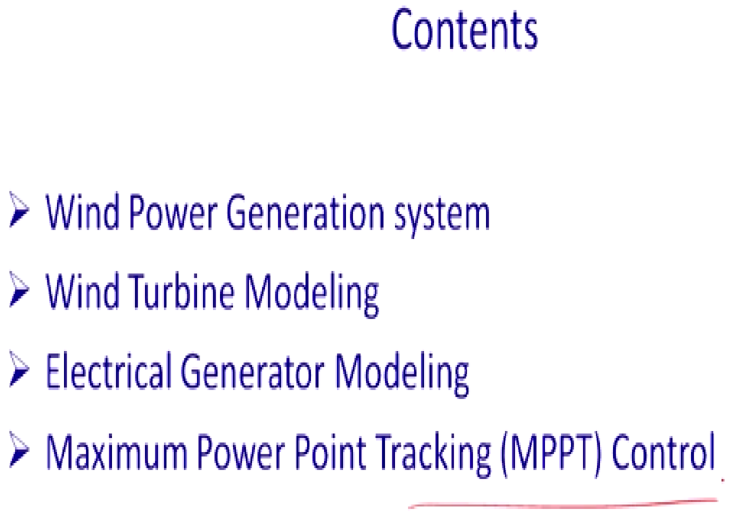
DC Microgrid and Control System

Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology – Roorkee

Lecture - 13
Modeling of Renewable Energy Resources (Modeling of Wind Energy System)

Welcome to our lectures on DC Microgrid and Control. Today we shall discuss about that modeling of the renewable energy, mainly we take out first uh wind energy, there after we shall do the modeling of the other renewable energy sources.

(Refer Slide Time: 00:56)

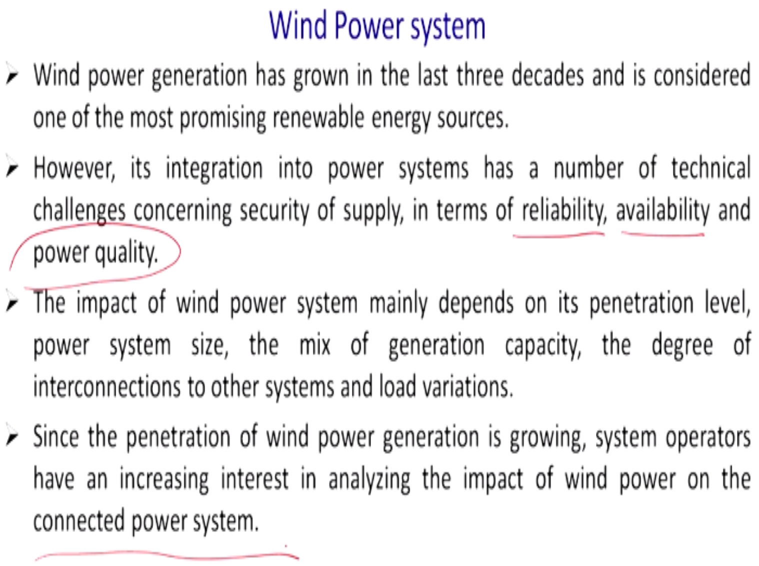


Contents

- Wind Power Generation system
- Wind Turbine Modeling
- Electrical Generator Modeling
- Maximum Power Point Tracking (MPPT) Control

So today we are going to cover wind power generation system and wind turbine modeling, thereafter electrical generator modeling and the maximum power point tracking of this to track the maximum power from the wind energy.

(Refer Slide Time: 01:08)



Wind Power system

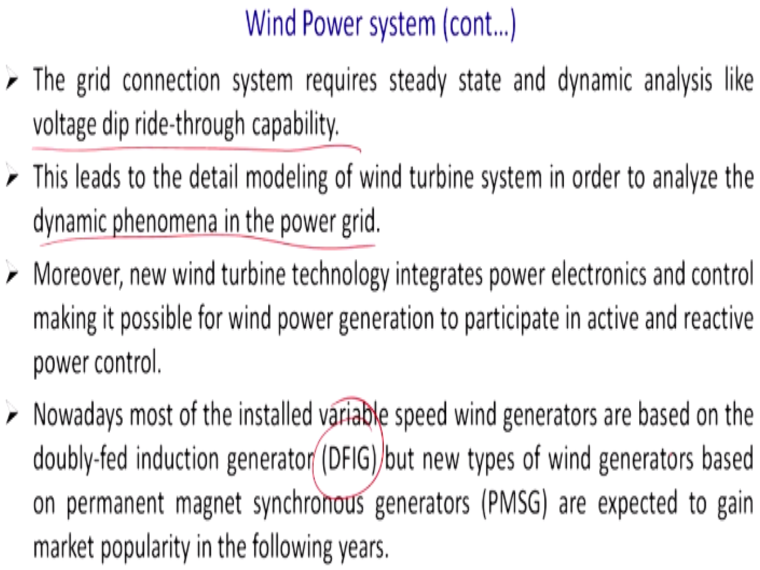
- Wind power generation has grown in the last three decades and is considered one of the most promising renewable energy sources.
- However, its integration into power systems has a number of technical challenges concerning security of supply, in terms of reliability, availability and power quality.
- The impact of wind power system mainly depends on its penetration level, power system size, the mix of generation capacity, the degree of interconnections to other systems and load variations.
- Since the penetration of wind power generation is growing, system operators have an increasing interest in analyzing the impact of wind power on the connected power system.

Now wind power generations, it is a we know all that wind power generation has grown with the last 3 decades and is considered one of the most promising renewable sources of energy because of the its availability throughout the day and night and harvesting is quite good. However, its integration to the power system has a number of technical challenges concerning security of supply in terms of reliability, availability and the power quality. These are 3 challenges.

Reliability actually you may, if it is a thunderstorm or something, you have to have peaks control and ultimately peak control does not work sometime, those are the problem. The availability of the wind to generate power at a low wind speed is also a challenge and also since it will be a variable speed, so you have to walk with the power quality issues. Impact of the wind power system is mainly depend on its protection level, that will come later how and does it mean by that, power system size, the mix of generation capacity, the degree of interconnections of the other system and the load variation.

Since the penetration of the wind power generation is growing, so I can see that gradually that more amount of wind is contributing to main supply, the system operator have an increasing interest in analyzing the impact of the wind power into the connected power system, that is something that become a mode of operation and study to how much wind penetration will have what kind of effect because it is a variable speed and how it will be changing and forecasting, altogether basic proposition has been come across.

(Refer Slide Time: 02:55)



Wind Power system (cont...)

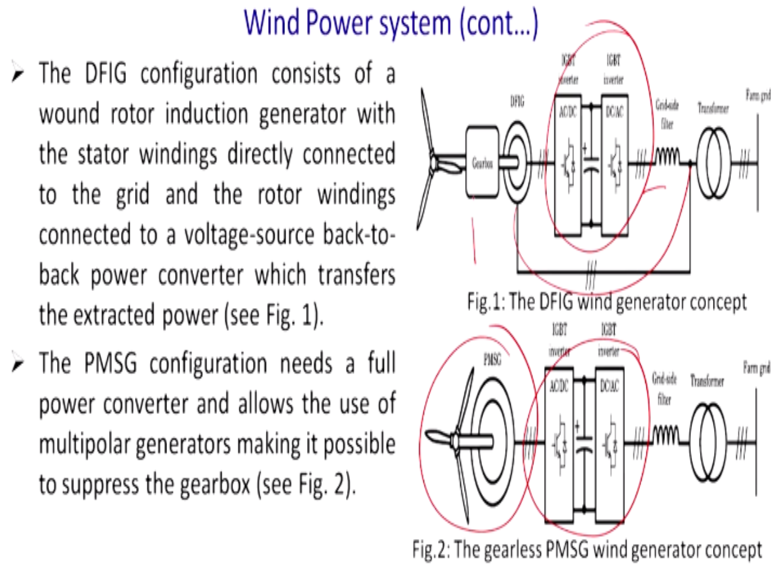
- The grid connection system requires steady state and dynamic analysis like voltage dip ride-through capability.
- This leads to the detail modeling of wind turbine system in order to analyze the dynamic phenomena in the power grid.
- Moreover, new wind turbine technology integrates power electronics and control making it possible for wind power generation to participate in active and reactive power control.
- Nowadays most of the installed variable speed wind generators are based on the doubly-fed induction generator (DFIG) but new types of wind generators based on permanent magnet synchronous generators (PMSG) are expected to gain market popularity in the following years.

The grid connected connections system requires steady state and the dynamic analysis like voltage dip through capability. So we require to understand its actually when it is running at a steady state what should be the generation and if really changing the wind speed what should be its characteristics or if load changes and what should be its characteristics, because it may be feeding to a local load instead of connecting to the grid. This leads to the detailed modeling of the wind turbine system in order to analyse dynamic phenomena in the power grid.

So that is something we required to see while modeling although little will be covered. Moreover, the wind turbine technology integrates power electronics and control making it possible for wind power generation to participate in active and reactive flow of power or control. We have seen how can you can change the flow of power, can control active and reactive power, same control technique will be applied here with the help of the power electronics.

Nowadays, most of the installed variable speed wind generation generators are best on the doubly-fed induction generator, so while we feed from the status side as well as rotor side, but new type of the wind generation based permanent magnet synchronous generators are also expected to gain the market popularity in the following years, but only problem in PMSG is that this permanent wind available in a single country in a bulk that is China. So ultimately China controls the market, that is one of the biggest disadvantage of PMSG.

(Refer Slide Time: 05:20)



Wind Power system (cont...)

- The DFIG configuration consists of a wound rotor induction generator with the stator windings directly connected to the grid and the rotor windings connected to a voltage-source back-to-back power converter which transfers the extracted power (see Fig. 1).
- The PMSG configuration needs a full power converter and allows the use of multipolar generators making it possible to suppress the gearbox (see Fig. 2).

Fig.1: The DFIG wind generator concept

Fig.2: The gearless PMSG wind generator concept

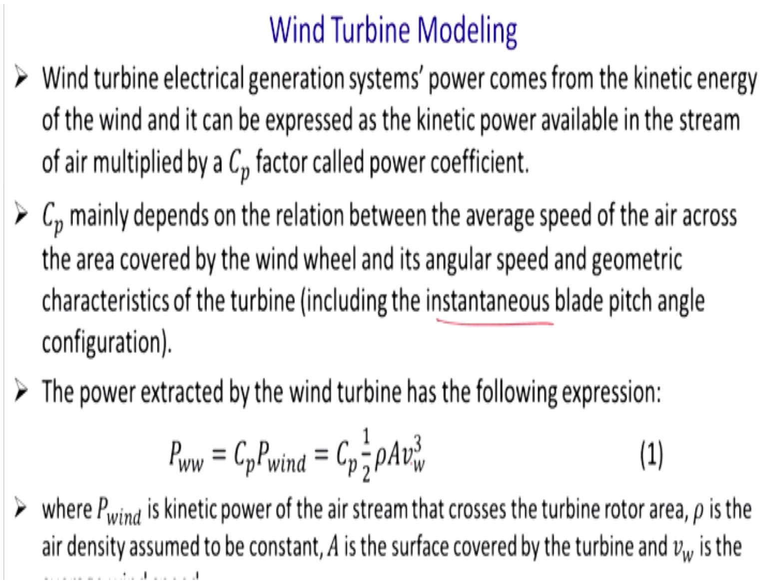
So, let us talk about the DFIG first. Doubly-fed induction generator configuration consist of a wound rotor induction generator because you have to fit power in stator as well as rotors, in slip rings it not possible, induction generator with the stator winding directly connected to the grid, you can see that. This is the stator winding, so that will be directly connected to the grid and the rotor winding connected to the voltage source back-to-back converter which transfer the extracting power, this is the actually it can.

If it is a if it is working in a super synchronous mode, then it will ensure, then it will extract power from the rotor also and it will supply. If it is working in a sub-synchronous mode, then you have to inject power to the rotor to maintain a synchronous wind. The PMSG configuration needs a or one of the advantage of that this was rotor power seized actually only the percentage of the bulk power, for this reason rating of this is dual converter is quite low compared to the total rating of the permanent magnet compared to the total lending of DFIG.

The PMSG configuration needs a full power converter and allows the use of multipolar generators making it possible to suppress the gearbox. So this is something, this is something we will be we may not have a gearbox here and here we can use a a permanent magnet synchronous motor or generator, in this case it will be generator, thereafter you may have a back-to-back AC to DC, thereafter DC to AC converter, and thus you can have a electric transformation and you don't require any gearboxes.

To make this actually the pole adjustment and ultimately you will feed the power, but disadvantages that this converter will see the whole rating of the PMSG, but generally it basically deals with the slip power. So gener this power is quite low in case of the DFIG, so power electronics ratings of this back-to-back inverter and converter is quite low compared to this PMSG, but here you have a gearbox, you don't require any gearbox.

(Refer Slide Time: 08:09)



Wind Turbine Modeling

- Wind turbine electrical generation systems' power comes from the kinetic energy of the wind and it can be expressed as the kinetic power available in the stream of air multiplied by a C_p factor called power coefficient.
- C_p mainly depends on the relation between the average speed of the air across the area covered by the wind wheel and its angular speed and geometric characteristics of the turbine (including the instantaneous blade pitch angle configuration).
- The power extracted by the wind turbine has the following expression:

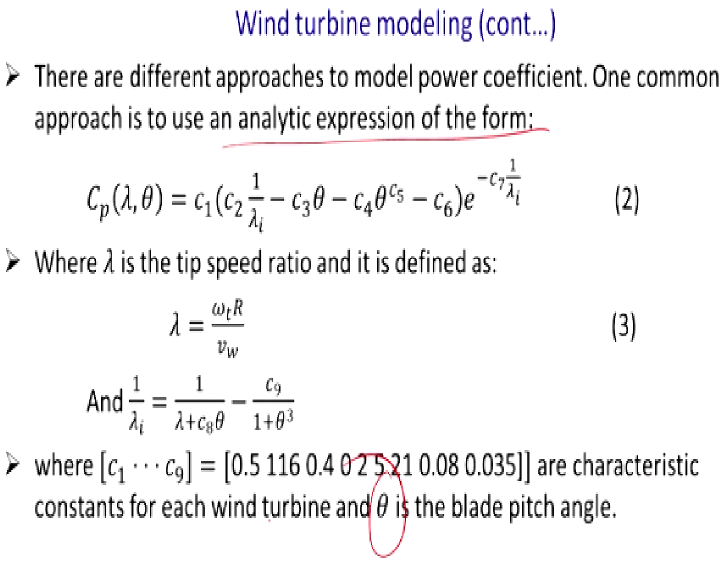
$$P_{ww} = C_p P_{wind} = C_p \frac{1}{2} \rho A v_w^3 \qquad (1)$$

- where P_{wind} is kinetic power of the air stream that crosses the turbine rotor area, ρ is the air density assumed to be constant, A is the surface covered by the turbine and v_w is the

Wind turbine electrical generation systems, power comes from the kinetic energy of the wind and it can be expressed as a kinetic power available in the stream of the air multiplied by a Cp factor called the power coefficient. Cp mainly depend on the relations between the average speed of the air across the area covered by the wind wheel and its angular speed of the of the angular speed and the geometric characteristics of a turbine including the instantaneous blade pitch angle.

Professor Soumitro Banerjee has done an NPTEL courses quite a long ago on renewable energy sources, you are requested to refer all those details there. So the power extracted by the wind turbine has the following expressions, that is Cp into wind and if you can expand that is the coefficient of the power that is half, rho is the density area and that it will be the proportional to the velocity cube. So, while increasing while uh if velocity of the wind speed is doubled, then energy transfer will be actually 8 times, so it is quite huge in terms of the power generation with a smallest change in the power on wind speed.

(Refer Slide Time: 10:00)



Wind turbine modeling (cont...)

- There are different approaches to model power coefficient. One common approach is to use an analytic expression of the form:

$$C_p(\lambda,\theta) = c_1(c_2\frac{1}{\lambda_i} - c_3\theta - c_4\theta^{c_5} - c_6)e^{-c_7\frac{1}{\lambda_i}} \qquad (2)$$

- Where λ is the tip speed ratio and it is defined as:

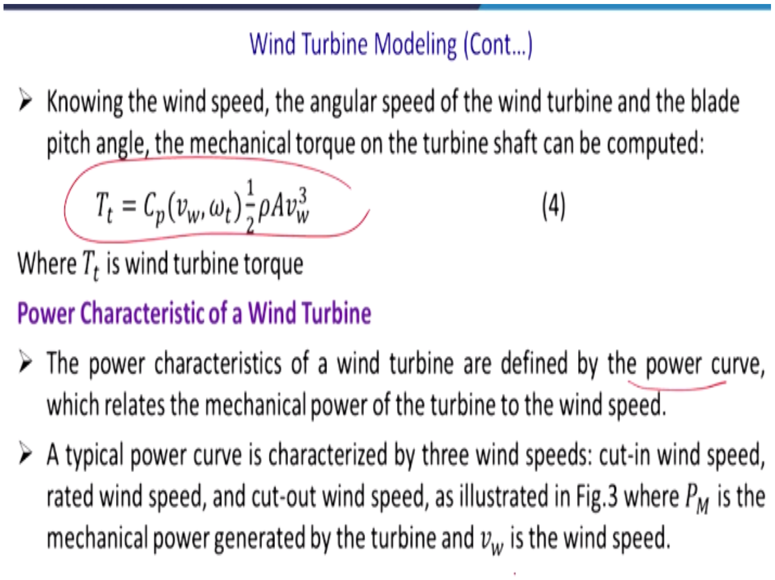
$$\lambda = \frac{\omega_t R}{v_w} \qquad (3)$$

And $\frac{1}{\lambda_i} = \frac{1}{\lambda + c_8\theta} - \frac{c_9}{1+\theta^3}$

- where $[c_1 \cdots c_9] = [0.5\ 116\ 0.4\ 0\ 2\ 5\ 21\ 0.08\ 0.035]]$ are characteristic constants for each wind turbine and θ is the blade pitch angle.

Therefore the different approaches to model the power coefficient, the common approach is to use the analytic expression form, that is Cp lambda and theta, it will be c1, c2 lambda I – c2 theta 3 and so on, while lambda is the speed ratio and is identified by lambda = Omega tR/wind speed and lambda I = 1/lamda + c8 theta – c9 theta where we can find out c1 to c9 can have this these values, you know 0.5, 0.16, 0.4, and so on, are the characteristic constants of the wind speed and where theta is the blade pitch angle.

(Refer Slide Time: 10:54)



Wind Turbine Modeling (Cont...)

- Knowing the wind speed, the angular speed of the wind turbine and the blade pitch angle, the mechanical torque on the turbine shaft can be computed:

$$T_t = C_p(v_w, \omega_t)\frac{1}{2}\rho A v_w^3 \qquad (4)$$

Where T_t is wind turbine torque

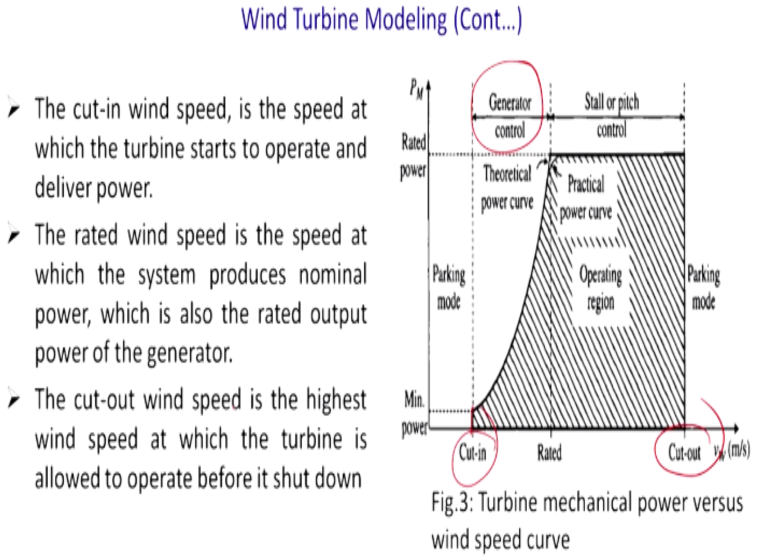
Power Characteristic of a Wind Turbine

- The power characteristics of a wind turbine are defined by the power curve, which relates the mechanical power of the turbine to the wind speed.
- A typical power curve is characterized by three wind speeds: cut-in wind speed, rated wind speed, and cut-out wind speed, as illustrated in Fig.3 where P_M is the mechanical power generated by the turbine and v_w is the wind speed.

Knowing the wind speed and the angular speed of the wind turbine and the blade pitch angle, the mechanical torque of the turbine shaft can be computed, that is very important thing. That is Cp V wind omega t that will be basically the function of these 2 parameters 1/2 rho A v square, where T prime t is a wind turbine torque. So, let us understand the power characteristics of the wind turbine.

The power characteristics of the wind turbines are defined by the power curve, we shall just come to this power curve, which relates the mechanical power of the turbine with the wind speed. A typical power curve is characteristics by the wind speed, cut-in wind speed, rated wind speed and cut-out wind speed and it will be illustrated in the next figure that is figure 3, where PM is the mechanical power generated by the turbine and the vw is the wind speed. So this is something that you will have to see.

(Refer Slide Time: 11:57)



Wind Turbine Modeling (Cont...)

- The cut-in wind speed, is the speed at which the turbine starts to operate and deliver power.
- The rated wind speed is the speed at which the system produces nominal power, which is also the rated output power of the generator.
- The cut-out wind speed is the highest wind speed at which the turbine is allowed to operate before it shut down

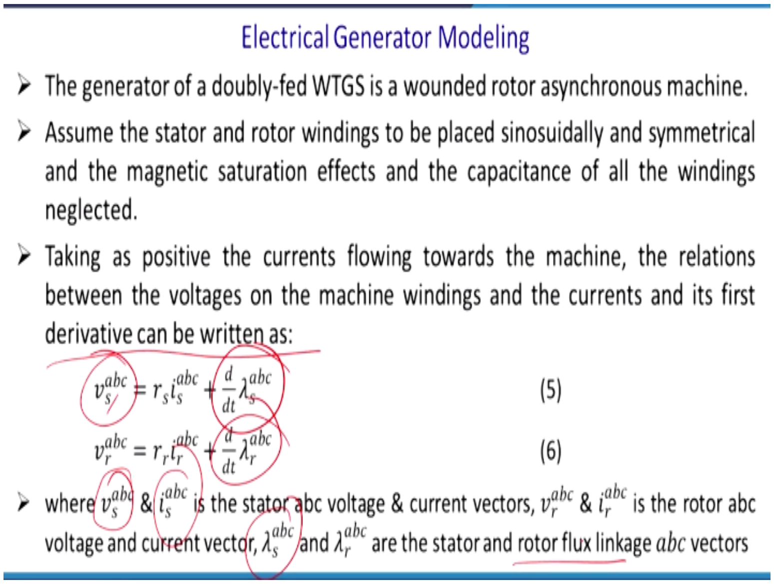
Fig.3: Turbine mechanical power versus wind speed curve

So, this is the cut-in speed, below that it is not possible to generate any energy, and this is the theoretical power curve and you know actually this is the generator control and in this region you require to operate. Thereafter, stall or pitch control, they have to align such a way that maximum air should pass, and it won't be affected by it. So here you will start, this is a rated speed, and there actually you won't allow the wind speed to go beyond it and thus you will have a pitch control and about this wind speed, you will have a cut-out.

The cut-in wind speed is the speed at which turbine start operating to deliver power, it is the lower cutoff. The rated wind speed is the speed at which the system produces nominal power which is also the rated output power of the generator, say it is a 10 metre per second square, so you take that value of the wind speed at a standard and may be 4 metre per wind speed is the cutoff, so in that region we say that this is the theoretical power curve.

The cut-out the cut-out wind speed is the highest wind speed at which turbine is allowed operate before it shut down. If it goes above it, we require to shut down for the tempera for the wind speed anomaly where it is due to the thunders or hurricane or whatever may be. If you try to operate that thing, we may actually damage the blade.

(Refer Slide Time: 13:55)



Electrical Generator Modeling

- The generator of a doubly-fed WTGS is a wounded rotor asynchronous machine.
- Assume the stator and rotor windings to be placed sinosuidally and symmetrical and the magnetic saturation effects and the capacitance of all the windings neglected.
- Taking as positive the currents flowing towards the machine, the relations between the voltages on the machine windings and the currents and its first derivative can be written as:

$$v_s^{abc} = r_s i_s^{abc} + \frac{d}{dt}\lambda_s^{abc} \qquad (5)$$

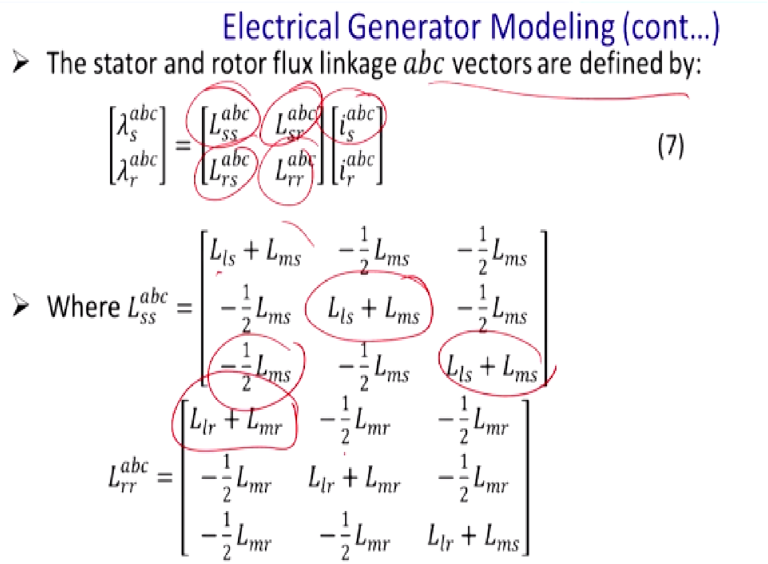
$$v_r^{abc} = r_r i_r^{abc} + \frac{d}{dt}\lambda_r^{abc} \qquad (6)$$

- where v_s^{abc} & i_s^{abc} is the stator abc voltage & current vectors, v_r^{abc} & i_r^{abc} is the rotor abc voltage and current vector, λ_s^{abc} and λ_r^{abc} are the stator and rotor flux linkage *abc* vectors

Now the generator of the doubly-fed wind turbine is wounded rotor asynchronous machine. Assume the rotor and the stator winding to be placed sinusoidal and symmetrical and the magnetic saturation effects the capacitance of the winding is neglected. Now taking the positive the current flowing towards the machine, the relation between the voltage and the machine winding and the current and its derivative can be written as you know Vs, v supply or voltage = i x s that is the flux linkage into the system that is actually it is n x 5 that is it is lambda.

So that is the stationary frame that is for the stator, same thing it will be on the rotor and wire this is the total parameter stator voltage of the abc phase and this is the stator current of the abc phase, the stator voltage and the current and the rotor parameter respectively and lambda abs, lambda s abc and lambda r abc are the rotor flux linkage and stator flux linkage and the rotor flux linkage respectively in abc frame.

(Refer Slide Time: 15:24)



Electrical Generator Modeling (cont...)

- The stator and rotor flux linkage *abc* vectors are defined by:

$$\begin{bmatrix} \lambda_s^{abc} \\ \lambda_r^{abc} \end{bmatrix} = \begin{bmatrix} L_{ss}^{abc} & L_{sr}^{abc} \\ L_{rs}^{abc} & L_{rr}^{abc} \end{bmatrix} \begin{bmatrix} i_s^{abc} \\ i_r^{abc} \end{bmatrix} \qquad (7)$$

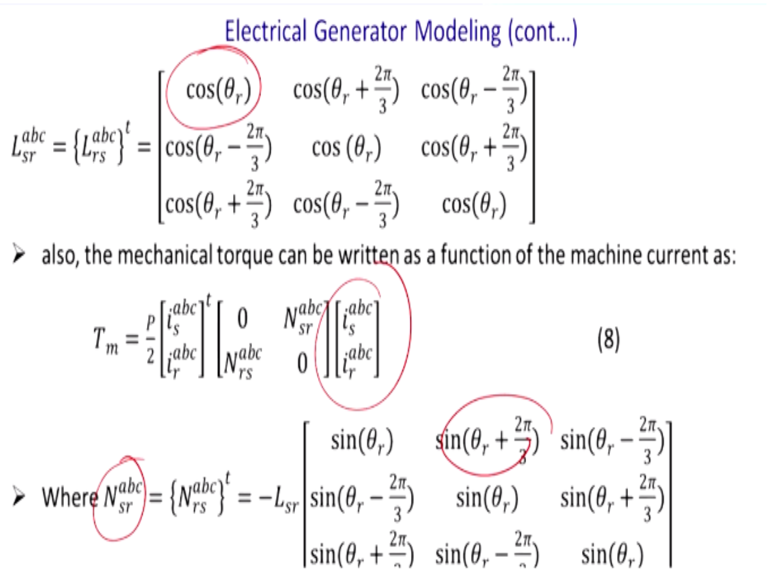
- Where $L_{ss}^{abc} = \begin{bmatrix} L_{ls} + L_{ms} & -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & L_{ls} + L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} & L_{ls} + L_{ms} \end{bmatrix}$

$$L_{rr}^{abc} = \begin{bmatrix} L_{lr} + L_{mr} & -\frac{1}{2}L_{mr} & -\frac{1}{2}L_{mr} \\ -\frac{1}{2}L_{mr} & L_{lr} + L_{mr} & -\frac{1}{2}L_{mr} \\ -\frac{1}{2}L_{mr} & -\frac{1}{2}L_{mr} & L_{lr} + L_{ms} \end{bmatrix}$$

Now where you know there can be a cross link, the stator and the rotor flux linkage abc vector are defined by you know by Lss that is for the mutual inductance into is abc, then this is (( )) (15:50) it is s and r, same way this will be the symmetrical matrices you will find, it will be rs and this will be for the rotor. Generally, what happens if you write and expand Lss, then you will find that ls x ms you will have 1/2 ms and and 1/2 ms, again this will be Ls + Lms.

This is the terms of this diagonal element and this will be the terms of half Lms of diagonal element that is between the mutual inductance between the stator and rotor. Same way you will find that the diagonal element is Lr, Lr + mLr so on and the of diagonal element will be half Lmr. I request actually student to go through the any machine analysis book of cross or other to understand this phenomena.

(Refer Slide Time: 16:59)



Electrical Generator Modeling (cont...)

$$L_{sr}^{abc} = \{L_{rs}^{abc}\}^t = \begin{bmatrix} \cos(\theta_r) & \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) \\ \cos(\theta_r - \frac{2\pi}{3}) & \cos(\theta_r) & \cos(\theta_r + \frac{2\pi}{3}) \\ \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) & \cos(\theta_r) \end{bmatrix}$$

- also, the mechanical torque can be written as a function of the machine current as:

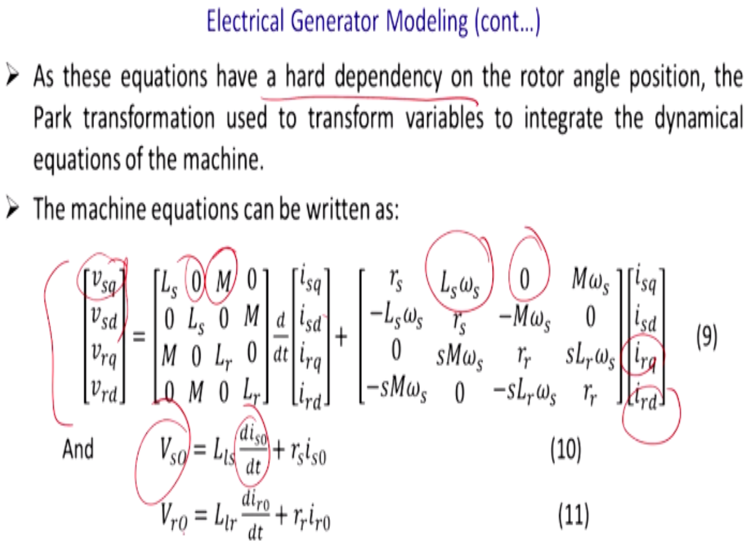
$$T_m = \frac{P}{2} \begin{bmatrix} i_s^{abc} \\ i_r^{abc} \end{bmatrix}^t \begin{bmatrix} 0 & N_{sr}^{abc} \\ N_{rs}^{abc} & 0 \end{bmatrix} \begin{bmatrix} i_s^{abc} \\ i_r^{abc} \end{bmatrix} \qquad (8)$$

- Where $N_{sr}^{abc} = \{N_{rs}^{abc}\}^t = -L_{sr} \begin{bmatrix} \sin(\theta_r) & \sin(\theta_r + \frac{2\pi}{3}) & \sin(\theta_r - \frac{2\pi}{3}) \\ \sin(\theta_r - \frac{2\pi}{3}) & \sin(\theta_r) & \sin(\theta_r + \frac{2\pi}{3}) \\ \sin(\theta_r + \frac{2\pi}{3}) & \sin(\theta_r - \frac{2\pi}{3}) & \sin(\theta_r) \end{bmatrix}$

Now Lsr abc = Lrs abc t, so we can split it, that is the theta is the angle between the stator and rotor with any any predefined reference and then we will find out the total angle, so we will actually convert this transformation, that is basically abc to Lr that coefficients are cos theta sine theta and so on. So, the mechanical torque can be written as a function of the machine current as, so that is the number of pole, is and ir of abc and these 2 element will be 0, that sr abc and rs abc into the current of stator and rotor.

Where similarly this Nr abc can be written as Lsr x sine theta and the sine theta r and there will be a different phase shift to accommodate the wanted to phase shift of this balanced reverse system.

(Refer Slide Time: 18:19)



Electrical Generator Modeling (cont...)

- As these equations have a hard dependency on the rotor angle position, the Park transformation used to transform variables to integrate the dynamical equations of the machine.
- The machine equations can be written as:

$$\begin{bmatrix} v_{sq} \\ v_{sd} \\ v_{rq} \\ v_{rd} \end{bmatrix} = \begin{bmatrix} L_s & 0 & M & 0 \\ 0 & L_s & 0 & M \\ M & 0 & L_r & 0 \\ 0 & M & 0 & L_r \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_{sq} \\ i_{sd} \\ i_{rq} \\ i_{rd} \end{bmatrix} + \begin{bmatrix} r_s & L_s\omega_s & 0 & M\omega_s \\ -L_s\omega_s & r_s & -M\omega_s & 0 \\ 0 & sM\omega_s & r_r & sL_r\omega_s \\ -sM\omega_s & 0 & -sL_r\omega_s & r_r \end{bmatrix} \begin{bmatrix} i_{sq} \\ i_{sd} \\ i_{rq} \\ i_{rd} \end{bmatrix} \quad (9)$$

And $$V_{s0} = L_{ls}\frac{di_{s0}}{dt} + r_s i_{s0} \quad (10)$$

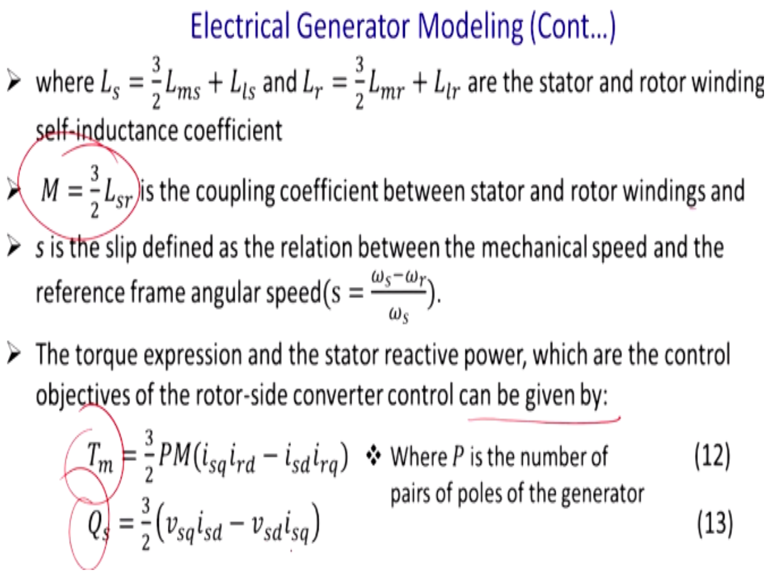
$$V_{r0} = L_{lr}\frac{di_{r0}}{dt} + r_r i_{r0} \quad (11)$$

Now as this equation have a hard dependency on the rotor angle position to see that actually theta r has been written, so for that reason, so it has a hard dependency on the rotor angle position, the park transformations used to transform the variable to integrate the dynamic equation of the machine, ultimately we shall go back to the your abc to the d-q and thus this is actually vsq and vsd, these are this is basically the d-q of stator side and vrq and vrd are the rotor side and you can find that that expression will be you know surviving is that you know this is actually Ls x isq.

Thereafter ist turn here it will be 0 because there will be no component of the resistance here, but there will be a mutual component that is actually here as M x rq and thereafter rt will be 0. Similarly we can split that thing and ultimately you will can generate these vectors and ultimately you will have a cross reference in these vectors, that is rs into sq, thereafter this will be the crossed term, Ls x omega s into isd you have seen while controlling this other parameter and with vqs.

There would not any real component rq will be 0 and again with the omega s will come that value will be the rt. Similarly, it follows for the other and you can write it by the inspections. So, and also this is a zero sequence component, if it is there so that will be actually Ls x stator and it will be in a zero sequence, so it is you will have this stator as well as the rotor.

(Refer Slide Time: 20:44)



Electrical Generator Modeling (Cont...)

- where $L_s = \frac{3}{2}L_{ms} + L_{ls}$ and $L_r = \frac{3}{2}L_{mr} + L_{lr}$ are the stator and rotor winding self-inductance coefficient
- $M = \frac{3}{2}L_{sr}$ is the coupling coefficient between stator and rotor windings and
- s is the slip defined as the relation between the mechanical speed and the reference frame angular speed($s = \frac{\omega_s - \omega_r}{\omega_s}$).
- The torque expression and the stator reactive power, which are the control objectives of the rotor-side converter control can be given by:

$$T_m = \frac{3}{2}PM(i_{sq}i_{rd} - i_{sd}i_{rq}) \qquad (12)$$

❖ Where P is the number of pairs of poles of the generator

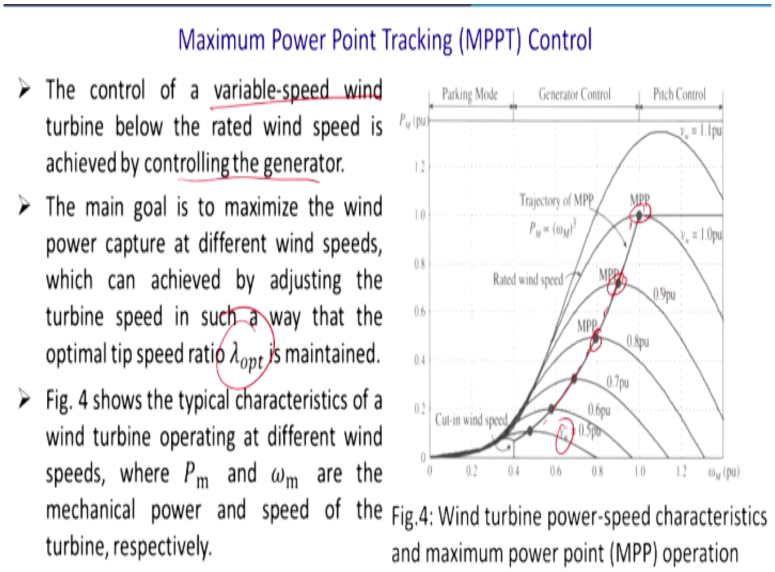
$$Q_s = \frac{3}{2}(v_{sq}i_{sd} - v_{sd}i_{sq}) \qquad (13)$$

Now we understand that the value of Ls is two-third Lms + Ls and thus and also Lr is actually 3/2 mr + lr are the stator and rotor winding of the self-inductance coefficient and thus M is basically becomes 3/2 Lsr and is a coupling coefficient between the stator and rotor winding and s is the slip defined as the relationship between the mechanical speed and the reference frame of reference where s equal to synchronous speed – actual speed/synchronous speed.

Please go back you know for this and you will find you know this s term actually associated with the rotor, so in the stator there is no s term and please do not confuse, sometime we have seen that people confuses that s is Lr plus no it is not Lr plus we are writing total in a differential form, so it is not in a Lr plus domain, this is in a t domain.

The torque expressions of the stator and reactive power which are the control objective of the rotor-side converter control and it can be rewritten as Tm in terms of this actual the in terms of the reactive, in terms of the torque in d-q frame, that is 3/2 P x M isqrd – isdrq where P is the number of pole pair and similarly the reactive power that is 3/2 vsq x isd – vsdisq.

(Refer Slide Time: 22:37)



Maximum Power Point Tracking (MPPT) Control

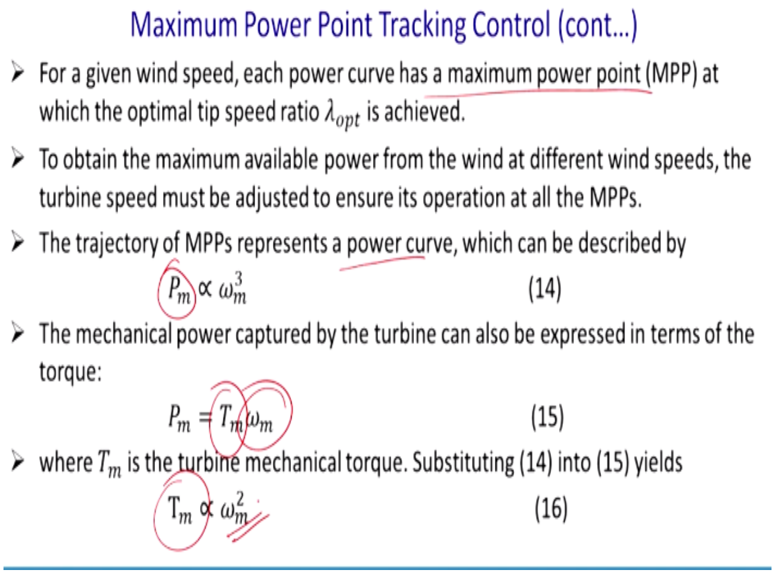
- The control of a variable-speed wind turbine below the rated wind speed is achieved by controlling the generator.
- The main goal is to maximize the wind power capture at different wind speeds, which can achieved by adjusting the turbine speed in such a way that the optimal tip speed ratio λ_{opt} is maintained.
- Fig. 4 shows the typical characteristics of a wind turbine operating at different wind speeds, where P_m and ω_m are the mechanical power and speed of the turbine, respectively.

Fig.4: Wind turbine power-speed characteristics and maximum power point (MPP) operation

So, this is the modeling and we required to spend time on little bit on the machine design part, essentially it is the basic motor. The now let us come to the picture. The control of the variable speed wind turbine, below the rated speed is achieved by controlling the generator, so you have a generator side control. What we do generally. So, these are the different maximum power point tracking, we try to actually align this pitch so that it actually get the maximum power.

The main goal is to maximize the wind power capture at different wind speed, which can be achieved by adjusting the turbine speed in such a way that the optimal tip speed the ratio is maintained, so that is something you required to ensure and that is the control. Figure 4 shows the typical characteristics of the wind turbine operating at different wind speed where Pm and omega m are the mechanical power and speed of the turbine respectively.

(Refer Slide Time: 24:01)



Maximum Power Point Tracking Control (cont…)

- For a given wind speed, each power curve has a maximum power point (MPP) at which the optimal tip speed ratio λ_{opt} is achieved.
- To obtain the maximum available power from the wind at different wind speeds, the turbine speed must be adjusted to ensure its operation at all the MPPs.
- The trajectory of MPPs represents a power curve, which can be described by

$$P_m \propto \omega_m^3 \qquad (14)$$

- The mechanical power captured by the turbine can also be expressed in terms of the torque:

$$P_m = T_m \omega_m \qquad (15)$$

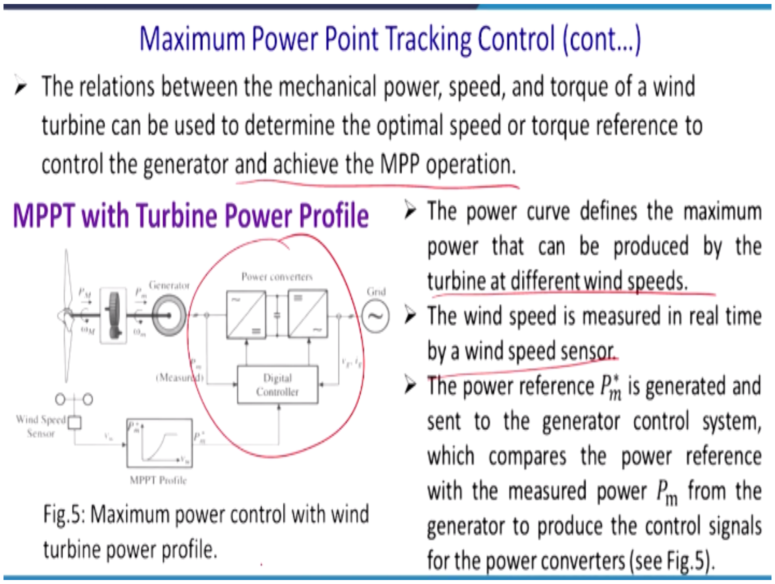
- where T_m is the turbine mechanical torque. Substituting (14) into (15) yields

$$\mathrm{T}_m \propto \omega_m^2 \qquad (16)$$

Now for a given speed, each power curve has a maximum power point, you can refer, so particular wind speed for this point, this point, this point and this is the wind speed, it is 0.5 per unit, 0.6 per unit, 0.7 per unit, 0.8 per unit, 0.9 per unit and something like this. The trajectory of the MPPS the maximum power point represents the power curve which can be described by the figure has been shown in figure 4 and that is Pm is proportional to omega cube.

The mechanical power captured by the turbine can also be expressed in terms of the Tm that is the mechanical torque and the turbine speed. So of course, we can equate these 2 and thus Tm we can see that this is proportional to omega square, ultimately torque will be proportional to the wind speed square, square of the wind speed.

(Refer Slide Time: 25:22)



Maximum Power Point Tracking Control (cont...)

- The relations between the mechanical power, speed, and torque of a wind turbine can be used to determine the optimal speed or torque reference to control the generator and achieve the MPP operation.

MPPT with Turbine Power Profile

Fig.5: Maximum power control with wind turbine power profile.

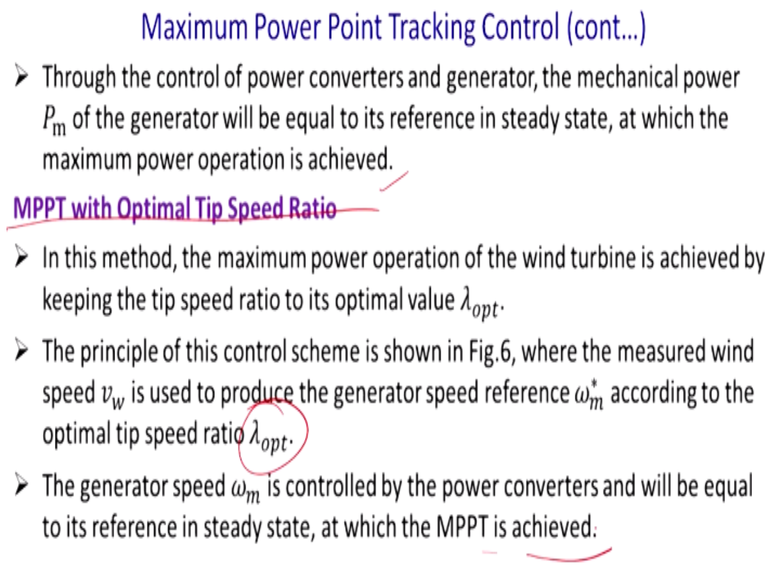
- The power curve defines the maximum power that can be produced by the turbine at different wind speeds.
- The wind speed is measured in real time by a wind speed sensor.
- The power reference P_m^* is generated and sent to the generator control system, which compares the power reference with the measured power P_m from the generator to produce the control signals for the power converters (see Fig.5).

So considering those aspect into the mind, we have to design it and this is the figure of the maximum power point control with the wind turbine profile and this is the wind turbine, there is a guitar gearbox, your feeding rotor and stator, DFIG, and this is the back-to-back AC to DC, DC to AC converter and stator directly connected to the grid and you have a digital control that will actually integrate power or actually take away the power from the system.

The relationship between the mechanical power, speed, and the torque and the wind turbine can be used to determine the optimal speed and the torque reference to the control of the generator and to track or to operate at the maximum power point. The power curve defines the maximum power that can be produced by the turbine at different wind speed. The wind speed is measured in a real time by the wind speed sensor.

The power reference Pm is generated and sent to the generator control system which compares the power reference with the measure power Pm from the generator to produce the control signals for the power converter. This is the overall picture of the power converter.

(Refer Slide Time: 26:59)



Maximum Power Point Tracking Control (cont...)

- Through the control of power converters and generator, the mechanical power P_m of the generator will be equal to its reference in steady state, at which the maximum power operation is achieved.

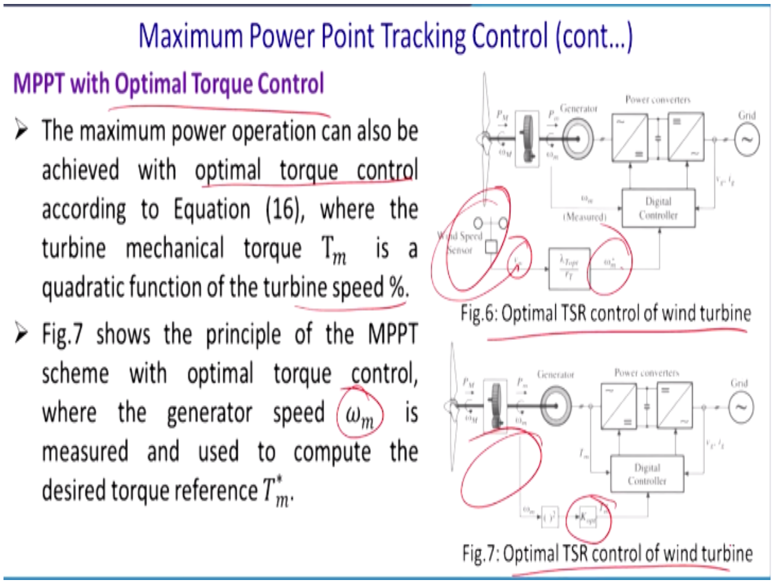
MPPT with Optimal Tip Speed Ratio

- In this method, the maximum power operation of the wind turbine is achieved by keeping the tip speed ratio to its optimal value λ_{opt}.
- The principle of this control scheme is shown in Fig.6, where the measured wind speed v_w is used to produce the generator speed reference ω_m^* according to the optimal tip speed ratio λ_{opt}.
- The generator speed ω_m is controlled by the power converters and will be equal to its reference in steady state, at which the MPPT is achieved.

Through the control of the power converter and the generator, the mechanical power Pm of the generator will be equal to the reference in steady state at which the maximum power operation is achieved. It is quite clear. Now we have to say about something on the MPPT with the optimal tip speed ratio. This method is the maximum power operation of the wings wind turbine is achieved by keeping the tip speed ratio to its optimal value.

The principle of the control scheme is shown in the figure 6, where the measured wind speed vw is used to produce the generator speed reference accordance to the optimal tip speed ratio of lambda. The generator wind speed vm is controlled by the power converter and will be equal to the reference in in steady state at which the MPPT is achieved.

(Refer Slide Time: 28:09)



Maximum Power Point Tracking Control (cont...)

MPPT with Optimal Torque Control

- The maximum power operation can also be achieved with optimal torque control according to Equation (16), where the turbine mechanical torque T_m is a quadratic function of the turbine speed %.
- Fig.7 shows the principle of the MPPT scheme with optimal torque control, where the generator speed ω_m is measured and used to compute the desired torque reference T^*_m.

Fig.6: Optimal TSR control of wind turbine

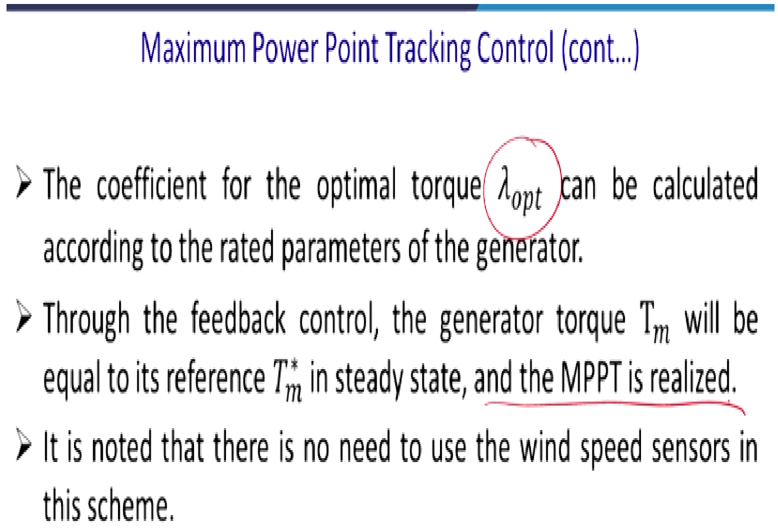
Fig.7: Optimal TSR control of wind turbine

Now you see that MPPT with the optimal torque control, this is a wind sensor and ultimately this that there will calculate the value of the wind speed, then that value will be computed and from there you know actually lambda opt/rt from their reference omega will be controlled and by digitally controlled by taking power and adjust injecting power, you will ensure that this rotor rotate at that omega and thus it will track the maximum power.

So, this is called optimal TSR control of the wind turbine. The maximum power operation can also be achieved with the optimal torque control according to the equation 16 where the turbine mechanical torque Tm is a quadratic function of the turbine speed. You have seen it in this equation and the figure 7 what does it do. So, it sense the speed from, it is carried out from here and thus you have a reference torque and you will control the torque of the system.

This is called optimal TSR control of the wind speed and figure 7 shows the principle of the MPPT scheme with optimal torque control where the generator spread omega m is measured, used to compare with the desired torque reference Tm. So, in that way, you will have both the control, you have a reference omega m and try to m and here is a torque control. So, both are been when used that is called optimal torque control method for tracking MPPT.

(Refer Slide Time: 30:15)



Maximum Power Point Tracking Control (cont...)

- The coefficient for the optimal torque λ_{opt} can be calculated according to the rated parameters of the generator.
- Through the feedback control, the generator torque T_m will be equal to its reference T_m^* in steady state, and the MPPT is realized.
- It is noted that there is no need to use the wind speed sensors in this scheme.

So, what we can conclude from here is that the coefficient for the optimal torque can be calculated according to the rated parameter of the generator. Through the feedback control, the generator toque Tm will be equal to the reference torque Tm prime, Tm star in the steady state, and the MPPT is realized. It is noted that there is no need to use the wind speed sensor in the scheme. So, in this scheme, you don't require any wind speed sensor, here you require the wind speed sensor. So, for this reason, TRS method of control is being preferred.

Thank you for your attention. We shall continue with our designing and modeling of the different kind of converter in our next classes.