Technologies for Clean and Renewable Energy Production
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Lecture - 30
Tutorial 6

Hi friends, now we will have a tutorial session in which we will solve some numerical problems based on last 4 classes.

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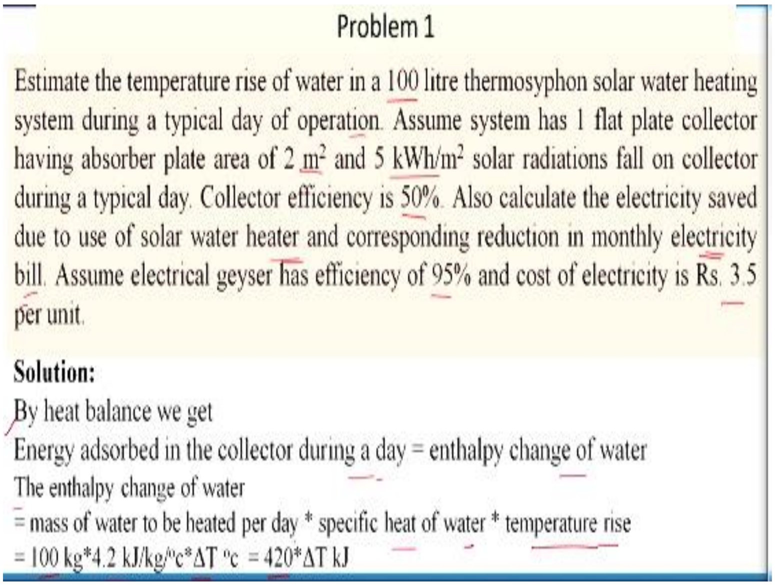

The first problem the statement says estimate the temperature rise of water in the 100 litre thermosyphon solar water heating system during a typical day of operation. Assume system has one flat plate collector having absorber plate area of 2 metre square and 5 kilowatt hour per metre squared solar reductions fall on collector during a typical day. Collector efficiency is 50%. Also calculate the electricity saved due to use of solar water heater and corresponding reduction in monthly electricity bill.

Assume electrical geyser had efficiency of 95% and cost of electricity is Rs. 3.5 per unit. So this is the problem statement. So we have to calculate the electricity saved due to use of solar heater and corresponding reduction in monthly electricity bill. Now this is a problem on solar system, that is solar thermal system is available and it is used to heat the water. Now we will see how to solve this. So if we get the heat balance, the energy absorbed in collector during a day that is equal to enthalpy change of the water.

The solar energy will be converted to the heat energy of the water. So energy absorbed in the collector during the day is equal to enthalpy change of water. So this is an energy balance equation. So now we will see the enthalpy change of water so that is equal to mass of water to be heated per day x specific heat of water into temperature difference. So what is the temperature rise?

Then in our case we have 100 litre thermosyphon solar water heating system, so 100 liter means equivalent to 100 kg that is 1 kg per litre the density of water is and then specific heat of water is equal to 4.2 kilojoule per kg per degree centigrade and temperature difference or temperature rise in this case equal to ΔT degree C. So that is equal to we are getting 420 x ΔT. So what is the temperature rise, that we have to calculate.

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- Energy adsorbed in the collector during a day = Solar radiations incident on collector per day *collector area *collector efficiency = 5*2*0.5 = 5 kWh = 5*kJ/s*3600s =5*3600 kJ

Thus, we get 5*3600= 420*ΔT

ΔT = 42.9 °C

Electrical geyser has efficiency of 95%

Electricity saved everyday = 5*2*0.5/0.95 = 5.26 kWh

Cost of electricity = Rs. 3.5 per unit

Money saved per day =Rs. 5.26*3.5 = Rs. 18.42

Reduction in monthly electricity bill = Rs. 18.42*30 = Rs. 553

So energy adsorbed in the collector during a day that is equal to solar radiations incident on collector per day x collector area x efficiency, so the collector efficiency. So then in our case the solar radiation incident on collector per day is given so that is equal to 5 kilowatt hour per metre square, so this is our solar radiation on that particular day and then 2 metre square is our area and then efficiency is 50% percent. So 5 x 2 x 0.5 then we are getting 5 kilowatt hour.

So now 5 kilowatt hour that is equal to 5 x kilojoules per second, then if we multiply it by 1 hour that means 3600 second, so we are getting 5 x 3600 kilojoule of energy which is coming through the solar system. Then we have energy taken by the water and now we are getting the energy received, solar energy converted into heat form in water is equal to this much. So this

5 x 3600 = 420 x ΔT. Then ΔT = 5 x 3600 / 420, so that is equal to 42.9 degrees centigrade. So this is the temperature rise of the water.

The next part of the problem we have to solve. So here electrical geyser has efficiency of 95% it is given. So electricity saved is equal to how much, so whatever we are getting this amount of energy which is converted by the solar system and given to the water that amount of energy would have come from the electricity, so that is equal to this 5 x 2 x 0.5, but the efficiency is 95% for the system geyser, so geyser has some efficiency of 95%, so we have to divide it by 0.95 to get the actual energy electrical energy required to heat the water to rise its temperature by 42.9 degree centigrade.

Then this much of electricity we are able to save by the use of the solar system in the price of 1 unit = 3.5 and this is the kilowatt hour so that is our unit, so we are having 5.26 x 3.5 = Rs. 18.42, so this is our save per day okay. So reduction in monthly electricity bill is equal to this 18.42 x 30 = Rs. 553.

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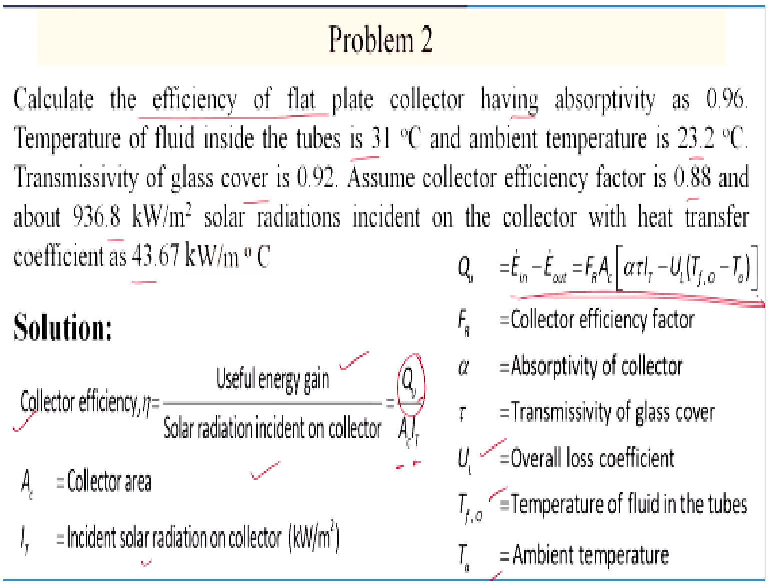

Now we are coming to problem number 2. So this statement says calculate the efficiency of flat plate collector having absorptivity as 0.96. Temperature of fluid inside the tubes is 31 degrees centigrade and ambient temperature is 23.2 degrees centigrade. Then transmissivity of glass cover it 0.92. Assume collector efficiency factor is 0.88 and about 936.8 kilowatt per metre squared solar radiations incident on the collector with heat transfer coefficient as 43.67. So this is a problem statement, we have to calculate the efficiency of the flat plate collector.

Now as already we have discussed in previous class on solar energy, that collector efficiency = useful energy gained/solar radiation incident on the collector. So useful energy gain is equal to Qu and Ac is the collector area and I_T is our incident solar radiation on collector. So this is the expression we have and we have also discussed that Qu is nothing but this one, it will depend upon the collector efficiency, it will depend upon absorptivity of the collector and then transmissivity of glass cover.

It will also depend upon the heat transfer loss, so overall loss coefficient and temperature difference between the water and ambient temperature, so that is temperature of fluid in the tubes and ambient temperature, so that we have discussed and you can be presented that way.

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$$\eta = \frac{Q_u}{A_c I_T} = \left[F_R(\tau\alpha) - F_R U_L \frac{(T_{f,o} - T_a)}{I_T}\right]$$

$F_R = 0.88$, $\tau = 0.92$, $\alpha = 0.96$

$U_L = 43.67$ kW/m °C

Temperature of fluid inside tubes, $T_{fo} = 31$°C

Ambient temperature, $T_o = 23.2$ °C

$$\eta = [0.88*0.92*0.96 - 0.88*43.67*(31-23.2)/936.8]$$

$$= 0.4572 = 45.72\%$$

By simplification, the efficiency is equal to Qu/AcI_T by it just we have in the previous slide. So that is equal to (F_R ($\tau\alpha$)-F_RU_L(T_{f0} - T_a)/I_T). So in this case in our case F_R is given as 0.88 efficiency factor, the collector efficiency factor 0.88, then τ is equal to given as 0.92 transmissivity and then absorptivity coefficient is equal 0.96. So these are given. So here transmissivity this one and absorptivity is 0.96 these are given and U_L is also given, this is U_L = 43.67 it is given.

So that is the loss in the heat transfer or heat transfer coefficient and then temperature of fluid inside to is given 31 degrees centigrade, so outside is also given to you. So now T_{fo} we have got, T_a we have got that is T_a = 23.2 and I_T we have got I_T also that is equal to 936.8, I_T is equal to given here 936.8 kilowatt per metre square. So if we put these values in this expression, then η = 0.88 x 0.92 x 0.96 - F_R 0.88 x $U_{L,}$ (43.67) x 31 - 23.2 / I_T that is equal to

936.8, so we are getting this equal to 0.4572 or in percentage it is 45.72%.

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Problem 3

A home requires 60 kWh of heat on a winter day to maintain a constant indoor temperature of 25 °C. (a) How much collector surface area does it need for an all-solar heating system that has a 30% efficiency? (b) How large does the storage tank have to be to provide this much energy? (Assume that the average solar radiation in winter is about 6.5 kWh/(m^2 day) and water of hot fluid in secondary loop is 60 °C). The heat capacity of water is 1 kcal/kg/°C and heat transfer loss in water can be ignored.

Solution

Since the average solar radiation in winter is about 6.5 kWh/(m^2 day) and the efficiency of the system is 30 %. The daily quantity of thermal energy obtained using collectors will be:

Thermal energy = 6.5*0.30 = 1.95 kWh/(m^2 day)

Now coming to the next problem, problem number 3 and it states that a home requires 60 kilowatt hour of heat on a winter day to maintain a constant indoor temperature of 25 degrees centigrade, then how much collector surface area does it need for an all-solar heating system that has a 30% efficiency. So this is our first part of the problem and the second part how large does the storage tank have to be to provide this much energy.

So we can assume that the average solar radiation in winter is about 6.5 kilowatt hour per metre square day and water of hot fluid in secondary loop is 60 degrees centigrade. The heat capacity of water is 1 kilocalorie per kg per degree centigrade and heat transfer loss in water can be ignored. So these are our conditions it is given and we have to calculate the surface area of the collector and we also have to calculate the storage volume the water volume actually which has to be stored for the transfer of heat absorbed by the system and transfer to the water.

Since the average solar radiation in water is about 6.5 kilowatt hour per metre square day and the efficiency of the system is 30%, efficiency is given as 30% and this is our total solar radiation. So daily the quantity of thermal energy obtained using these collectors, that will be 6.5 kilowatt hour x 30%, 0.3 that is equal to 1.95 kilowatt hour per metre square day, so this is our effective energy which we are able to get into heat form in the water which can be transferred into the water.

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Therefore, the required collector surface area is as follows:

Collector surface area = 60/1.95 = 30.769 m^2

(b)

As there is no heat transfer loss,

The heat generated by the solar system = Heat taken up by the water

Now, heat generated by the solar system = 60*860.421 kcal (1 kWh= 860.421 kcal)

Further, Heat taken up by the water = mass of water*heat capacity*temperature difference = Mass of water*1kcal/kg/°c*(60-25)°C = Mass of water*35 kcal (mass is in kg unit)

Thus, 60*860.421 kcal = Mass of water in kg*35 kcal

Mass of water in kg = 60*860.421/35 = 1475 kg

= 1475 kg = 1475 L (because the density of water is 1 kg/L)

Therefore the required collector surface area, what would be the collector surface area we need, we need 60 kilowatt hour, so then for 60 kilowatt hour for 1 metre square provides 1.95 kilowatt on that day, so 60 / 1.95 = 30.769 metre squared is the collector area which will be required to get the sufficient amount of energy to maintain the room temperature at 25 degrees centigrade. In second part as there is no heat transfer loss, so what we can assume that the heat generated by the solar system is equal to heat taken up by the water.

So heat generated by the solar system is equal to how much, we have 60, this is our 60 kilowatt hour, so 60 kilowatt hour that it is required, so 60 into, so it was in kilowatt hour we have to convert into kilocalorie, so this is the relationship 1 kilowatt hour is equal to 860.421 kilocalorie, so this if we multiply 60 x 860.421 so that that will be in kilo calorie unit. So this amount of energy is coming from the solar system. Then heat taken up by the water is equal to mass of water into heat capacity water and temperature difference.

So mass of water we have to calculate here and then heat capacity 1 kilocalorie per kg per degree centigrade is given and temperature difference as it is given say the hot fluid in secondary loop is at 60 degrees centigrade and ambient temperature is 25 degrees centigrade, so the difference is 60 - 25, so we are getting that mass of water into 35 kilocalories, so this is the kilocalorie and mass will be kg unit. So this energy and this energy will be same.

So 60 x 860.421 kilocalorie is equal to mass of water in kg into 35 kilocalorie, so same unit we are having. So mass of water in kg that is equal to 60 x 860.421 / 35 = 1475 kg. Now the density of water is 1 kg per litre, so that will be 1475 litre also. So 1475 litre of the storage tank it should have.

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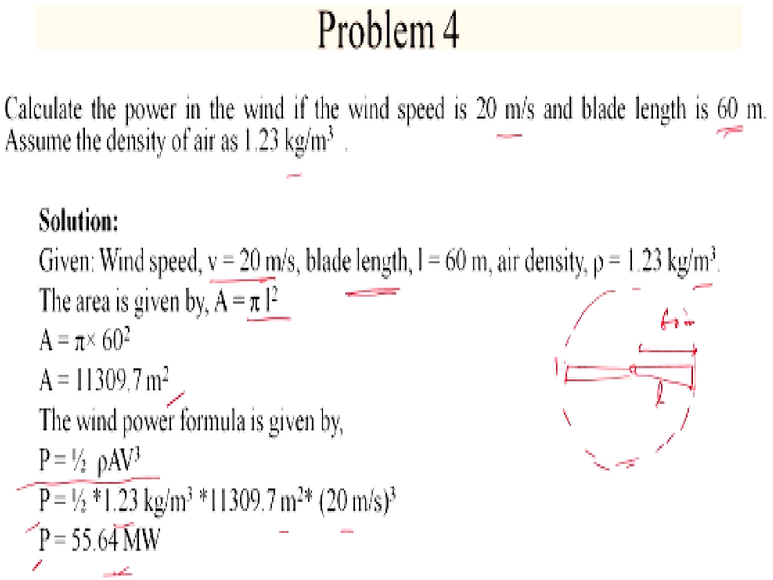

Next we are going to problem number 4. So here the statement says calculate the power in the wind if the wind speed is 20 metre per second and blade length is 60 metre. Assume the density of air as 1.23 kg per metre cube. So very, very simple, we have to calculate the power in the wind if the wind speed is provided and blade length is also provided. So what is your basic expression, the wind power formula that is $P = 1 / 2 \times \rho \times A \times V^3$ where ρ is the density of air, A is the surface area on which the wind is blowing that is related to the diameter of the rotor and then V is equal to wind velocity.

See in our case what is our wind velocity wind speed that is equal to 20 per second it is given and blade length l is equal to 60 metre. So this is our rotor, so this is our blade, so 60 metre. So when it will be rotating, so this area will be covered, so this is the area A which you are getting that A, and V is the wind speed already 10 metre per second and rho is the 1.23 kg per metre cube already given.

So we will put this value here, so we have to calculate the area, so area is equal to so now equal to πr^2, so π this r = l here, so this is our l, so $\pi \times l^2$, so πl^2. So πx60 square, that is 60 metre, so 60 square, so that is equal to 11309.7 metre square. Now we have got A value, ρ value, and V value, we will put this value here together will have P. So P = 1/ 2x 1.23 kg per meter cube x 11309.7 metre square x 20 metre per second cube that is equal to it is coming 55.64 megawatt, in this unit we will get the kilowatt, so the kilowatt is converted to megawatt here.

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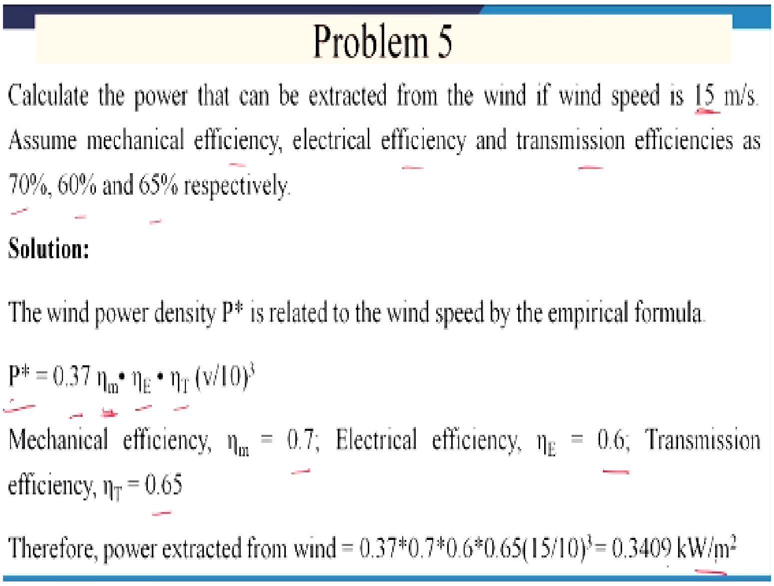

Problem 5, here the statement says calculate the power that can be extracted from the wind if wind speed is 15 metre per second. Assume mechanical efficiency, electrical efficiency and transmission efficiency as 70%, 60%, and 65% respectively. So in wind turbine, the wind speed is given and it is also given different efficiency of the different processes that is mechanical, electrical and transmission. As you know the formula P^* = 0.37 x mechanical efficiency x electrical efficiency x transmission efficiency x $(v/10)^3$.

Then mechanical efficiency here is equal to 0.7, electrical efficiency here is equal to 0.6 and transmission efficiency is equal to 0.65. So we will put this value here and our v is given 15 metre per second, so we will put it here, so then this expression we are getting that is equal to 0.3409, but here the P will be in kilowatt per metre squared unit as per the expression.

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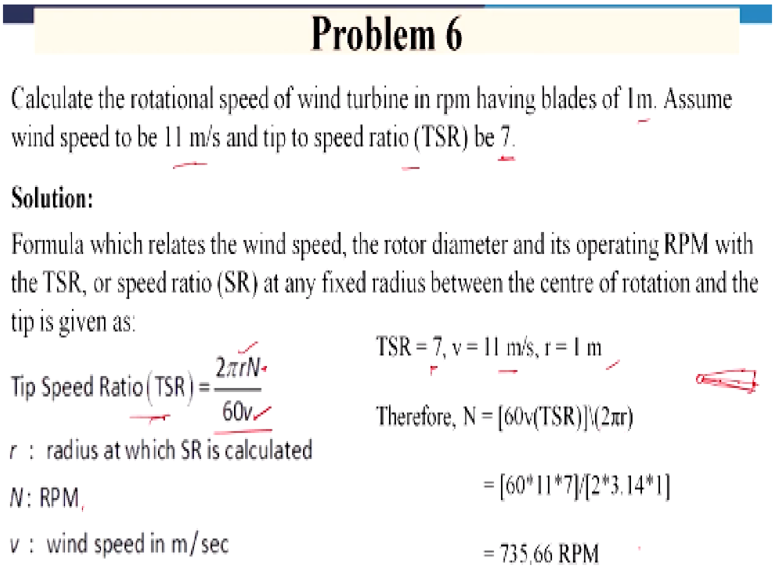

Next we are coming to problem number 6. The statements says calculate the rotational speed of a wind turbine in rpm having blades of 1 metre length, 1 m blade. Assume wind speed of to be 11 metre per second and tip to speed ratio be 7. So these are the conditions it is given we have to calculate the rotational speed of wind turbines. So wind turbine what is the rotational speed and then the blade length is given that is 1 metre and wind speed is also given 11 metre per second and tip to speed ratio is equal to TSR that is equal to 7.

So now we have seen that there are some relationship between the tip speed ratio and the rpm, so here tip speed ratio TSR = 2 π r N / 60v, we have already discussed in our previous class and where this r is the radius at which SR is calculated. So if we have a turbine blade here rotor, so if I want to calculate that tip speed ratio at the tip here or the axis any point I can get the SR, speed ratio I can calculate at any point, so maximum is our length of this.

So then r is the radius at which SR is calculated any value, so the maximum is full length of the blade. Then N is the rpm of the rotor and then v is the wind speed. So now we have the expression. Now TSR we have to maintain at 7, so TSR is 7, this v is equal to 11 metre per second that is the velocity of wind and r length of this is equal to 1 metre it is given. So then by this expression, we have to calculate the N. So N is equal to we are getting 60vTSR/ 2πr, so we are getting 60 x 11 x 7 / 2 x 3.14 x 1, so then it is coming to 735.66 rpm. So this is the rpm of the rotor for the wind turbine we are having.

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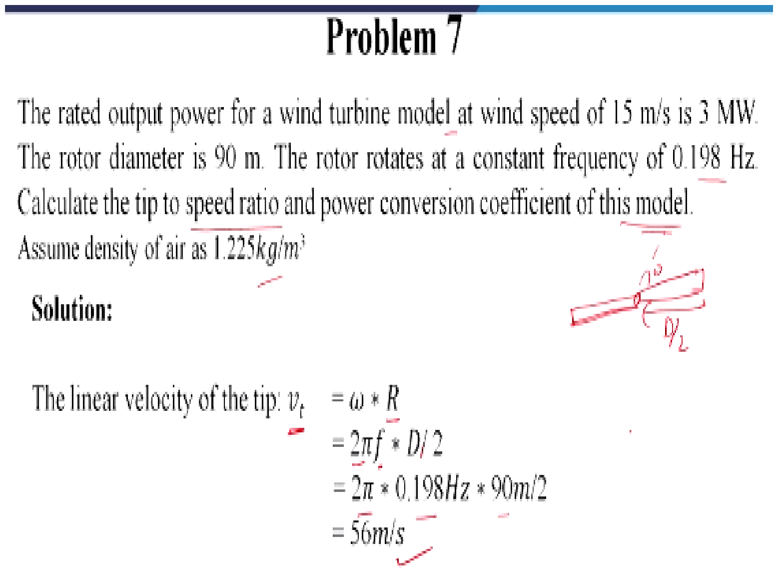

Our last problem, statement says the rated output power of a wind turbine model at wind speed of 15 metre per second is 3 megawatt. The rotor diameter is 90 metre. The rotor rotates at a constant efficiency of 0.198 hertz. Calculate the tip to speed ratio and power conversion coefficient of this model. So assume density of air as 1.225 kg per metre cube. So this is the condition given, we have to calculate the tip to speed ratio and power conversion efficiency of this model.

So if we think about the relationship between angular velocity and linear velocity so that linear velocity of the v_t will be equal to angular velocity into radius, so of this see if it is a fan is moving, so then will be the radius value and after some certain time it is making some angle, so ω x r = v_t that we know it very well, so but this $\omega=2\pi$ x f, what is this ω, that is equal to 2π x f, that means f is the frequency, so per second how many revolutions, 1 revolution 2 π degree.

So 2 π x number of revolution f frequency, so 2π x frequency x D / 2, D / 2 that is equal to 90 metre / 2, so rotor diameter is given with the blades. So here this is 90, so this will be half, D / 2, total is D, so D / 2 we are getting. So then this value is coming 56 metre per second. So 56 metre per second is the linear velocity of the tip.

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The tip to speed ratio: $r = v_t / U$

$= 56m/s / 15m/s = 3.7$

The wind power at the wind speed of 15 m/s: $P = 1/2\,\rho A U^3$

$= 1/2 * 1.225 kg/m^3 * \pi * (45m)^2 * (15m/s)^3$

$= 13MW$

The power conversion coefficient: $\varepsilon = 3MW / 13MW = 23\%$

Then the tip to speed ratio r = v_t /U that is equal to tip speed by the speed of the wind ,wind speed, so 56 metre per second we are getting for the tip speed and then 15 metre per second is the wind speed. So r = this by this is equal to 3.7, so that is tip to speed ratio we are getting 3.7. The second part, the wind power at the wind speed of 15 metre per second equal to 1 /2 x ρ x v^3, here is AU, so what is this, we are getting in this case 1/ 2 x 1.225 that is given for ρ and A is equal to 5 x $(90 / 2)^2$, so 45^2, x 15 metre per second to the power cube.

So then we will be getting equal to 13 megawatt. So the wind power has the energy potential of 13 megawatt, but the plant is giving us 3 megawatt, so the conversion efficiency is 3 megawatt / 13 megawatt, that is equal to around 23%. So now we have solved number of problems based on our previous classes. Thank you very much.