Energy Resources and Technology
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Lecture - 31
Tidal Energy (Contd.)

In the last class we have understood why tides occur and in that process we have seen that the tides are mainly caused by the effect of the moon. The effect of the sun is there, but the effect of the moon is 2.2 times stronger than the effect of the sun. So, when we consider the tides, we will essentially consider lunar tides and we have understood that within a lunar day, there are two high tides and two low tides. Therefore, two full tidal cycles in a lunar day remember, which means 24 hours 48 minutes. The solar day and lunar day are a bit different, because if the moon were static, then we would see, as the Earth rotates around its axis we see it come back exactly 24 hours later, but since moon itself is moving, therefore it comes back to the position 24 hours 48 minutes later. So, that is a lunar day. In a lunar day therefore, they would be two high tides and two low tides.

The effect of the solar tide would be only to enhance or to cancel a part of the lunar tide. So, that is how we would understand it. So, whenever, from now onwards, when we talk about the tidal cycle, we will essentially mean the lunar cycle. We have also understood that the open sea has only about 2 feet of tidal variation, which is very small and that is enhanced by the specific topography of certain coastal sites and that is why in various parts of the coastline we will find tidal variation going to different heights and there are specific places where the tidal oscillation, natural tidal oscillation and the ingoing water and outgoing water that kind of cycle they match and there is a resonance and there you find very high tidal variations and that can go as high as 30 feet and naturally, we have to utilize those particular sites where you have a large tidal variation; but not only that, there is another thing that you have to consider.

How actually would you utilize the tidal energy? Essentially, you somehow have to confine the water that goes in during the high tide and allow it to pass through turbine, right. In order to do that, therefore you need to construct a dam, so that the water cannot naturally go out without going through the turbine.

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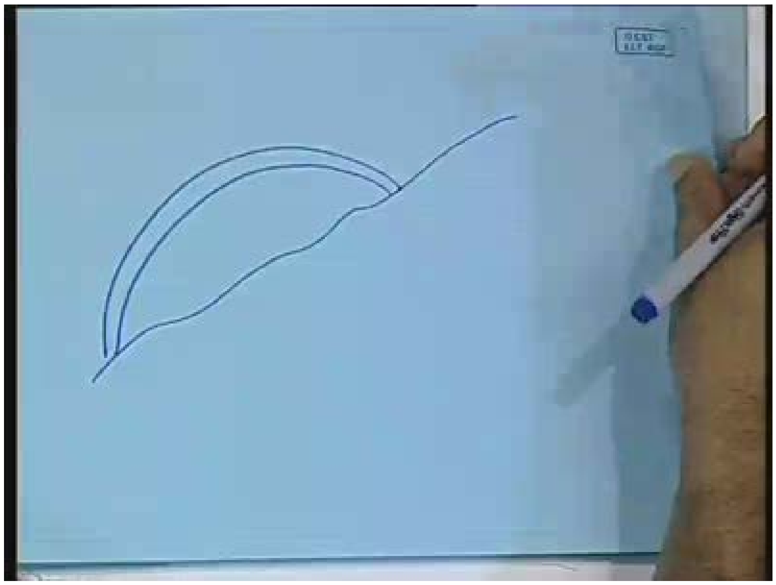

So, suppose this is a coastline, then you will have to enclose, suppose in this part there is a high tidal variation, you would have to enclose a part something like this with a dam, with a physical civil engineering construction, in the middle of the sea which is very expensive. That is why we never do that. We never do it like this, that there is a coastline and you simply build a dam to enclose some amount of water.

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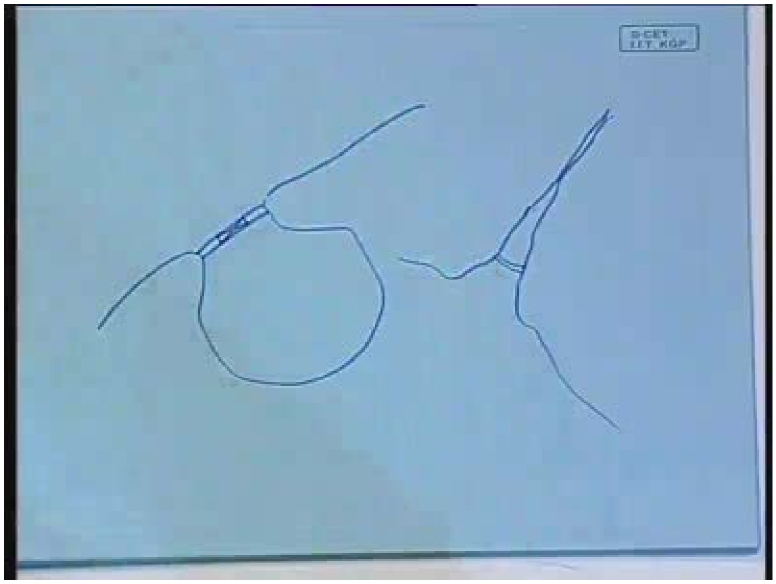

What is actually done is that we will look for a site which would be something like this, where we can get away by building a much smaller construction. Then only it justifies economically. You might argue that after it is constructed there is no expenditure, because you are not really spending anything on the, on actually getting the energy. True; that is true for all renewable energy sources. There is no recurrent, there is very little recurrent cost except for maintenance, but nevertheless if the installation cost is very high, it has a certain life time, so you have to calculate the economics on the basis of the installation cost and the lifetime and if that becomes higher than the regular price of electricity in the market, then it does not justify itself. That is why we have to look for the cheapest possibility and often therefore, we have to look for this kind of specific geography of the place.

Now, it happens very often in estuaries of the rivers where for example a river is coming for example here and it sort of expands and then its goes, so this is the, this is the flow of the river. So, if you can construct a dam here, you can enclose a reasonably large amount of water mass. So, the essential point is that you have to enclose an amount of water mass, enclose in such a way that as the sea level here varies, as the sea level varies, goes up and down, the water would come in and would go out and that can go in or out through a turbine. That is the essential concept.

Now, if that is the essential concept, then you have to have a turbine here. Whenever we put this symbol means with a cross, you assume that it is a turbine. Now, it so happens that the turbines can either be one way turbine or a two way turbine. Now, one way turbines are significantly cheaper than two way turbines. That is why in many installations, people prefer to have just a one way turbine. Now, since during the high tide water would come in and during the low tide water would go out, then you have to make a choice, which one do you utilize high tide or ebb tide?

Normally, people use the ebb tide, remember, if it is one way turbine. Why, because during the ebb tide more water is available. Why? Because, mostly these things are estuaries or river, so there would be more water coming in, more than the amount that has come in through the high tide. That is why during the emptying you have more energy available. So, how would the structure of this system look? It would look something like this.

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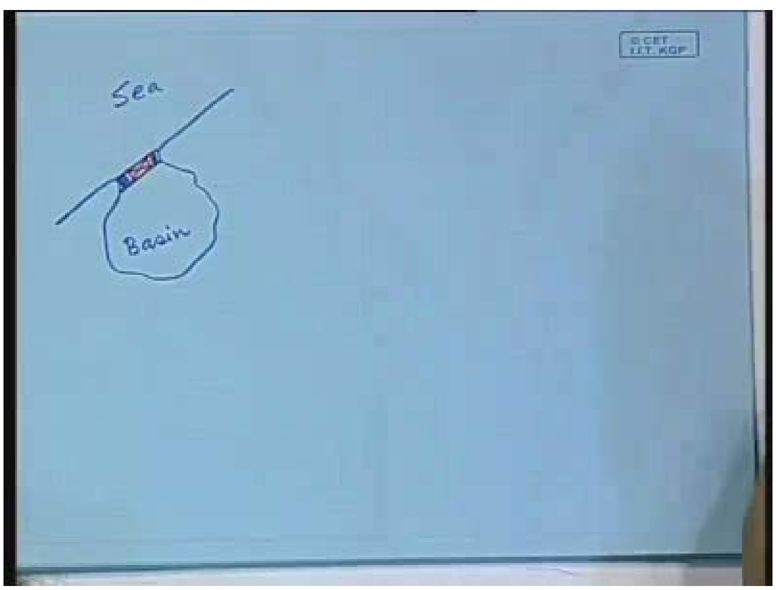

You have some area enclosed. You have the dam constructed and you have the turbine installed here. During the high tide the water comes in and now, if it is a one way turbine you are not allowing the water to go in through the turbine. So, you have to have additionally some gates. These are called the sluice gates, which allow the water to go in or out without going through the turbine. So, during the high tide you open this sluice gate, so that water comes in and during the low tide you close the sluice gates and allow the water to go through the turbine. So, during that period you generate energy. So, this is the sea level and this is the, this is called a basin, the tidal basin. So, would the structure be understood? There is a turbine and there are a few sluice gates.

Now, let us draw the cycles of the various levels. What are the levels? There are two levels available, the sea level and the basin water level. Sea water level during the tidal variation would vary approximately sinusoidaly and this sinusoid will have a time period of how much? 12 hours 24 minutes, 12 hours 24 minutes, within that there would be a full sinusoidal cycle of the sea water level.

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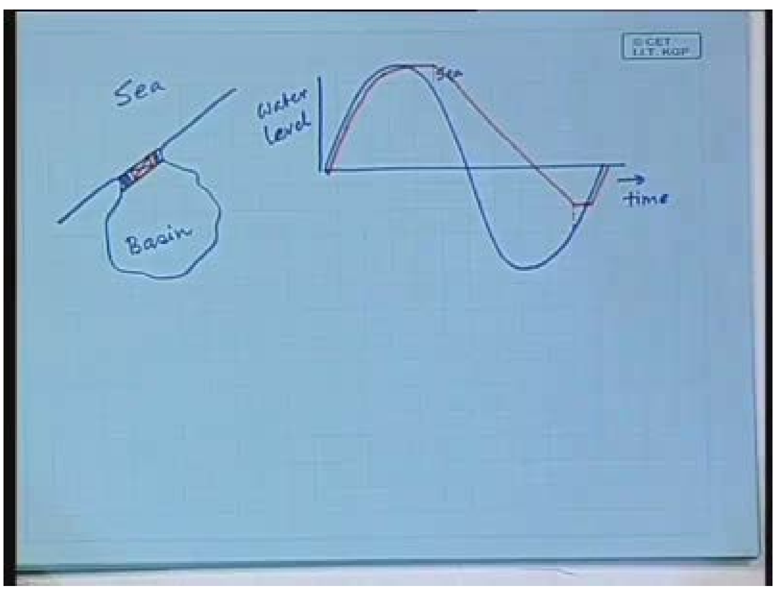

So, we can draw that. The axes are, in this side it is time and this is the, this is the water level. So, here we are drawing the sea water level. Now, how will the basin water level react? Here, we are talking about a one way turbine. The basin water level, during the high tide remember what is happening? You have the sluice gates open and therefore, the basin water level very closely follows the sea water level, which means that it will go like this, very closely following the sea water level. But, then as the two levels become equal then you cannot keep the sluice gates open any further. So, you close the sluice gates. As a result, the basin water level remains the same, while the sea water level falls and beyond a certain time, the height, the head means the difference of the two levels, becomes sufficient to generate electricity. At that time, you allow the water to pass through the turbine which means then the level in the basin will also increase, will also decrease and the sea water level is also decreasing, so they follow each other but with a difference because in order to produce electricity, you have to have a certain head. So, it is not like opening a sluice gate. So, you have something like this, all right.

Why is this falling? Because, water is emptying through the turbine and this is falling because of the natural tidal variation and after sometime, again the head becomes insufficient to generate electricity. Then again the sluice gate is closed and then, after the two levels become the same the turbine was closed, sluice gate is also closed. At this time, this sluice gate is open, sluice gate is open not the turbine and then it follows the same route as here. That cycle repeats itself. Is it understood now?

So, what is happening? The sea water level is varying approximately sinusoidaly. During the high tide, the basin water level is following the sea water level, because the sluice gates are open and at this time the sluice gates are closed, the turbines are also closed till a certain head builds up. At that point of time, the turbines are opened and then there is generation of electricity. Notice, the generation of electricity is not constant, because the head is varying really. Can you see that? At this time the head is small, at this time the head is largest, again the head falls and finally at this time the turbine has to be stopped, because there is no longer sufficient head to generate electricity and then both are closed till the two levels become equal. Then the sluice gates are again opened.

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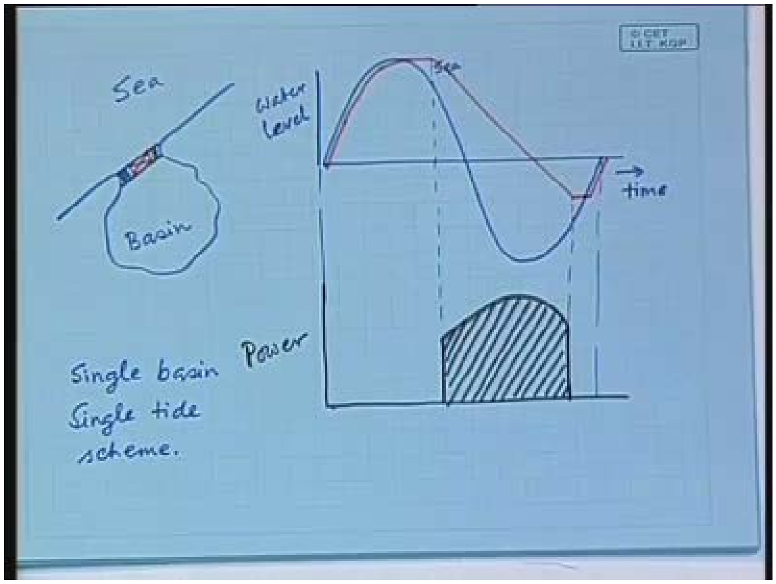

If I now draw, if I now draw the power output characteristics, it will be something like this. Power output starts at this point and it goes up to this point, within this whole cycle. The cycle is from here to here. Within this whole cycle you have the power output, only during this time. So, it starts at a certain value, it goes up maximum at this point, so it should be something like this. So, this is the curve for the power output. So, this is the, now this scheme is called the single basin, there is only one basin, single tide scheme. In cases where you have ready availability of one way turbines, cheaper, there people prefer this particular scheme. But of course, if you have a two way turbine you definitely can produce more electricity. So, let us now work it out for a two way turbine.

In case of a one way turbine though, the amount of power you generate is not half that you can generate by a two way turbine. It is more than half, it is above 65% that you can generate by a two way turbine. Why? Because of this particular fact that during the ebb tide more amount of water is available, in general. So, that is again, that is another reason why many people, many of the installations have preferred the one way turbine and a simple single basin single tide scheme.

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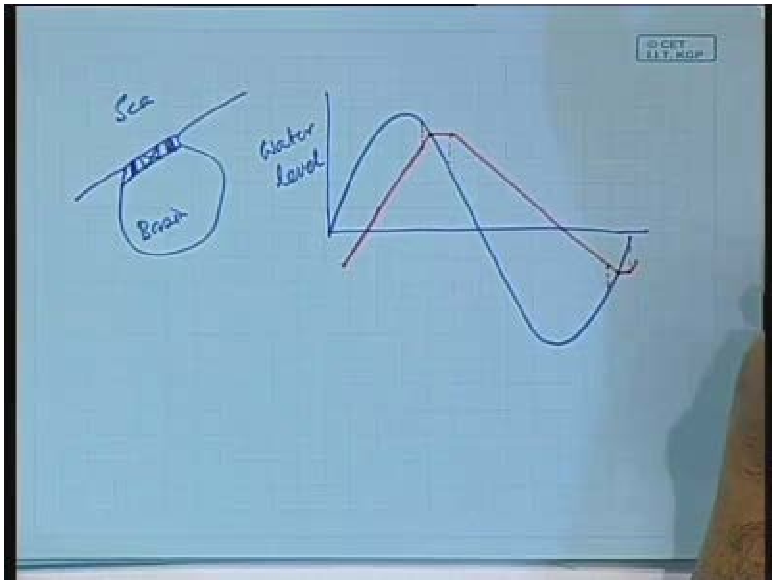

Now, if you have a two way turbine, again the shape of the scheme is very similar. You have the sluice gates here, this is a basin and this is the sea. You have the tidal variation like this, a sinusoid. Now, this is the sea water level variation. How will the scheme work? Starting at this point, let us assume, now it is going into the high tide. When it is going into the high tide, then the turbines are open, at that time the turbines are open therefore, there should be a difference between the two levels, in order for the turbines to work. But the turbines since there are open, the water is going into the basin from the sea and therefore, it should go up.

So, it goes up like this, so this is the basin water level, till a point where you can no longer run the turbine, because the head has become too low. When the head has become too low, you stop the turbine and keep both the turbines and the sluice gates closed or you might open the sluice gates, till it goes to this point. The turbine cannot function, but you can still open the sluice gates till the water levels become equal and then both are closed, till sometime when again the head builds up. Again you have to open the turbine in the opposite direction, so that the basin water level falls. Basin water, now water empties through the turbine till a time when the levels are equal. At that time again the sluice gates are open, so that it goes very close to the sea water level. When they are again equal, it is closed till the head builds up and then it starts, it comes here. The whole cycle then again repeats.

Student: Sir, in the case the basin empties slower than it fills up …

Not really, not really, the rate of filling up or rate of emptying depends on two factor, two factors. One is the diameter of the turbine, how much water it can allow through. This is more or less constant. The power generation will be dependent on the head, but after all the same amount of water can flow through, water is incompressible stuff, so the head will not make the more water or less water to flow. So, same amount of water will flow with some velocity. So, depending on the velocity of flow that depends a bit on the head, so when the head is large, there will be a larger amount of water flowing. When the head is small, there will be smaller amount of water flowing, but nevertheless the point is that the rate of flow does not depend on whether it is high tide or low tide. Rate of flow depends on the aperture of the turbine and the head difference that you have. So, in this case how much, what will be the curve for the power generated?

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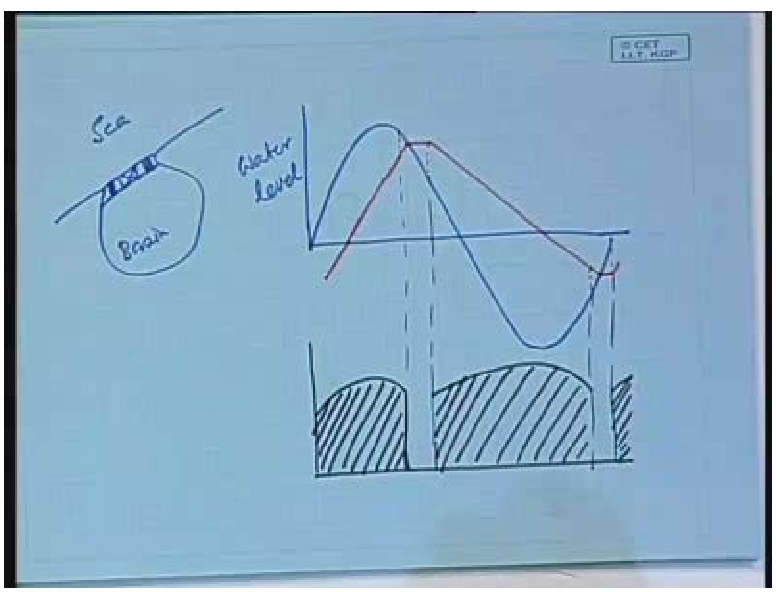

Power generation curve will be, notice that at this time you have the power generation stopped, at this time it is again started, at this time it is again stopped, at this time it is again started and in between you have the power generation curve, say like this. At this time it is highest, so you have and it comes here. So, these are the periods where you do not have any power generation. These are the periods where you do not have any power generation. In fact, the advantage of the tidal power generation is that you have the power free. It is a renewable source of energy, but the disadvantage is that you have this times when you can generate no power.

As a result, unless the power system is strong enough that means it has excess capacity through other means, these times create problem, because suddenly there has to be load shedding because you are not generating so much power. So, if you have very large tidal power plants that often create a problem for the power plants, power stations, because there is, there are these no load periods, no generation periods. Different countries have tried to solve this problem in different ways and some countries have offered special incentive for creating industries that take the power when it is available. So, at that period of time when it is available, when it is generated, the power is very cheap. So, industries find it more convenient to use that and at these periods around 2 hour periods they simply switch it off, you go for lunch. Only the lunch is then tuned to the lunar cycle, not the solar cycle, the way we are used to. That is one way and I will, I will tell you there are also ways to allow the system to generate continuous power. I will come to that, but before that a natural question is how much can it generate?

If say, I am able to enclose, obviously the generation is dependent on how big is a basin and that of course depends on the topology of the site, the geography of the site, but nevertheless suppose you have found a certain place where it is possible to generate tidal power, the natural question is how much can it generate? Without understanding things in terms of quantities you never become engineers. So, we have to understand that. For a particular site, let the total tidal variation be R. What is meant by total tidal variation?

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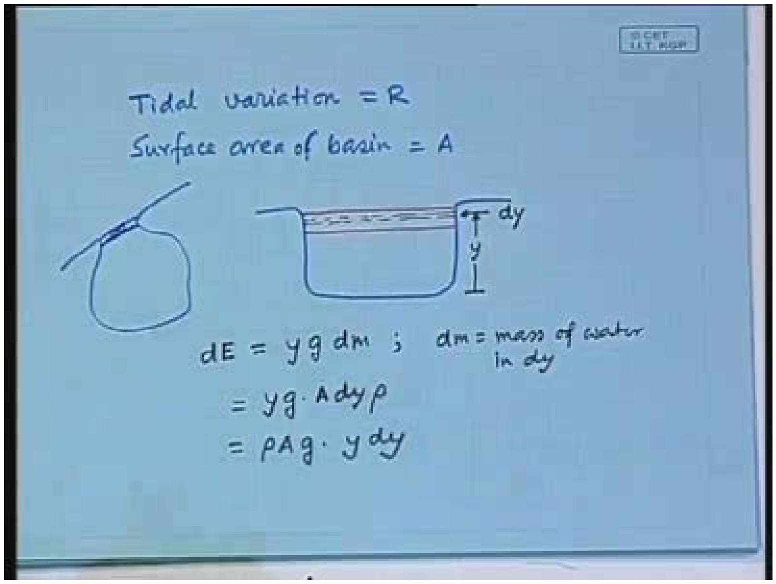

From the lowest point of the ebb tide to the highest point of the high tide, so that is the tidal variation is R say. The surface area of the basin let this be A. Now, we are considering say a place something like this. So, this is the area A, here will be the turbine. This is the area, A and if you see sideways, we will, for the sake of simplicity we will assume the sides to be vertical. It is not actually vertical and we will take care of that later, but let us assume the sides to be something like this, so that you have this level at the highest point and this level at the lowest point. It goes, goes on varying and this difference is your R.

Now, we are considering, how much energy, as the water goes from this level to this level how much energy is available? Essentially that is that is potential energy, potential energy of the water. So, we will consider a thin, we will consider a thin slice of this water. This slice is say dy, at a height y. So, then your energy, dE potential energy is mgh, right. So, it will be H is y g. Let the mass of the water be dm, so dm. So, obviously we know dm, because that is nothing but the volume of water times the density. So, this is equal to yg times A dy times rho, right; stands to reason? So, let me write it correctly. This is rho A g times y dy.

Now, that has to be integrated over R. So, this height is R, so you start from this level to this level. So, if you take this as the day time level, then it goes from zero to R that becomes easier to calculate, so zero to R.

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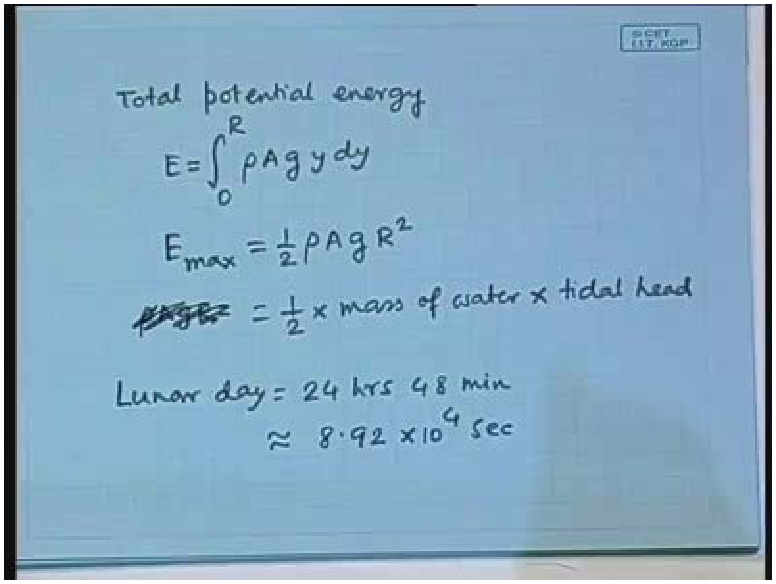

So, the total amount of energy available is integral zero to, this is E, zero to R rho A g y dy. Rho, A, g are constants, they come out, y dy, integrate it, pretty simple, the amount of … Then we will write it as E max, because that is the maximum amount of energy available. E max is then rho A g, then how much, by 2, yes, so half. Now, you might notice that this is, what is rho A g times R? What is rho A g times R? Rho A g R is the mass of water in this height R, times R is the mass times R, you have, the actual amount of energy available is half that. So, normally people think that you have the total mass and this is the total height, so the amount of energy should be rho Ag R square, but it is actually half that. That is what I wanted to prove. So, half the amount of, half the mass times the tidal head, so this is I will write it half, right.

Now, this amount of energy is available how many times per day? Four times per day this amount of energy is available. If it is a two way turbine, then this amount of energy is available four times per day. Day means what?

Student: Lunar day.

Lunar day, so 24 hours 48 minutes, so lunar day is approximately, this is approximately equal to 8.92 into 10 to the power 4 seconds. Ultimately we want seconds, because we want to calculate the power in watts.

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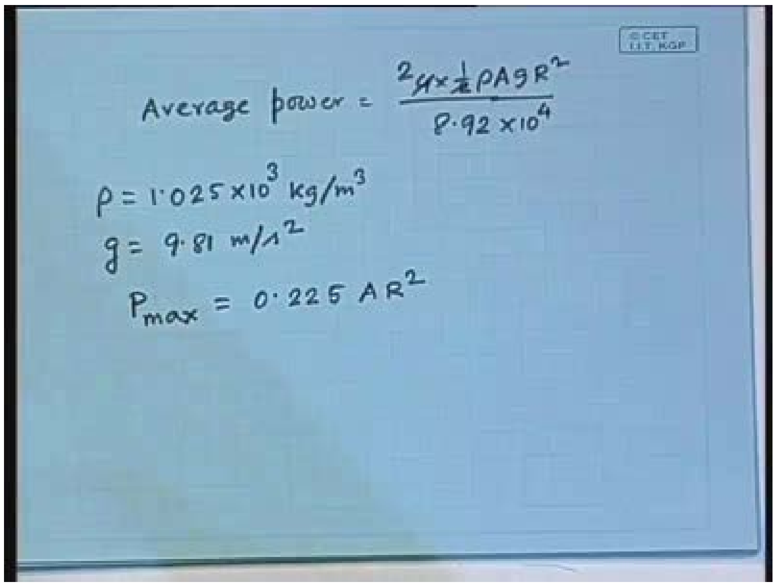

So, the total amount of the average power that can be, not total, total energy we can talk about, but average power, average power is 4 into half rho A g R square. This is the amount of energy available. It was available four times within a time. Now, this of course cancels off, that is 2; now, we have to substitute these values in order to estimate the numbers. Rho, rho is approximately 1.025 into 10 to the power 3 kg per meter cube, g is you know, these are known. So, this gives you, P will be, we will give the nomenclature P max, because this is the theoretical maximum that you can generate, right, so this comes to be, can you just substitute this and tell me the values, something times AR square.

No calculator? It comes actually to be 0.225 AR square. So, that is the maximum amount of energy that you can generate and depending on the specificity of the say, site you have the A and the R. So, given the A and R you can calculate, but that is the maximum. In reality, because of many of the non-idealities, you can normally generate not more than one fourth of it. So, let us, let us first try to understand how much is the actual power generation?

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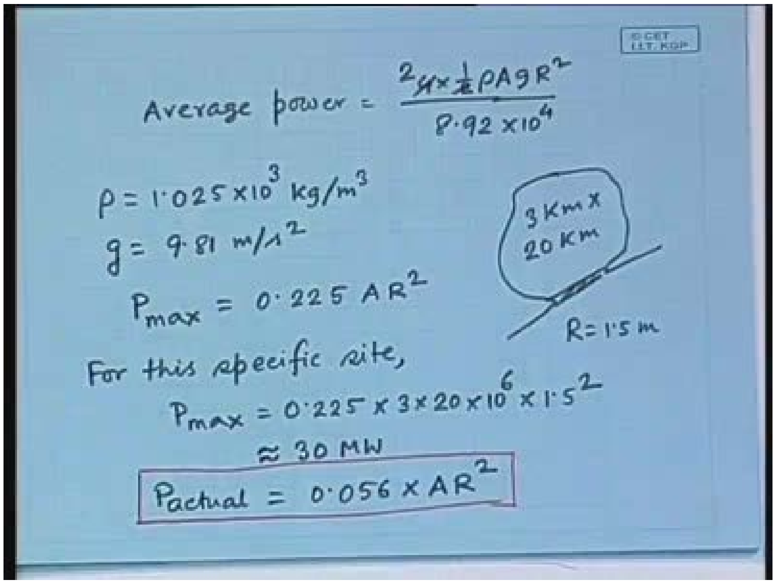

Suppose you have a basin area. The basin area is say, 3 km times 20 km. Normally, it is elongated. Why because, normally it is the estuary of a river that is why 3 km by 20 km I have, I have put. Can you just substitute it here and assume R is equal to 1.5 meters only. Then, 3 was kilometers, so that has to be 10 to the power 3, so into 10 to the power of 6 times, fine. This comes to be how much?

Student: …

Around 30 megawatts.

Student: 20 megawatts

Around 20 megawatts. How much? How much does it come to be? Twenty point … Yeah, I guess it will be close to 30, so approximately 30 megawatts. So, normally you can easily see that an amount of water contained in about 60 kilometer square would produce about 30 megawatts. But that is the theoretical maximum amount of energy. The actual production will be about one fourth of that, which is about approximately 8 megawatts. So, approximately 8 megawatts can be generated from a thing like this.

Suppose now we allow us to increase the head to 2 meters from 1.5, small amount of increase, how much does the power capacity increase? Can you just calculate? Now, you will see the effect of R square, so normally you would say the P actual, it is within the, is equal to one fourth of this. So, this would be approximately 0.056 times AR square. This is what you should keep in mind that this is the actual power production capacity, the average power production capacity of the site.

How much does it come to be? If you increase it to, who has a calculator? You have? If you increase it to just 1.5 to 2 meters, how much does it change? You will find that is quite a lot, about 13 megawatts it will come to be.

Students: …

No, no, no, you have to then make it one fourth.

Students: …

So, if you make it one fourth, kithna atha hai?

Students: ….

One fourth, approximately 13, right, yes. So, just if you increase it from 1.5 to 2, it increases from 8 megawatts to 13 megawatts; quite a lot of increase, right. So, that you have to keep in mind. You have to, one has to select the sites that have good power generation capacity, good head.

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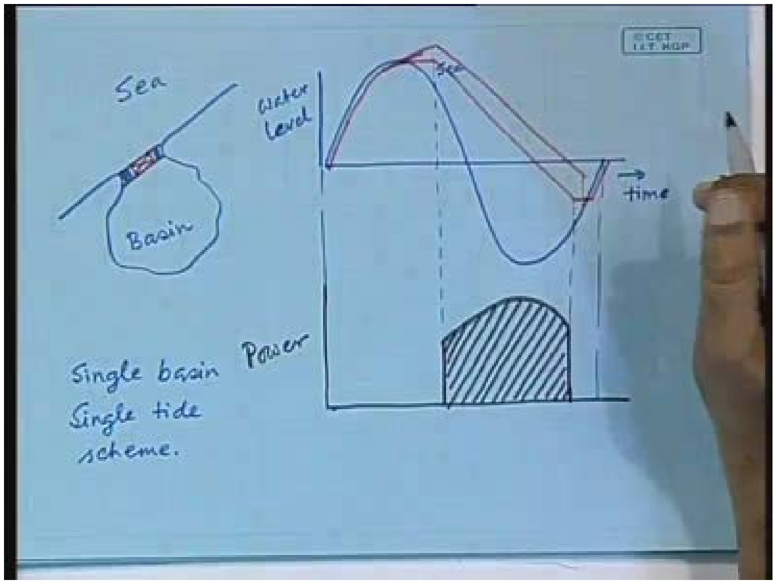

Now, one thing that is almost universally done is that here we have the, you might consider both, but let us consider this. At this point, the sea water level and the basin water level become equal. A trick is played at this time. The trick is, when they become equal, then use the turbine as a pump and put in additional amount of water into the basin. When the head difference is very small, then you would need very little power in order to pump, right, so that the basin water level becomes, goes up like this and then at this time, you get more amount of head available and then it goes down like this, right. It can generate for a larger amount of time. Not only that, all the time it has more head available, so you pump when the head difference is small, you utilize when the head difference is large.

As a, as a result, the same quantity of water can produce a lot of more power. That is a concept; that is the idea that is almost universally used, because you can enhance the capacity a lot. Let us calculate how much you can enhance. Let us calculate how much you can enhance by this method. Suppose we additionally pump 10% water, the total amount of water that was coming in, let it be Q and you additionally pump in 10% more water. So, the actual water that has come in is 1.1 Q and as a result, the head has gone up to 1.1 R. Assume that and then let us go ahead to calculate.

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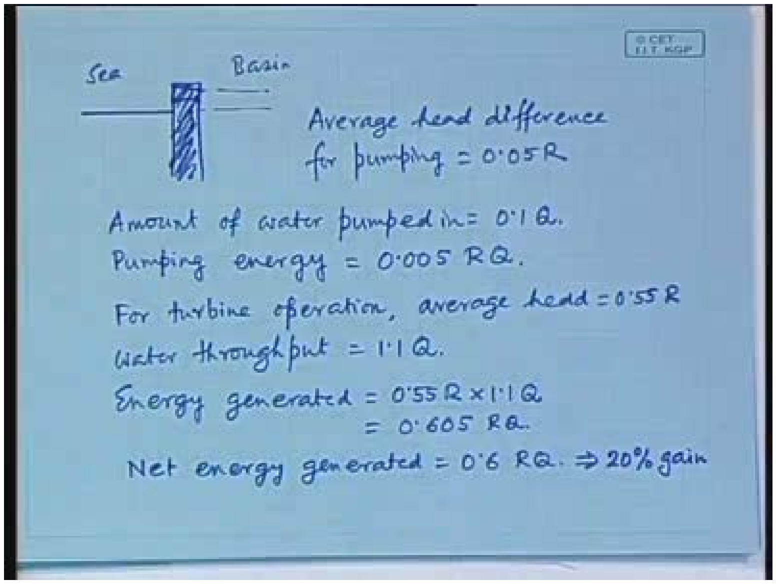

Now, when you are pumping, the pumping means if this is the sea water level, you have the and at that time it was like this and then you, this is the dam, this is the sea and this is the basin and you increase it to this much point 1, point 1 R. So, what is the average head difference against which you have to do the pumping? 0.05 R, so average head difference. How much water was pumped in? If the total amount of water that normally comes is Q, it is 10% of that, so point 1 times Q that is the amount of water that is pumped in, amount of water pumped in is 0.1 Q. So, pumping power, pumping energy not power, is this times this. So, this is 0.005 RQ; that amount of energy has been spent in the pumping affair.

Now, the gates are closed and you wait till the head builds up and that is when you allow the water to flow out. It had gone up to a head of 1.1 R. So, now when you try to utilize it, how much is the head available on an average? 0.55 R; so, for turbine operation average head 0.55 and how much is the total amount of water going through the turbine?

Initially it was Q, now it is 1.1 Q. So, water through put, so the total amount of power generated, total amount of energy that has been produced, so energy generated is equal to 0.55 R times 1.1 Q is equal to how much? 0.605 RQ, fine

Now, this amount of has energy has been generated and this amount of energy has been spent. So, how much is the net gain? Net energy generated is then this minus this 0.6. If you did not have pumping, how much would be the net energy available half RQ, right, we have already seen that. So, by doing that additional pumping you have got 0.5 to 0.6. So, how much is the gain in the percentage? 20%. So this implies 20% gain. That is exactly why we always do pumping in addition to the turbine operation.

In many cases, separate pumps are installed and if the turbine is constructed such that the same thing can be also used as pump, then the same thing is used as pump, clear. There is a bit more to be covered on, as I told you, the various ways of obtaining smooth continuous power, but before that let us get back to the particular site characteristics. It is here.

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Notice, we were yesterday talking about this site, the Gulf of Cambay or the Gulf of Khambhat. Notice that it is estuary of many rivers and it has an elongated part and it is possible to construct dams here, somewhere here. But still, if you notice the sizes, the size of the dam that would be necessary is 25 to 30 kilometers, very large. Naturally, that would entail a very large capital expenditure, even though the amount of water that would be enclosed is very large. So, it has been estimated that this site has a power generation capacity of close to 5000 megawatts, huge, but still the problem is that the capital expenditure is also huge, due to which the country has not yet been able to establish such a tidal power plant. But, it is a very large tidal power generation site that is possible. So, notice that you have, you can put the dam somewhere here or here or here depending on how much you can spend and depending on that you will have different amounts of energy made available, because different amount, different sizes of basins can be created.

Unfortunately in India, the other sites that are possible are not very good tidal generation sites, because a tidal head is not all that high or the coastline is rather flat rather than having that kind of estuary, a structure. The other rivers, there are many rivers, but other rivers do not have that much of tidal variation, except at Sunderbans and Sunderbans has a problem that it is not just one estuary. It is a very, very large number of rivers that is finally meeting the sea; very, very large means there can be something like 50 different rivers going into sea. So, you will need to construct many small dams in many places in order to enclose any amount of water and as I told you, there are environmental objections, which is very justified. That is why that has, that site has not been chosen as yet. So, let us stop here and in the next class we will talk about how to produce continuous power from tidal power generation.

Thank you.