produce depends on how much is the wind. How much wind is coming and unless the wind turbine is properly, you know, matched with the characteristic of the site, it may not produce optimally, which I will come to later, but first let us understand how to attain, obtain this kind of characteristics. This is the standard wind turbine characteristics.

Only, let me also mention that here we have argued that you should not go beyond the rated power output, right, which is a logical argument. You should not go beyond the rated power output, but there exists certain generator configurations which can allow, want to extract say 30 to 40% more power output without overheating. What these are, I will come to that later, but there exists this kind of electrical conversion mechanisms, by which you can do that.

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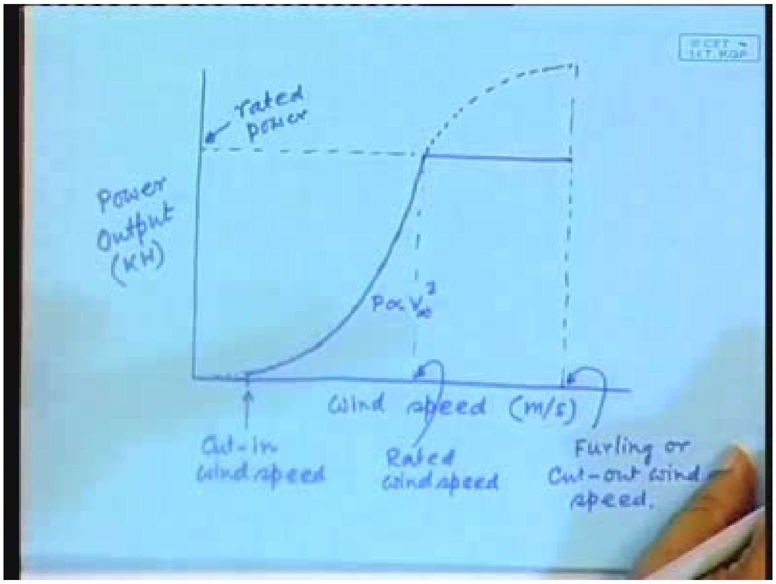

If you can do that, then you can relax and sort of go this way, but you of course have to stop it at the furling wind speed. So, here we get more power output if you can install that kind of generators. But, normal run off the mill generators will have a definite rated power level. So, we will proceed with the assumption of this characteristic, but you should also know that it is possible in some generators to go beyond that, clear.

Let us start. What means do we have at our disposal? How can we do this control? There are in the main four things that we have.

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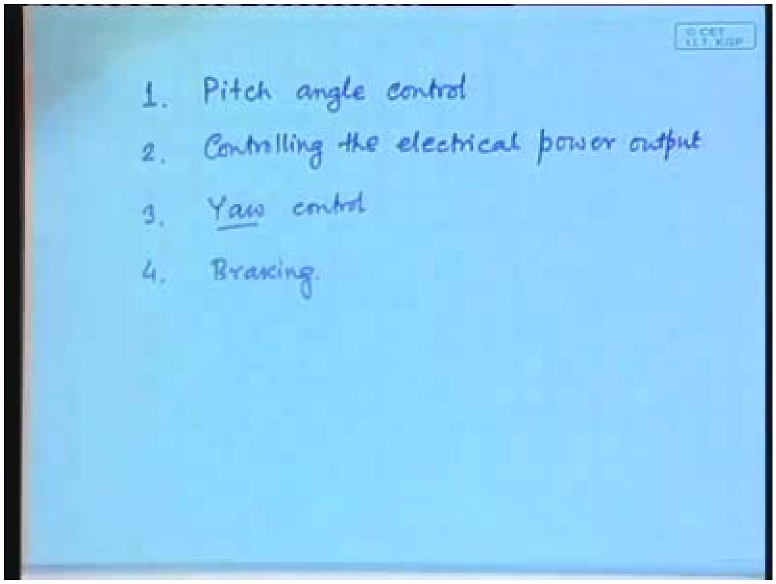

1 - controlling the pitch angle, 2 - controlling the power output. Pitch angle control, controls the mechanical power input. Electrical power output can be controlled, which I will discuss in somewhat details later. I will not be able to go into great details, because you have not studied electrical machines and power returns to that extent. But nevertheless, you have to presently assume that it is possible to control the electrical power output by some electronic means, power electronic interfaces. 3 - what is yaw control, I will come to that and fourthly, braking. Let us come to this one by one.

Let us start from yaw control, because when I talk about this, when I mention this word yaw, you need to know what it is. Yawing essentially is the means of orienting the wind turbine in the direction of the wind. That is yaw. That means a horizontal axis wind turbine has to be oriented in the direction of the wind, right; it has to be turned and in the last class I have shown that the whole head of the wind turbine sitting on top of the tower is like a turntable, it can, it can rotate and there is a servo motor doing this turning business. So, that is the yaw control.

Now, this yaw control can also be used, atleast theoretically, for controlling the power output, because if there is a wind coming this way and if you do not want that much of power output, simply orient it away from it. You might argue this way; actually it is possible, theoretically possible, but never done. Why? Because, if you are looking away from it, then all the blades that are turning, they will face, they will see the wrong direction of the wind and as a result, they will produce stress which is undesirable, so and more over if you use yawing as a controlled mechanism, you will have to all the time move it and this huge structure sitting on top of a tower, turning it is not easy job; it requires power, not only that it also makes sound. You can hear that sound yawing. So, it becomes somewhat undesirable to do that, but nevertheless you should know that it is control mechanism in your hand, but there is another issue here as related to the yaw control.

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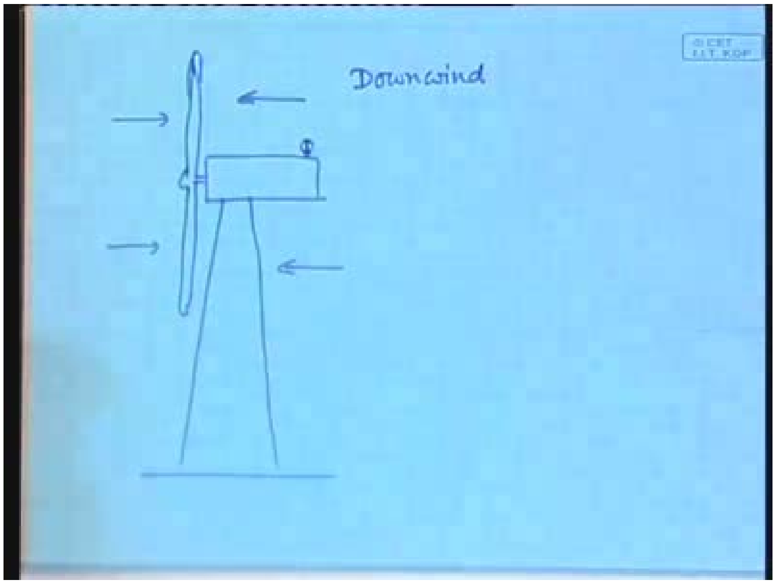

Suppose a wind turbine is situated like this and the wind is coming this way, it is possible. You can design the wind turbine, so that it could come this way or you could also design the wind turbine so that it comes this way. If it comes this way it is called a downwind turbine and if it is downwind, can you do yaw control? Do you need to do yaw control? No, because it automatically turns. Can you see that? The thrust force will act on the blade, right. The thrust force will act on the blade and the pivot is here, so that if it is disoriented, the thrust force itself will orient it back, right. So, if you have a downwind

wind turbine, you do not need to have a yaw control. But, the disadvantage is that then the tower shadow effect will be larger, because here the tower is there and the tower will produce a blockade in one position of the blade. So, that will produce a torque pulsation. So, some companies prefer downwind wind turbine, because you do have to have yaw control, but some other companies prefer upwind.

If it is upwind like this, then you have to have a mechanism for yaw control. So, in the downwind wind turbine, the advantage would be the whole mechanism of turning the thing will have to be, will be unnecessary, while in upwind wind turbine they will be necessary, clear. So, that is point about yaw control and yawing normally is controlled. There are two possible ways. You need to know which direction is the wind coming from. Now, either if it is a wind farm that means there are places where because of the advantage of high wind speed, a large number of wind turbine, say may be a 1000 of them are put in a single place. So, the whole thing works as a system and then it is not necessary for each one to detect the direction of the wind, because all of them will face the same wind from same direction. So, there can be just one place where the wind direction is sensed and the sense is sent to all the wind turbines to do the orientation. In that case, there will be a central controlling station from which the control is activated.

Else, you can have small perpendicularly directed that means this way a small, again wind turbine something that is oriented at orthogonal direction to this one which senses whether the wind is coming from this direction or it is coming from sideways. If it is sideways, then this will rotate and will give the error signal which can be used to turn the whole turn table. For singly operated wind turbine, this is the option, but for large wind farms you have a better option available, clear. So, that is the point about the yaw control and as I told you, yaw control can theoretically be used for controlling the power output, but it is actually not done, because it produces loud noise and stress on the blades. What it leaves us is the issue of pitch control.

Now, about that we have understood a few things.

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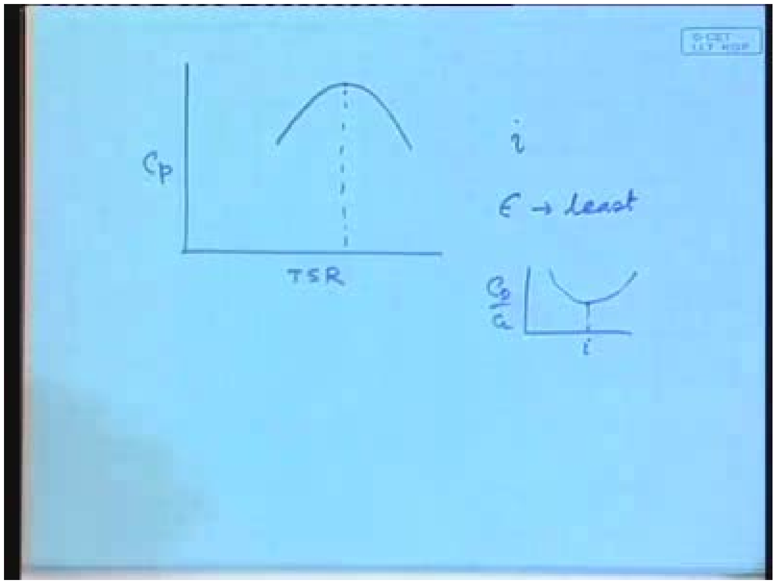

Firstly, we have understood in the last few lectures that the tip speed ratio versus C p, power coefficient characteristics is like this. What does it mean? It means that the maximum C p that is where you want to operate in this zone, in this zone we want to operate at maximum power coefficient and that happens at a specific value of tip speed ratio and the tip speed ratio is the speed of the tip which is related to the angular speed of rotation divided by the wind velocity. So, as the wind velocity changes what should we do with the speed of rotation? It should change proportionally, then only you can keep this constant. So, as the wind speed changes, that is a variable thing that you have to cope with, as the wind speed changes, you have to vary the speed of rotation, the omega the angular velocity exactly in proportion to the wind speed, right and then only you can replace. Seen from the point of view of individual blades, we have seen that it works at its maximum aerodynamic efficiency at a specific value of the angle of attack, i, small i; you have seen that, right.

What was the logic? The logic was that epsilon should be least, least possible. From the aerofoil characteristics, we get the value of the lift coefficient versus i, the drag coefficient versus i, and from there we find the least value of epsilon. How? By drawing the tangent or simply you divide the C D by C L and draw a graph. So, you draw a graph

C D by C L and you get the minimum point that will be corresponding to a specific value of i and that i, that angle of attack should be maintained. That is the logic from the point of view of each aerofoil.

In order to maintain this i, what is this i?

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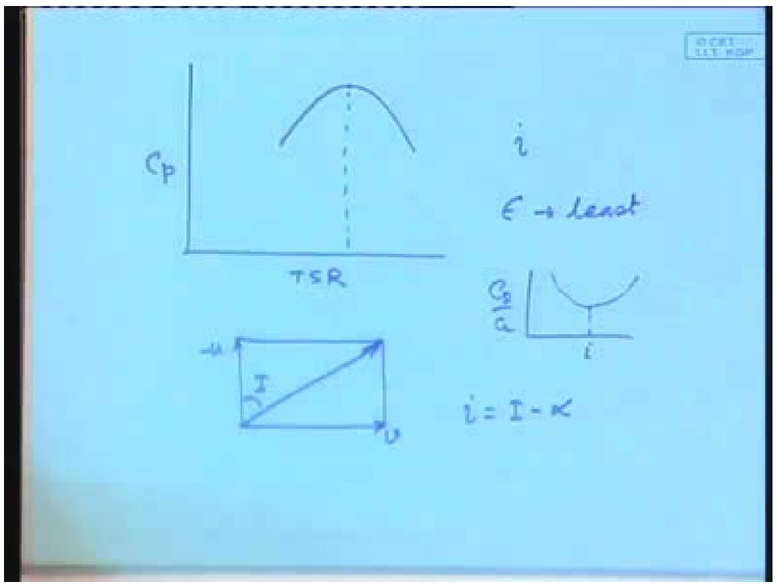

That was if you remember, this the velocity parallelogram, this was our v and this was our minus u and this was our relative wind and this was capital I and the small i was capital I minus the pitch angle, right, just to recall. So, if we want the keep the small i constant while the capital I varies, capital I varies, why? Two reasons; first, V varies with the wind speed varies and secondly u varies. At this point of time, we are not considering the variations from the inside edge to the tip. We have already seen that that varies and for that we need to give a twist. But here, we are considering the speed of rotation of the whole thing and as the v changes i changes, capital I also changes. But, all the time your objective should be to keep the small i constant and that can be done by continuously varying the alpha, pitch angle. So, the pitch angle has to be varied, right. In what way?

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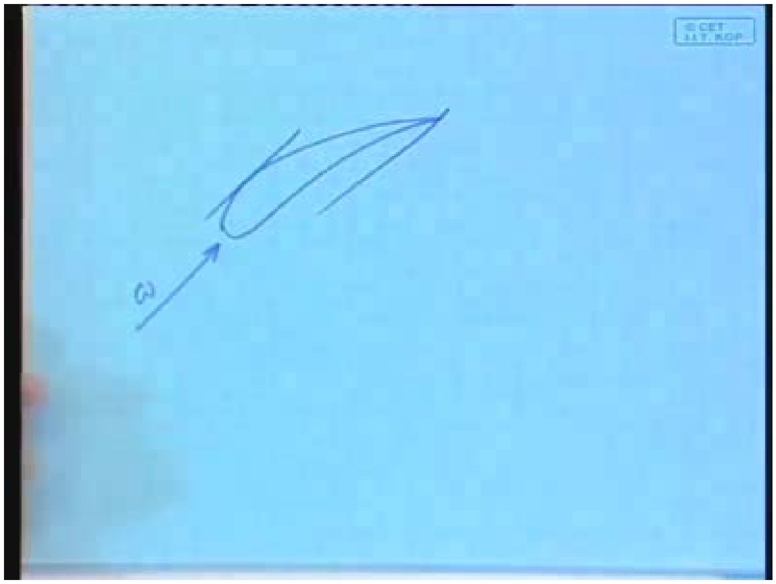

This is theoretically fine, but if you want to go back with some sort of round about idea, then you might think this way that here is my aerofoil and I should orient in such a way that the wind actually is seen to be coming from this direction w, so that the seen, the wind sees the least area and if it sees the least area, it will produce the least drag force.

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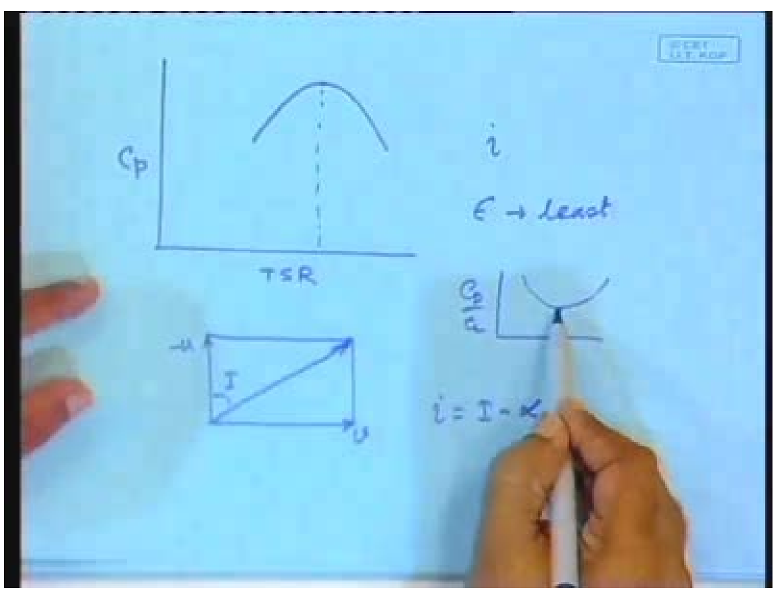

If the drag force is reduced, logically that should give me this point, least drag force. So, you should always try to orient the aerofoil in the direction of the relative wind. So, that is the logic.

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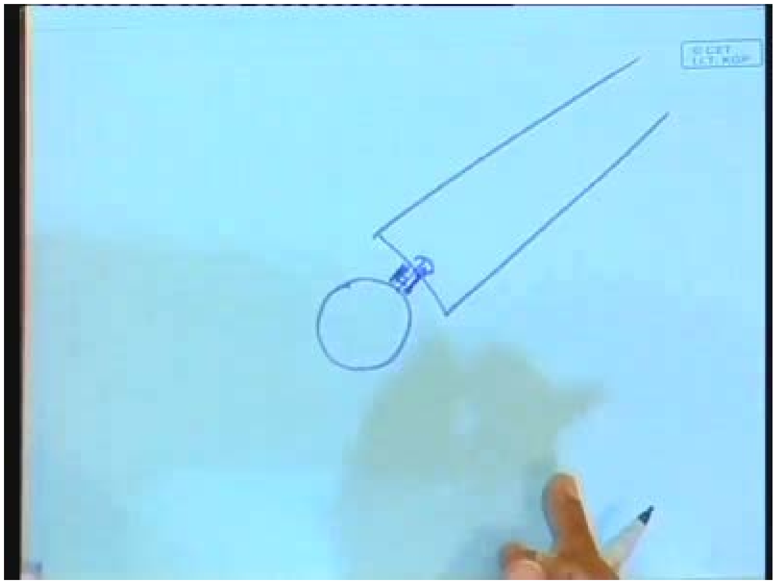

In any case, you have understood that this can be achieved only by continuously varying the pitch angle and the pitch angle you imagine that this whole blade, here is the centre, here is the axis and here is the whole blade, say. Then, at this point there has to be a motor situated that can turn it like this. So, these blades are not actually firmly attached to the axis. There is a scope for this to turn and that is the pitch angle control. So, at these points, there would be motors, servo motors doing this turning business.

What will be the logic? What will the logic be? The moment you say that there has to be a servo motor and it should turn, then you have to, you have to think of how to control it. How to control it means theoretically I will always keep i constant, fine; but, ultimately you have to devise the whole the thing in terms of some kind of a reference signal, some kind of error signal and finally, you have to do the control. Are you really sensing all the time what is capital I? No. Are you really sensing all the time what is small i? No;

because, in that case, you have to have sensors along the blade which you cannot really do. So, how to do that? There are two ways of doing this.

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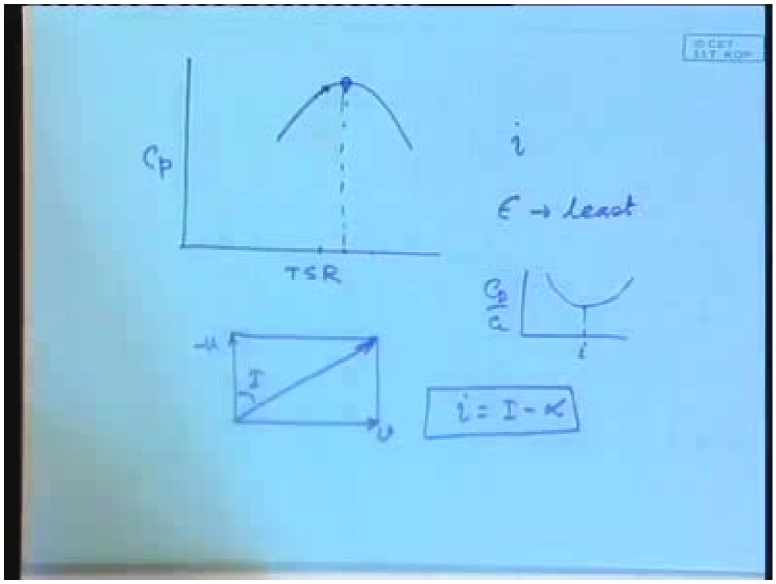

One, you have seen that the C p versus TSR characteristic reaches its peak at a specific value, at a specific TSR. Now, the TSR signal that means the value of the tip speed ratio for which maximum C p is attained that can be measured and kept as a reference and as the wind speed varies that can be sensed. There is no difficultly about it. If it is a wind farm, there can be single central station at which the wind speed is measured continuously. So, you have a sense of the wind speed. Sense of the rotational speed that can also be obtained very easily, because the turbine is rotating you can always sense what is the speed. So, all the time, in real time, you can measure the TSR, right.

Now, if you find that the TSR is less than the reference TSR here, that means, I am now operating somewhere here, what has to be done? Something has to be done in order to move it this way. That means you essentially have to speed it up, right, you have to speed up the wind turbine. How can you speed up the wind turbine? Then, you pitch it and if that results in the increase of the speed, you know that you are pitching in the right direction. That means you change it, change the angle and if it changes like this, you know that you are going in the right direction. If it is too high, then you have to go this way. So, there will be essentially different ways of orienting the pitching, clear.

There is another thing in our hand, I will come to that later. But, essentially the pitching should aim at this. The change of the pitch angle should aim at this, should aim at keeping I minus alpha constant. i should be, the alpha should be so changed that this is constant, this is … There is another lever in your hand that is as I told you, the control of the power output.

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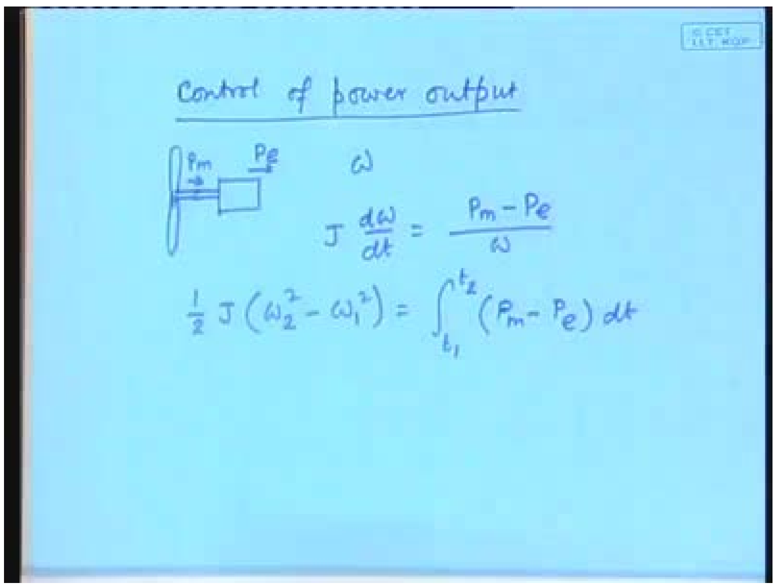

Now, if power output is controlled that means from the wind turbine, from the wind turbine there is mechanical power going and then, I am schematically drawing, there is electrical power and this electrical power, this is P m and this is P e. So, a mechanical power is going into the generator and the electrical power is withdrawn. Obviously, the speed will depend on the difference between the two, right. Imagine, it is rotating at a specific angular velocity, omega and now the P m, P m the mechanical power, remains constant. But, you will deliberately reduce the electrical power. What will happen? There will be a difference between P m minus P e. If there is a difference in P m minus P e, then what will happen?

You can write the equation as J, the angular moment of inertia times d omega dt is equal to P m minus P e by omega. You can easily see that there will be a positive value here, the speed will go up. There will positive value here, the speed will go up, because this is positive and how much will the speed go up? You can, you can integrate this. You will write half J, after some time the speed is say omega 2 square minus omega 1 square. This happens over a time period of t 1 to t 2 P m minus P e times dt. So, if you allow this to be positive, after some time this, it will change, the speed will change from omega 1 to omega 2 and you will have a larger speed.

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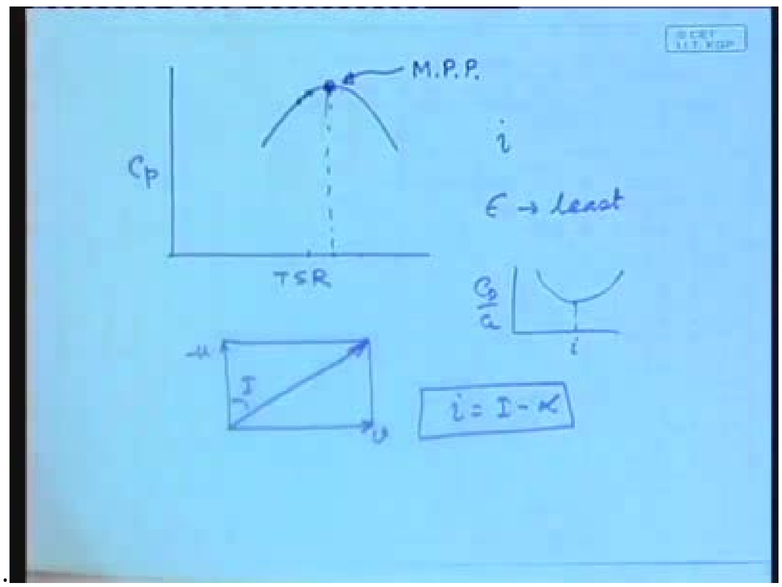

So, as I told you, you need to operate; you need to operate here. If say, you find that it has come here, right, that is another thing that you can do. You allow less amount of power to come out. As a result, what will happen? It will speed up and it will come back here. When it has come back here, you have now more power available. Then, you again increase the power output, but by then it has reached here, clear. So, all the time you can work in the neighborhood, in the vicinity of this maximum power point. Here is the maximum power point. So, the take home message is that the pitch angle control will be controlled by this. Even if you do a pitch angle control it may or may not work at the MPP. So, in order to get at the MPP, you additionally have to control how much amount of power you are taking out of the machine and ultimately operate here and this power output of the machine, P e that can be controlled. Presently, at the present time, you just take it from me that it is, it can be controlled and how it can be controlled, I will come to that later.

Yes, of course, in some generator configurations it can be controlled, not all. So, in some generator configurations you have this additional lever in your hand, but not in all generator configurations. In cheaper electrical systems, you do not have this control. There is a problem of working this way. What was the logic I said? I said that the logic is that you store in a microprocessor. The controller is driven by a microprocessor, in that you store the value of the tip speed ratio and depending on that, you do your control, fine. Logically it is simple, but the practical difficult is firstly how do you find out this? For a big wind turbine it is not easy. Secondly, that means you cannot put the big wind turbine into a wind tunnel and do the testing. So, it has to be, somehow this has to be obtained.

Supposing somehow you obtained it, but this does not remain the same throughout its life time. Why? Because, the blades that are initially smooth will slowly become rough; you cannot help it. As it becomes rough, the maximum power point that means the value of TSR at which the maximum power point is reached that also will shift. So, even if you can obtain it for a particular time that means when it is first installed, you cannot logically guarantee that it will remain the same throughout its life time. Then what to do? That is why some of the more modern control systems incorporate a different control strategy. That control strategy is something like this. Notice that it is a one humped curve and the peak is smooth, means differentiable. What is the character of, what is the distinctive character of this peak as compared to any of these points?

At any of these points if you change the TSR the C p changes, but at this point if you change the TSR the C p does not change, …., right, convinced? That can be used as a means of obtaining the maximum power point. What do we do? Supposing you are here, you reduce the power output of the electrical system, so that its speed goes up. As the speed goes up, this system senses that now C p is going up. If it is going up, then I should reduce the power output even further, so that it goes up further that I am going in the right direction. But as it reaches here you change it in further, it does not change, right. So, if you change the TSR, tip speed ratio and if as a result, the power coefficient does not change, you know that you have reached that point.

Now, just build this in as a continuously checking logic. That means if the wind speed changes everything changes, the speed has to be changed, the pitch angle has to be changed, everything has to be changed, fine, but ultimately it will again get back to its maximum power point by the same logic. At the different wind speeds, it should again check am I working at this point? That means if I change my TSR now, am I now getting into this point, this valley. So, that is another logic by which this is done, clear.

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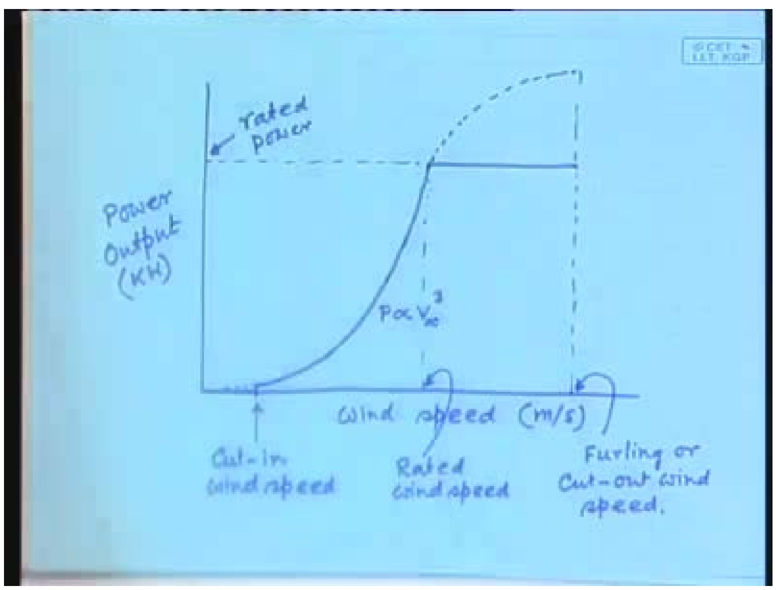

So, we have more or less understood what can be done here in order to obtain the maximum power output, right. Again to repeat, we have essentially two levers in hand. One - the pitch angle control which controls the mechanical power input, two - the power electronic control that controls the electrical power output and with that you ultimately obtain this. The logic for controlling the pitch angle should be to keep the i constant at the optimal value and the logic for varying the power output through the electrical means should be to obtain the maximum power point in the C p TSR characteristic.

What about here? How to flatten it? You would notice that this is the region where the wind contains more power, but you are not extracting that. How can you do that? Here also you have, but here remember, here it cannot be done by electrical means, because electrical power outputs maximum value you have reached already, so that if you want to reduce the speed you cannot simple do that by extracting more power out of it. Why? Because, you are already at the peak, right. So, at this point you have to do it mechanically and mechanically how?

There are two ways. One is where as we have seen that so far we were controlling the pitch angle in order to obtain the maximum power output. Suppose we now deliberately do it wrongly, what will happen? It will give less power output. So, the one way is to pitch it in the wrong direction, so that the power output reduces. So, that is one, one means available in your hand. That means, here the power output will be kept constant; the power, mechanical power output will be kept constant by changing the pitch angle in such a way that it gives out less amount of power. But always remember, it has to see that it is there; it should not reduce further. So, what pitch angle gives, what pitch angle gives, the proper output that has to be judged.

So, all the time the power output is measured and depending on that the pitch angle is controlled. What will happen? If you change the pitch angle very badly it will tip. The moment it tips, the moment it goes beyond, below the rated power, you know that you have changed it more than it should, so you can change it. So, this can be built into a sort of continuously operating logic in the control mechanism, so that you change the pitch angle in the wrong way.

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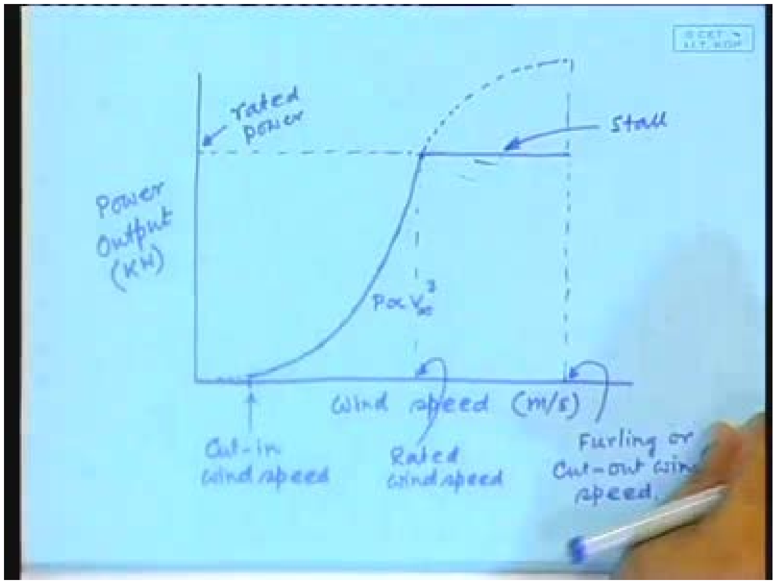

This is called the, this part is called stall part, where you are not aiming at utilizing the complete power that is available in the wind, this stalling part and there are two ways of stalling it.

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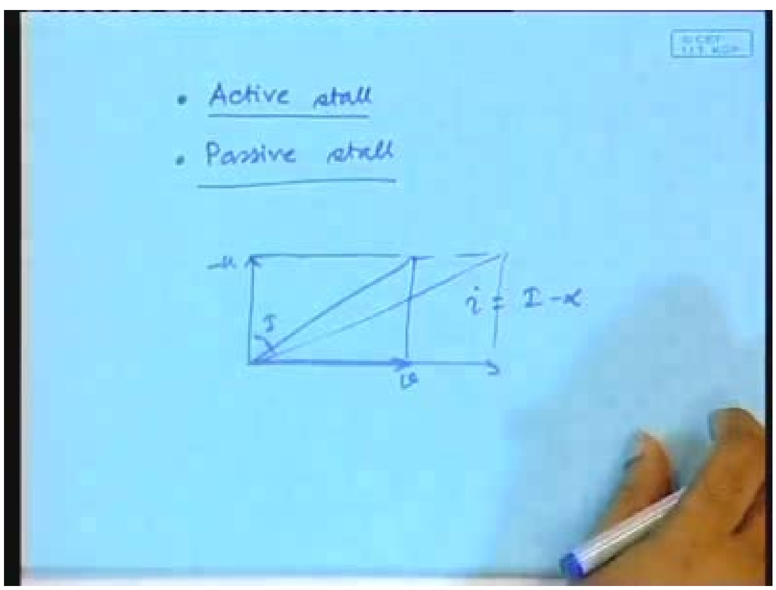

One is called the active stall and the other is called passive stall. Active stall is what I just described. That means you change the pitch angle in such a way that the stall happens. It does not extract as much power output. But, in that case you have to have the pitch control mechanism operative. As I told you, for small wind turbines, pitch control mechanism is often, does not justify itself, right. If the pitch control does not justify itself, you do not have the pitch control, then you cannot do this. Then what? Then, still you have to protect the wind turbine. There is still a mechanism available for it. That is as I told you, when we drew the rectangle of the velocities, this was the velocity of the wind and this was the velocity of the blade and we drew this and this was our I. Just let me rewrite, i is equal to I minus alpha. Alpha is fixed now. Small wind turbine, we do not have the scope of varying the alpha, so that is hard, fixed. Then what happens?

As wind speed changes, as wind speed changes, it becomes larger. This capital I changes, it becomes like this. If the capital I changes, the small i also changes, which means it is no longer operating at the optimal point. This means that even if you do nothing, the output power mighty vary, will vary and the whole thing can be so designed that it if you change the wind speed beyond its rated speed, then it automatically drops, clear. That means at the design stage, the design of the blade itself, this whole logic can be built into it, so that as the wind speed varies, wind speed changes, increases beyond the rated value, the i changes such that the power output falls. That is called the passive stall. So, passive stall is normally used in small wind turbines, which do not have the active stall mechanism, but otherwise the active stall is the same as pitch angle control. But here, the objective of the pitch angle control is stalling rather than obtaining the maximum energy out of it.

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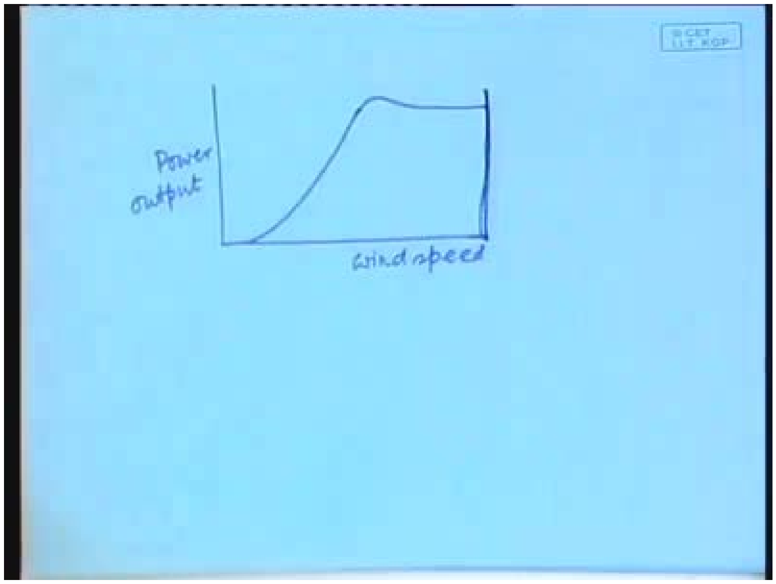

If you have the active stall control over the passive stall control, then the energy output will be something like this. You want it to be flat here, but it becomes … So, it becomes something like this. So, here it is the wind speed and here it is your power. Why this hump, because this is the, this is range, zone in which you are essentially shifting from this mode of operation to that mode of operation and there is a twilight zone, where the wind contains a lot of power, but you have not yet shifted completely to this, so if you have a passive stall, then what will happen? It will still increase for some time and then as the angle changes much it will fall and at this point again it has to be completely stopped.

Stopping that means at very high winds, how to stop it? Again there are two ways. One, you change the pitch angle in completely wrong direction, so that it produces absolutely zero torque. That is also possible. That means the wind is coming, you simply change it in such a way that it produces zero torque. If it produces zero torque it will stop, it will completely stop. So, that is one way of stopping it. But still, normally after having reduced the speed that way, one operates the mechanical break like the same break as you have in a car, mechanical break, finally it is completely stopped. When a gusty wind comes or there is a prediction of a cyclone or something like that, the whole wind farm has to be completely shut down. You cannot allow it to rotate, because if it rotates then you may, it may go off. There are other reasons for this.

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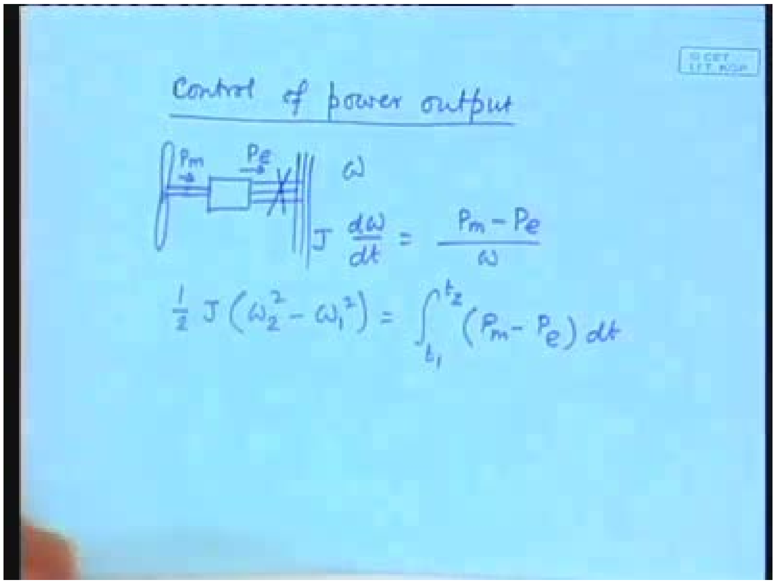

Supposing the wind turbine is connected to the electrical line from here. Let us …. the electrical line is going and in an electrical line that is connected to further networks, the grid, there can be a shutdown of the grid itself, right; there can be shutdown of the grid itself. That means you have seen load shedding, you have seen that there is a complete failure of the grid or there can be some kind of electrical failure in any of these lines. Then, obviously, this line is cut off. P e suddenly goes to zero, but P m is there. What will happen? It will increase speed endlessly and the blades will simple break. So, that can also, that also has to be stopped. So, there has to be a protection mechanism, so that if the speed of rotation goes beyond a certain value, then the breaking mechanism must spring into action and stop it, because these are not uncommon, breakages of the electrical lines are not uncommon. You have seen that, even though you have a reasonably secure power supply, you do have load sheddings. Similar things can happen here. If this line does not have power, you are gone. So, these are other control strategies you need to have, clear.

So, we are more or less, we have covered all this.

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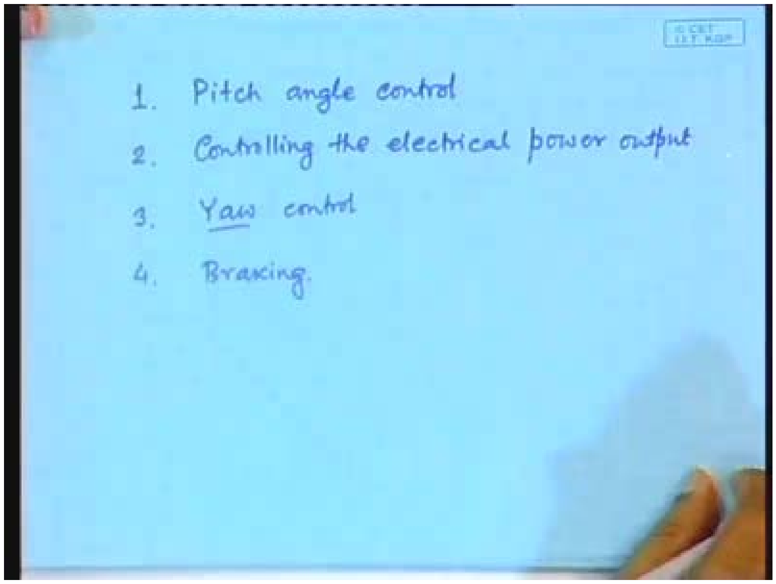

Pitch angle control, electrical power output, the details I will come that later, yaw control and breaking. Obviously, in all these controls one important input is the measurement of the wind speed or suppose you do not have any wind turbine anywhere, but you see, feel a particular place is windy and you say that now I want to utilize this wind in order to generate power. Obviously, being engineers, you cannot really say, oh, when I stand there I feel it very windy; you cannot say that. You ultimately have to quantify that. That means you have to measure wind speed. How to measure the wind speed? There are exactly three different ways of measuring the wind speed.

One, if there is anything that changes with the change in wind speed, you can use that as a measurement instrument. But, there are three things that one normally does.

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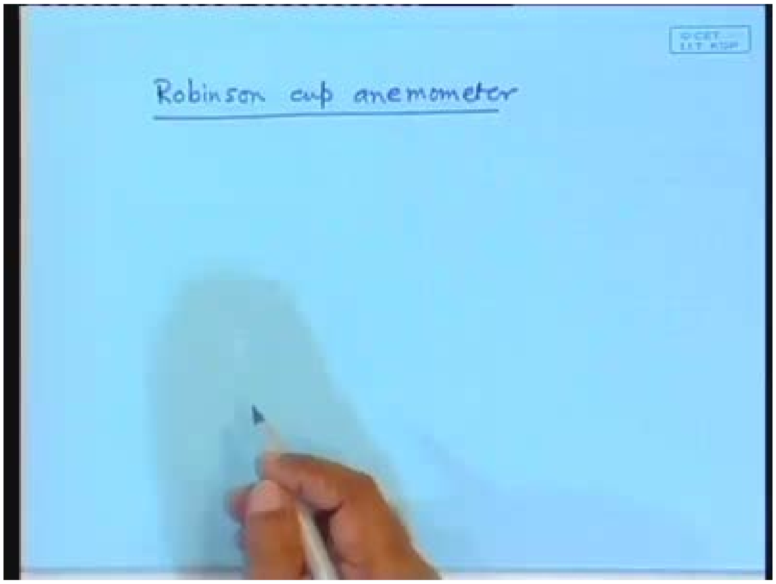

One is called the Robinson cup anemometer. It is called the Robinson cup anemometer. Speed measurement, wind speed measuring instruments are called anemometers; anemometers are wind speed measuring instruments.

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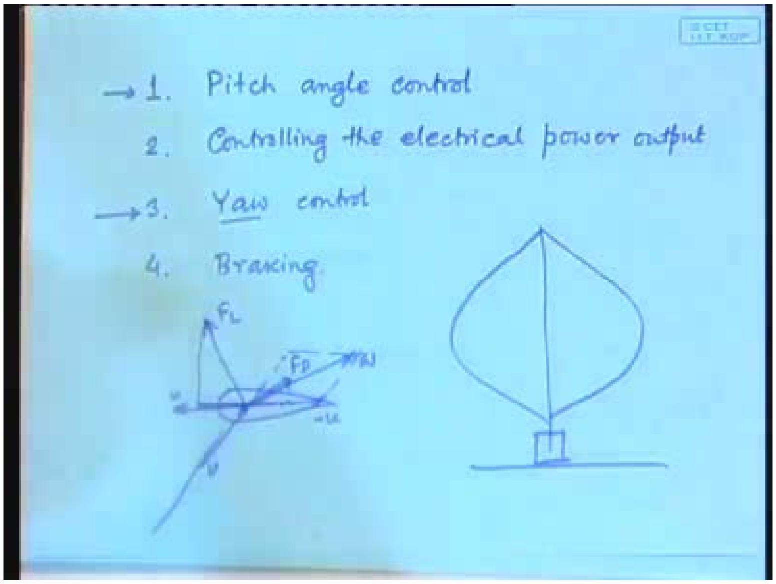

Now, the Robinson cup anemometer is, oh, wait, wait, before coming to all these, let me also tell you that all these control strategies that I have talked about, actually this and this, will work only for vertical axis, horizontal axis wind turbines. For vertical axis wind turbine, like I have already talked about this Darrieus rotor, in the Darrieus rotor, obviously there is no question of yaw control, because it is symmetrical in all the directions. It does not depend on the direction of the wind, yaw control is out of question. Pitch angle control is also out of question, because here you cannot change the pitch angle. The aerofoil is directed like this and it is simple there. You cannot change the direction. So, pitch angle control is not possible in case of the Darrieus rotor. In that case what can you do? First, you can still control the electrical power output and two, the advantage of the Darrieus rotor is that at very high wind speed, it stalls automatically.

At very high wind speed, if you again draw the force parallelograms, you will realize that at very high wind speed the force reduces. That means all the time you have the force created like this. This is moving this way, so this is your u and there will be some kind of v and you have to draw the parallelogram by completing with minus u. So you have got this and you will have the speed and this is the F D and this is F L, right. So, the actual force that produces the torque is the difference between this and this. This will produce the torque and this will try to resist. The difference will actually produce the net torque and if this becomes much larger you will find, as it goes around this whole circumference, that the net torque becomes almost zero, so that at very high wind speeds, at very low wind speed it has no torque, at very high wind speeds also it has no torque. At zero u it has no torque. Only at optimal condition it has torque. So, it has an inherent protection, it does not break by itself, clear. But, also the disadvantage is that you do not have the active control mechanisms by which you can extract the maximum power. You have to rely on its own inherent characteristics.

Okay, now, Robinson cup. The Robinson cup anemometer is somewhat similar to the Savonius rotor. What was the Savonius rotor, where you had cut two cylinders into half and joined them; here also, you do not have to cut cylinders, but it is a combination of two small or three small hemispheres like this.

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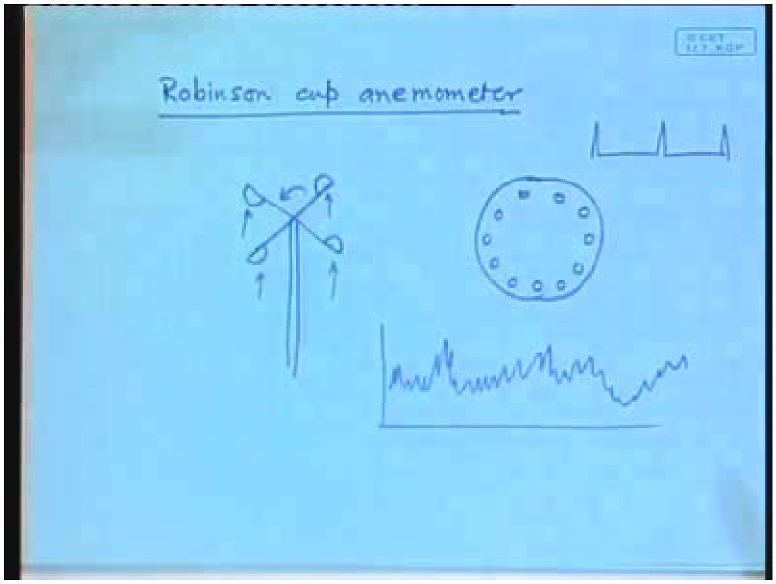

I am drawing four of them, small cups, so that as the wind comes, as wind comes it produces differential torque in the two sides. As a result, it turns this way and this rotation can be measured either by having a small tachogenerator connected with some kind of an electrical measuring device that means it produces a voltage which is proportional to the speed of rotation or you can have a, one of the other, nowadays one normally uses digital measurement. In that case, there is a, the simple way of measuring is that you have a disk with holes in it. You shine light, so that the light goes through only these holes and there is a detector at the other end. So, if this fellow rotates, the detector will detect, right and you can easily find out its frequency. That will be proportional to the frequency of the wind.

So, the Robinson cup anemometer is essentially a measuring instrument that relies on the thrust force produced by the wind, so that it rotates and that rotation is ultimately measured. Normally it is measured as electrical sensing. Nowadays it is always measured as a, you know, integrated instrument that also does the data login. That means the data is continuously logged, so that at the end of the day you can insert a pen drive and get that data for the last six months and get back home and analyze the data. There are cheaper versions in which you do not get the actual wind speed variation over a length of time, but you have the average wind speed measurement. There is a display where the average wind speed is displayed and the measurement of the average wind speed is done by this fellow automatically. So, you put it in a remote location, go there periodically and read off the average wind speed. There are also instruments available like that.

So, one thing is that you can, through this kind of instrument, continuously measure the wind speed and then do that, use that as the input to your analysis. So, in the next class, we will start from there. That means what can we do with this kind of a measured data? What will the data look like? After you have got the data back from that source, that place, as some kind of a, you know, data set that you bring in a pen drive and plot it, what will it look? It will look a very, very erratic and wavy, unruly waveform. Something has to be done in order to extract meaningful things out of it, because ultimately this data has to be used in order to analyze how suitable a site is or if you install a particular wind turbine in that site, how much power is it going to generate? All these very, very technically meaningful information has to be obtained from this kind of a very unruly and wavy data. There has to be a large amount of processing to be done with this data. We will come to that mathematics in the next class.
Thank you!