Technologies for Clean and Renewable Energy Production
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Lecture - 35
Tutorial

Hi friends, now we will have a tutorial session, and we will solve some numerical problems on the basis of our discussion held in the last 4 classes.

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PROBLEM 1

Calculate the theoretically power available from a flow of 1 m^3/s water with a fall of 100 m. Due to energy loss the practically available power will be less than the theoretically power. If the efficiency is 80% then calculate the actual power that can be obtained.

Solution:

The theoretically power available from falling water can be expressed as

$$P_{th} = \rho q g h$$

Where, P_{th} = power theoretically available (W)

ρ = density (kg/m^3) (~ 1000 kg/m^3 for water)

q = water flow (m^3/s) = 1 m^3/s

g = acceleration of gravity (9.81 m/s^2)

h = falling height, head (m) = 100

The statement of the first problem is calculate the theoretically power available from a flow of 1 metre per second water with the fall of 100 metre. Due to energy loss, the practically available power will be less than the theoretically available power. If the efficiency is 80%, then calculate the actual power that can be obtained. So this is a problem statement, so you know this is the problem of a hydro power plant based on the hydro power plant.

We know the energy equation of hydro power plants, so we will use that energy equation so that we can get the theoretically available energy in the water, and then if we multiply it by the efficiency, we will get actually available energy. So we know that the theoretically power available from falling water that can be calculated by this formula that Pth theoretically available power in watt that is equal to ρ x q that is the water flow volumetric flow rate that is meter cube per second and the g is the acceleration due to gravity and h is the falling height.

So that is mgh like so, the m is replaced by q x to ρ, so this is the expression we have discussed in our previous class. Now we have the data of to ρ, we have the data of q, we have the data of g, and we have the data for h. So in this case, ρ is equal to say we can assume that is equal to 1000 kg per metre cube for water and q is given 1 metre cube per second and then g is 9.81 meter per Second Square and he is nothing but 100 metre which is given here.

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Thus,

$$P_{th} = (1000\ kg/m^3)\ (1\ m^3/s)\ (9.81\ m/s^2)\ (100\ m)$$
$$= 981000\ W = 981\ kW$$

Practically available power can be expressed as

$$P_a = \mu P_{th} = \mu \rho q g h$$

Where, P_a = power available (W)

μ = efficiency = 0.80

$P_a = 0.80*981 = 784.8$ kW

So we will put this in this expression and will calculate the value of Pth and it is coming as 1000 x 1 x 9.81 x 100 that is equal to 981,000 watt or 981 kilowatt. So this is the theoretically available energy. Now, practically available energy we have to multiply it by efficiency of the system with the Pth, so μρqgh, so we will put it here and as the efficiency given is equal to 80%, so 0.80 x this much, 981 kilowatt, so we are getting 784.8 kilowatt, so this is the practically available energy. So problem number 1 we have solved.

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PROBLEM 2

A turbine develops 9000kW when running at a speed of 140 rpm and under a head of 30 m. Determine the specific speed.

Solution:

Shaft power = 9000 KW

Turbine Speed = 140 rpm

Head = 30 m

Specific speed can be calculated using the fo $Ns = \frac{N\sqrt{P}}{H^{5/4}}$

Now,

$$Ns = [140\ (9000)^{1/2}]/\ (30)^{5/4}$$
$$= 189.16\ rpm$$

Now we are moving to problem number 2. The statement is a turbine develops 9000 kilowatt when running at a speed of 140 rpm and under a head of 30 metre. Determine the specific speed. So this is again a problem related to hydro turbines and here we have to define the specific speed. So, specific speed is nothing but the speed which is equivalent to a turbine having the same sides and that turbine which can produce unit power by using unit head.

As we have discussed in the previous class that Ns is the specific speed which can be related with the speed of the turbine the power rating of the turbine and head available, so N x root P/H to the power 5/4. Now P and H both are 1, then Ns is equal to N when P and H are both 1. So this is the definition of Ns and if we put in this case we will put the P and H value provided in the statement N value also given in the statement and we will calculate the Ns value.

Now what is the value of N that is a turbine speed or the rotation of the rotor or the turbine shaft that is equal to 140 rpm as given here and then P power rating is given also 9000 kilowatt, so shaft power is 9000 kilowatt and then head is 30 metre, it is 30 meter. So we will be putting this value here so 140 x 9000 to the power 1/2, that is power rating to the power 1/2 and divided by 30 to the power 5/4. So this and we are getting that 189.16 rpm. So 189.16 rpm is the specific speed of that turbine.

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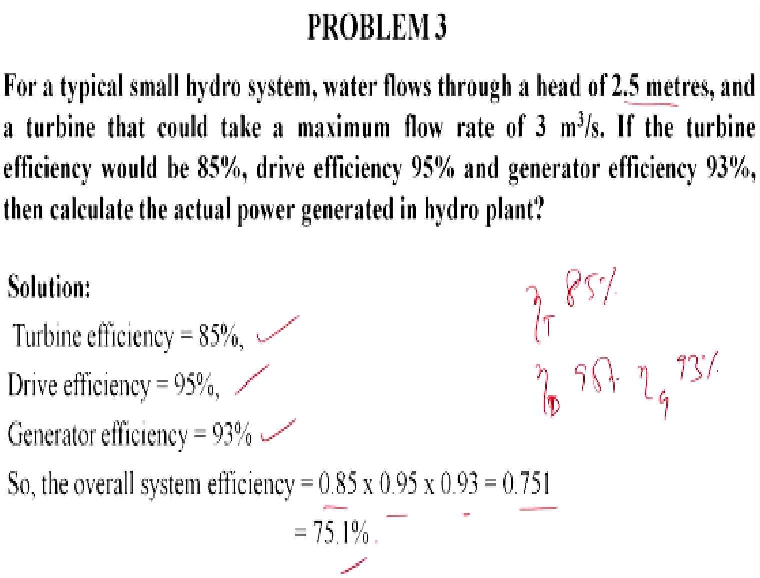

Now let us move to problem number 3. So it says for a typical small hydro system water flows through a head of 2.5 meters and a turbine that could take a maximum flow rate of 3 meter cube per second. If the turbine efficiency would be 85%, drive efficiency 95% and generator efficiency 93%, then calculate the actual power generated in hydro plant. Again a problem based on hydro power plant.

In this case, different types of efficiency has been that is the turbine efficiency 85%, efficiency of drive is equal to 95%, and efficiency generator 93%, so these are the efficiencies. So we will be getting the overall efficiency multiplying by these point 0.85 x 0.95 x 0.93, so that is overall efficiency for the energy conversion and then we will use the energy expression and we will get how much energy is available.

So now the turbine inefficiency is given 85%, drive 95%, generator efficiency 93%, so by multiplying of these we are getting point 0.751 or 75.1% overall efficiency.

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Now,

Head = 2.5 metres

Flow rate = 3 m^3/s,

Therefore, the maximum power output of the system, $P_{th} = \rho\, q\, g\, h$

$= 1000 \times 3 \times 9.81 \times 2.5 = 73575\ W = 73.575\ kW$

(density of water = 1000 kg/m^3)

Practically available power can be expressed as

$P_a = \mu\, \rho\, q\, g\, h$

$= 0.751 \times 73.575 = 55.254\ kW$

So then we will use the energy expression. So here head = 2.5 meters, flow = 3 meter cube per second and then the maximum power output of the system that can be theoretically maximum power which can be available that is equal to Pth that is equal to ρ x q x g x h. So we will be putting the ρ value 1000 and q is 3 metre cube per second, so 3 and 9.81 g and h is 2.5, so we are getting 73575 watt that is equal to 73.575 kilowatt.

So then what will be the practically available power, so we have to multiply it by efficiency, overall efficiency you have got that is equal to 0.751, so this 0.751 x 73.575 that is equal to 55.254 kilowatt. Now the problem is solved.

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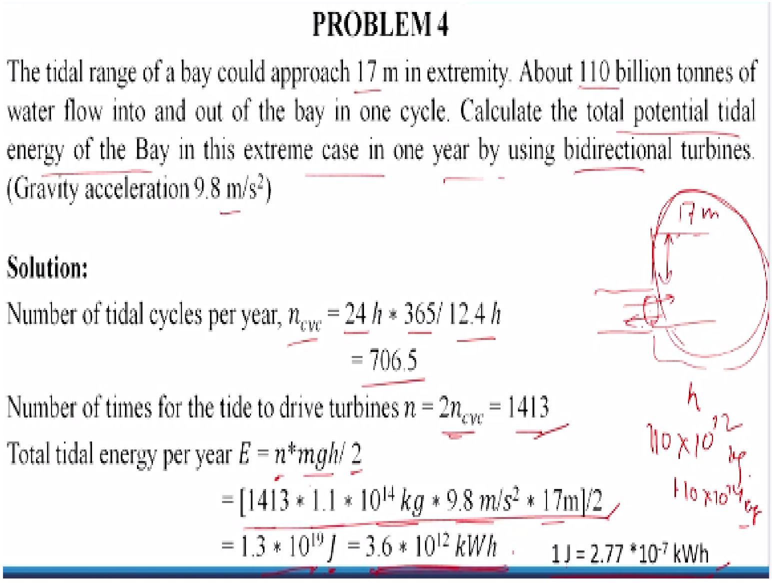

We are coming to the next problem, problem number 4 and which says the tidal range of a bay could approach 17 metre in extremity about 110 billion tonnes of water flow into an out of the bay in one cycle. Calculate the total potential tidal energy of the bay in this extreme case in one year by using bidirectional turbines. Gravity of acceleration 9.8 meter per Second Square. So this is a problem based on the hydro turbines but water level is generated through the tides, so tidal energy in fact.

So here we have sea level if we have then it will be during high tide water will go towards the river directions and we will be having some water head, we will be having some water head here, so this water head maximum is equal to 17 metre and it is also given that 110 billion tonnes of water flow into and out of the bay in one cycle, if this is our bay, so it is one cycle it is going out and again low tide this is going in high tide and low tide is going out.

So both the cases if you install one turbine, so if you install one turbine here, it will be able to generate electricity as the turbine is bidirectional it is given. So we will be using here also the energy expression for the calculation of the available energy and which can be converted. So now again it is told that we have to calculate on a yearly basis. So in a year, how many times of tides we will get that we have to calculate because one tide is the source of the availability of the head.

So that is why we will be calculating number of tides cycles, number of cycles per year, so that is equal to, so we have 365 days x 24 hour total hour and divided by 12.4 hour, at 12.4 hour is required for one tide, so one cycle we are getting total 706.5 cycles in a year. So the number of times of the tide to drive turbines for once we are getting two movement of the turbines in opposite direction, so number of times for the tide to drive the turbines is 2 x n cycles per year, that is in cvc, that is equal to 2 x 706.5, so 1413, so 1413 times our turbine will run.

Then what would be tidal energy here mgh x n/2, why so this is the potential energy which is stored here, this region this bay that will provide the electricity through the conversion in the turbine. So potential energy is converted to kinetic energy of the water, then it is mechanical energy of the shaft, and then through the generator it will give electricity. So in case of hydro turbines which we had used energy expression is equal to mgh, but here mgh/2 because this height will not be constant, this height which is the maximum height h which will not be constant.

It will be maximum initially, then again it will be reducing and come to 0. On the other case, it will be 0 and gradually it will increase, so that way, so this will be divided by 2, average is taken. So mgh x number of times the turbines is operated, so that n x mgh/2 that will be the energy potential for this turbine. So total tidal energy per year is equal to n x mgh/2, so here n = 2nc that is equal to 1413, so we will be putting here 1413, and m, m is equal to what, m is equal to it is told that 110 billion tonnes of water, so means 110 x 10 to the power 12 kg of water.

So you can write it here 1.10 x 10 to the power 14 kg of water. So this 1.1 x 10 to the power of 14 kg of water we are getting and g is equal to 9.8 metre per second squared already given and then height is equal to 17 meter maximum height, so that will be divided by 2, so we are getting here this much of energy which is available throughout the year, so that will be equal to 1.3 x 10 to the power 19 joule or if we want to convert it into kilowatt hour then we can use this expression that 1 joule is equal to 2.77 x 10 to the power -7 kilowatt hour.

So if we use this conversion in terms of kilowatt hour that this joule will be converted to 3.6 x 10 to the power 12 kilowatt hour. So this is the energy which is generated throughout the year. So our problem was we are asked to calculate the total potential tidal energy of the bay in this extreme case in one year by using bi directional turbines, so this much of energy we can produce in a year by using bidirectional turbines in this extreme case. Now the problem is solved.

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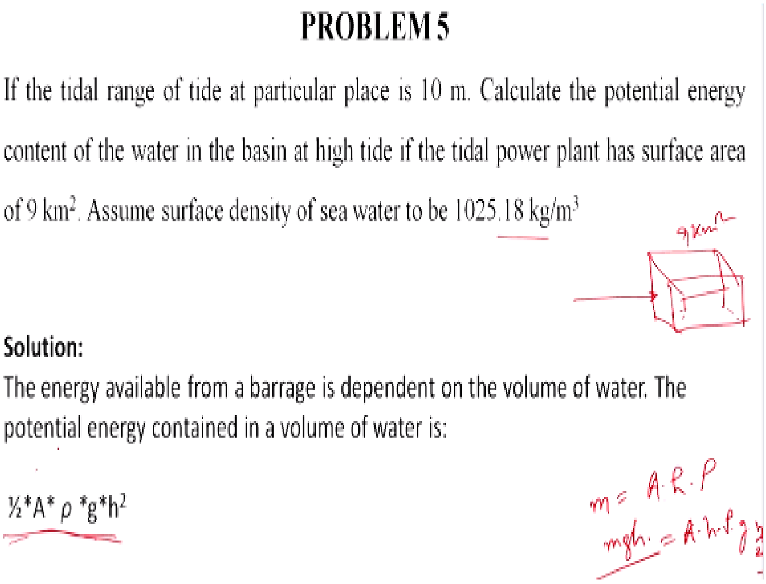

We are coming to next problem. So problem number 5. So, this says if the tidal range of the tide at a particular place is 10 metre. Calculate the potential energy content of the water in the basin at high tide if the tidal power plant has surface area of 9 kilometer square. Assume surface density of seawater to be 1025.18 kg per metre cube. So this is again a tidal energy problem and it is asked to calculate the potential energy content of the water in the basin at high tide, if the tidal power plant has surface area 9 kilometer square.

So, in this case, what will be the energy content that you see the energy content, potential energy contained in a volume of water that is equal to 1/2 x A x ρ x g x h square. So, here we have one surface area say. So, say water is going this direction and we have this surface area that is equal to 9 kilometer square surface area. So, 9 kilometers square surface this way. So, then what will be the height of it that will be the volume. So A x h that is a volume x ρ this is the mass, so that is equal to mass, A x h x ρ.

Then if I want to use the formula mgh, so mgh is equal to A x h x ρ that is n, A x h x ρ x g x h/2, this height is the water height is not fixed here, so h/2 it is mentioned, so h/2 we are taking the average. So that is 1/2 x A x ρ x g x h square that is the energy potential of the tidal barrage.

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where:

- h is the vertical tidal range,
- A is the horizontal area of the barrage basin,
- ρ is the density of se water water = 1025 kg per cubic meter (seawater varies between 1021 and 1030 kg per cubic meter) and
- g is the acceleration due to the gravity of Earth = 9.81 meters per second squared.

The factor half is due to the fact, that as the basin flows empty through the turbines, the hydraulic over the dam reduces. The maximum head is only available at the moment of low water, assuming the high water level is still present in the basin.

For the present case:

Tidal range of tide = 10 m

The surface of the tidal energy harnessing plant = 9 km^2

Specific density of sea water = 1025.18 kg/m^3

So in this case, h is the vertical tidal range, A is the horizontal area of the barrage basin just we have discussed this already horizontal area and then ρ is the density of the seawater. So, density of the seawater normally varies from 1021 to 1030 kg per cubic metre. So, you can assume any value in between these 2. So, the average one is taken 1025 kg per cubic metre and g is the acceleration due to the gravity of earth we know that 9.81 meters per second square.

Then I just discussed the factor half is due to the fact that as the basin flows empty through the turbines, the hydraulic over the dam reduces. The maximum head is only available at the moment of low water assuming the high water level is still present in the basin. That is why the half is considered. So in this case total range of tide is 10 metre and then the surface of the tidal energy harnessing plant = 9 kilometer square and specific density of seawater is 1025.18 kg per metre cube. So, we will be putting these values in our energy expression.

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Thus,

Mass of the water = volume of water × specific gravity

= (area × tidal range) of water × density of sea water

$= (9 \times 10^6\ m^2 \times 10\ m) \times 1025.18\ kg/m^3$

$= 92 \times 10^9\ kg$

Potential energy content of the water in the basin at high tide

= ½ × area × density × gravitational acceleration × tidal range squared

$= \frac{1}{2} \times 9 \times 10^6\ m^2 \times 1025\ kg/m^3 \times 9.81\ m/s^2 \times (10\ m)^2$

$= 4.5 \times 10^{12}\ J$

So, mass of the water = volume of water x specific gravity that we know. So, volume of water mean area x tidal range of water x density of the seawater. So 9 x 10 to the power 6 metre square, so 9 kilometer square, so that is converted to metre square. So, 9 x 10 to the power 6 metre squared and then tidal range 10 metre and is 1025.18 kg per meter cube is the density of the seawater. So, by the multiplication of these 3 terms, we are getting here 92 x 10 to the power 9 kg. This is the mass of the water.

Then potential energy content of the water in the basin at high tide will be 1/2 x area x density x gravitational acceleration x tidal range square. So, 1/2 into this area x this is equal to mass basically and g and h square. So, we are getting 4.5 x 10 to the power 12 joule. So, now we have solved the problems. Total 5 problems are solved on the basis of our discussion held in the last 4 classes. So, thank you very much for your patience.