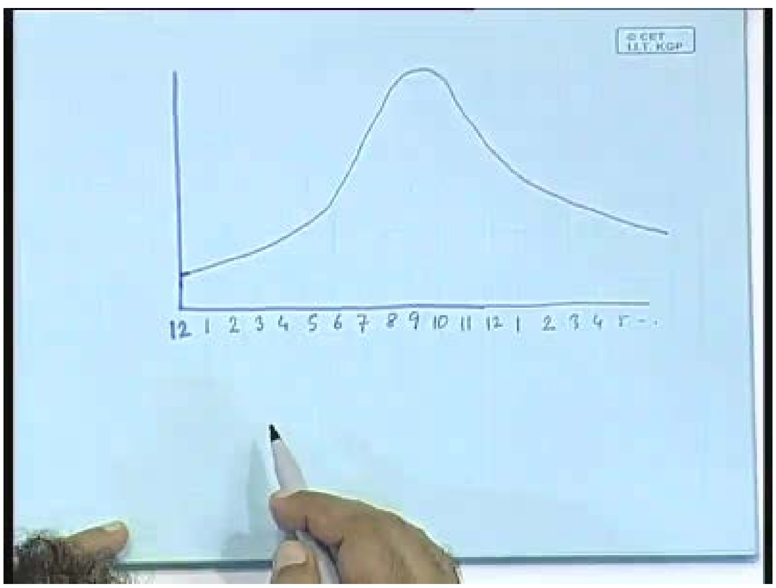
Energy Resources and Technology
Prof. S. Banerjee
Department of Electrical Engineering
Indian Institute of Technology – Kharagpur

Lecture - 10
Hydroelectric Power

So, in the last few classes, we were talking about thermal power plants and as you know the load is a, load means we are consuming all the time; consuming electricity all time and that electricity consumption is continuously varying. Why because, when the institute starts say, about 8.30, all the lights would be switched on, the industry starts at around say, 9.30, 10 o' clock, all the machines will be switched on; again at about 5 o' clock, the machines will be switched off. So, naturally the load that the power stations have to carry will be varying load. Again, in the evening all the lights will be on. In the summer all the fans are on, in the winter fans are not on. So, you have a varying load.

(Refer Slide Time: 1:44)

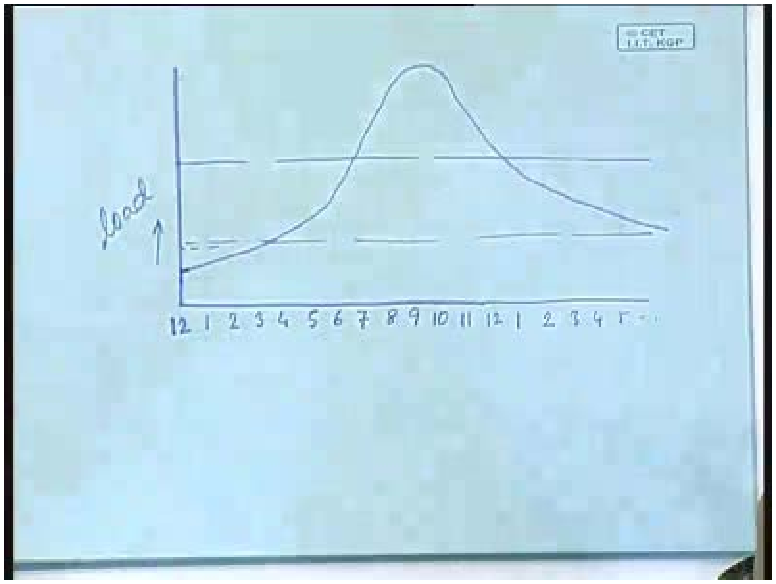


In general, if you plot it, the variation of the load against time is called the load curve, say we start from midnight and 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, again the same thing continues, right; we have to plot 24 hours, so 1, 2, 3, 4 and all that. So, at midnight you would obviously expect very low load. So, you can start from very low load period and then it will, it will be expected to increase around this time, right. So, around say, 8 o' clock, 9 o' clock, the lights will be on, the offices will be turned on. So, you can expect say, something like this, right and then it goes down. It may not be exactly like this though, because that varies from season to season, that varies city to city, city or rural area, it depends on that, but what I am trying to point out is that the load is continuously varying and there is a particular time, normally that comes in the evening, like say 7 o' clock to 9 o' clock prime time, when the load is the highest. That is the peak power, peak load, ….. So, the whole power generation has to satisfy this varying power load.

How do you do that? Now, as we have understood the structure of the power plant, there, a huge boiler is there that is producing the steam and that steam is going into the turbine and the turbine is rotating, thereby producing the power. In order to change the amount of power produced, yes, you can increase or decrease the amount of steam that goes into the turbine; yes, you can do that. That is a short term thing, but after all the steam is coming from the boiler and in order to change the steam production of the boiler, the coal production has to be, coal input has to be changed. Obviously, you can feel that in such a huge thing, that whole thing will be a very slow affair. You cannot really change the steam output very fast. Moreover, such a, such a big plant cannot be started very fast. Because, suppose such a 5 storey building that is the boiler, it has to be heated up to the temperature and then only the coal starts firing and only when the temperature reaches certain level you get the steam output and steam also has to reach that particular pressure, so that process takes hours. In very big power plants, even days; may be of the order of a day.

So, this variation, it is rather difficult for big power plants to take. Big power plants normally can work more or less at the same power level and small variations are allowed all right, but not much. Relatively smaller power plants can vary relatively faster, obviously because the size is smaller, but nevertheless there is a limitation to it. So, meeting the peak load, meeting the whole varying load demand is normally a problem. How to meet that problem? You can meet that problem only with that kind of a resource, which can be varied very fast and one of the resources that can be varied very, very fast is hydroelectric power. That is why in those states which have an even balance between coal fired thermal power plants and hydroelectric power plants, they are very well off, they can easily meet their demands; while the states that depend more or less completely on thermal power plant, there they have a reasonable amount of difficulty in meeting the peak load, right.

(Refer Slide Time: 6:23)



So, normally you would say that here is the amount of load, this amount of load. Here, here is the load that means power, power demand. This is the base, right. So, this is called the base load. Now, what, this is called the intermediate load and above this is called the peak load and peak load comes for a period of say 2 to 3 hours per day, intermediate load comes more and base load is always on. So, that is the basic idea. In general, the large thermal power plants cater to the base load, the medium sized thermal power plants cater to the intermediate load and peak load is a problem, which I will come to a little later. But, where you have the availability of hydroelectric power, there you can use that for the peak loading purpose.

Also, if you have hydroelectric power, hydroelectric power after all comes from the rain and the rain is varying all the time, so if you have a rainy season, you have a huge amount of water available and then, that can be, the same water can be used to cater to base load, because it is there, any way you have it, so that the majority of the power production can be shifted to hydroelectric in those periods and even the lean periods, you may use it only for the peaking purpose. So, you can easily see that a good balance between the hydroelectric power availability and the thermal power availability makes a power system rather sound.

Now, hydroelectric power is not available everywhere. For example, near Kharagpur, you are, you have more or less seen the place, our place and the places around it. Have you gone on a bicycle around? Yes, obviously. You have noticed that there is no place where you can really generate the hydroelectric power nearby, because the land is rather flat. In order to generate hydroelectric power, you need elevated water which is allowed to come down losing its potential energy and thereby you can generate. So, in flat land, you see, it is rather difficult, unless you have got a reasonably sized river that has already a flow and that flow can be utilized. We will come to those, those things later.

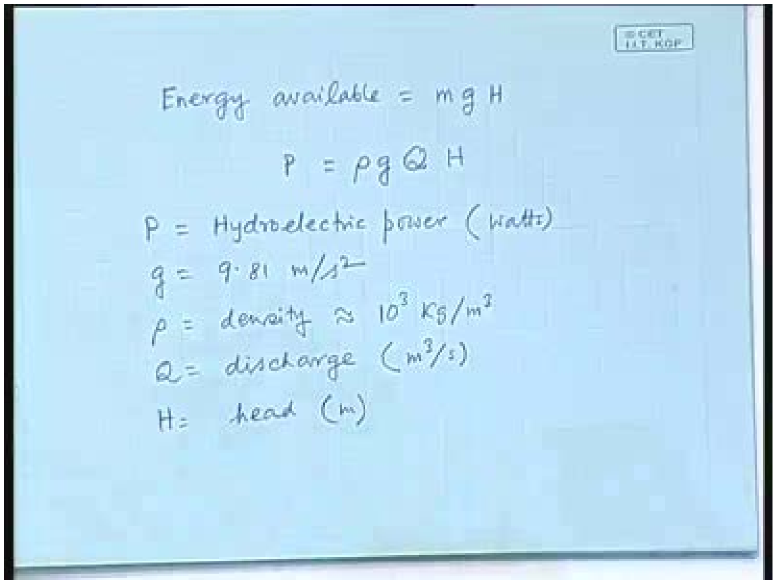
The point that I am trying to drive home is that hydroelectric power is not available everywhere. Coal fired power plants are also not economical everywhere. Why because, coal is available in certain spots and if you have to carry that coal across the country to another place, it becomes rather uneconomical. So, for the whole country, it is advantageous to have the coal fired power plants, where there is availability of number 1 - the coal, number 2, water. Also, it needs water, a lot it for the cooling purpose and the hydroelectric plants where the availability is there and naturally the whole system has to be interconnected, so that the places where excess hydroelectric power is produced, they can transport that power to the places where it is required and where the coal fired power plants are there, they can transport that power to the places where they are required. That is why the whole countries electric power network is interconnected. It is called the power grid.

The whole countries power system is interconnected. All the loads are there, all the machines, all the generators, all are interconnected, except for those isolated cases like the Andamans, where obviously you cannot have a connected power, there has to be a, you see, it is an island, therefore the power grid is also islanded. So, my point is that in order to run the whole system properly, you need to have hydroelectric power. So, the next topic that we will discuss is hydroelectric power.

Now, in hydroelectric power, what are you actually doing? You are actually using the energy that is available in stored water, in the form of its potential energy. Either you can use that potential energy directly, converting that potential energy directly into the kinetic energy of rotating shaft or you can first convert it into kinetic energy of the rushing water through a, say a nozzle, allow it to impinge on something, make it rotate thereby. So, you have the options of either using the potential energy directly or converting it first into kinetic energy of the water and then utilizing it directly and you can also have a mixture of the two and these categorize the different types of turbines that are used. But, essentially you need number 1 - a flow of water, a difference in level from where it is flowing to where it is going. That is called a head.

Remember, it is not this head. The head is the difference between the two levels from where it is coming and to where it is going. So, you need to have a level difference that is a head and you need to have a certain amount of water that is coming in and what is the total quantity of energy available? mgH.

(Refer Slide Time: 12:39)

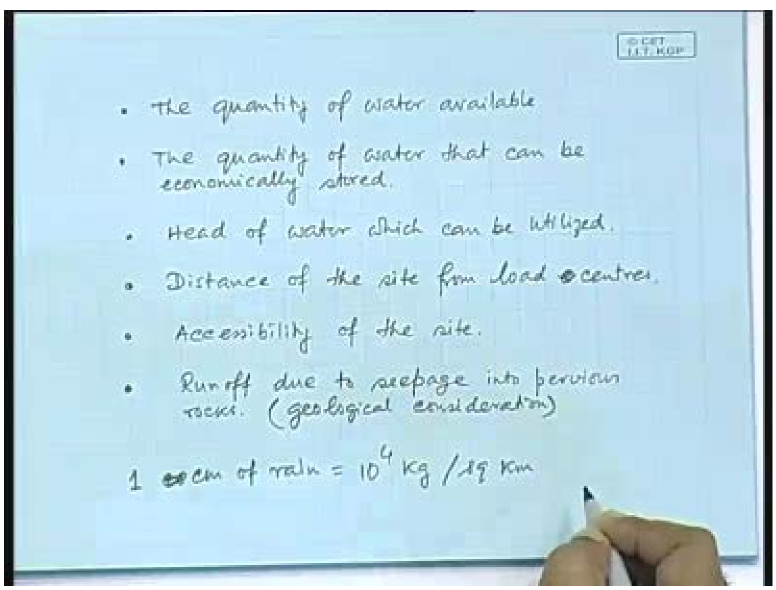


So, energy available … Now we are often more concerned with power rather than energy. So, power is the rate of mass and the water we generally measure in volume, not in kilograms, right. So, we will need to write it in the form of rho, g; rho is the density of water; g is the acceleration due to gravity and the Q, which is the discharge flow rate and H. Now, how are they expressed? So, this is P; power is this. Power is then, the hydroelectric in Watts. Normally we would write it in megawatts though; I am writing only the basic unit. g is …, obviously that is known. Rho is the density of water which is, you know that? Yes, all right and you have the Q is the discharge, it is m cube per second, right and you have the H, which is the head. So, if these are known you can find out the power, right.

Now, in deciding on whether a particular site is suitable for hydroelectric power generation or not and in order to decide whether, decide the, what will be the design criteria, I will come to that later, but you need to plan certain things. You see a river, a flow, some kind of an elevated place where you have some amount of energy available. It is not difficult to see that in order to have power generation, you have to have water and that water has to be all the time available. It is either a perennial kind of river or the water is available only during seasons and it has to be stored and then only it can be made use of at all times. So, obviously, there are certain things, you can easily see, that you will need to understand. Number 1: how much is the water available? What is the seasonal variation of the water availability? Depending on that, how much will be the storage capacity? Depending on that how much will be the capacity of water carriage? That means there has to be a tube designed and its diameter will depend on how much water you expect to flow which will again depend on the capacity of the turbine; you need to decide that. The amount that will not be able to flow here will have to be diverted through something called spillway. That means during the rainy season you cannot allow all the water to pass through the turbine. There will be excess water which has to be spilled out, so all these amounts need to be designed, right.

So, we will now take up this, this particular problem. If you suppose chance upon a place which looks like a feasible site, how do you make these decisions? This is the essentially engineering problem. So, what we will need to know essentially are a few things.

(Refer Slide Time: 17:22)



1: The quantity of water available, 2: the quantity of water that can be economically stored. A novice might claim that all the water that is coming will ….. No; that is not feasible. Obviously, the storage will depend on the availability of a particular type of site.

In general, the geographical location has to be such that in most sites, it is surrounded by some kind of a hilly terrain, so that you do not have to construct a dam. In one side you construct a dam, so that you enclose a certain amount of water. So, all these geographical considerations have to be taken into account in order to decide this. Then, we need to understand the head of water which can be utilized. Then, we need to understand the distance of the site from the load center, because many of the hydroelectric power sites are situated in a very far off place and in that case, the transport of the power from that place to the load center is also economical consideration. So, this needs to be understood and then the physical accessibility. If it is a very inaccessible place, but a very good site, then it may not be considered a very good site, because people have to be there, people have to be transported there. So, the availability of transport is also important consideration.

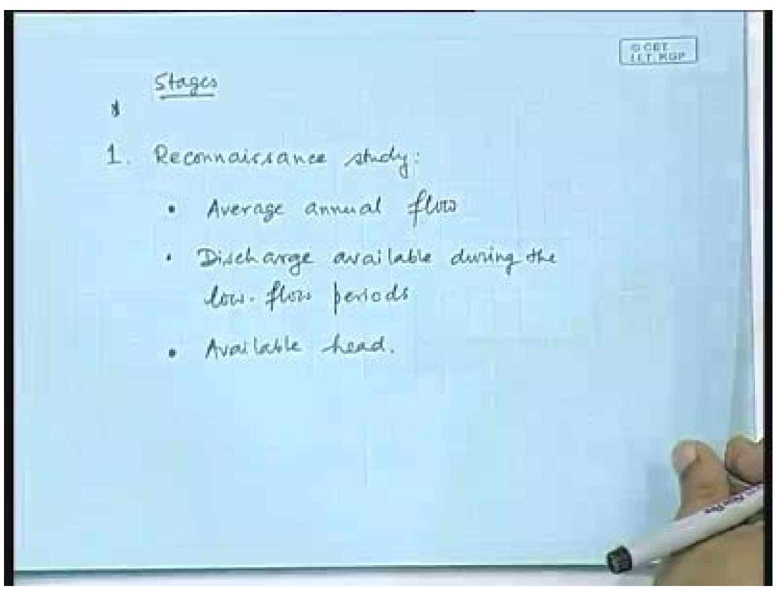
Just imagine the situation where you have a very good hydroelectric power plant, but people have to be transported by helicopter. Obviously, that will not be a very good consideration because of the expense in that. So, accessibility of the site will be another consideration. Then, you have to also consider the seepage. Imagine the situation where you have created a dam, but the rock underneath is very pervious, so that water does seep through which means that the amount of water that is stored will not be there, it will seep through and go away. So, such, this is a geographical, geological consideration. This has to be also considered.

So, these are the issues one needs to take into account while at least making the initial plan whether a particular site is feasible for that purpose or not. Also there is another factor. The region where you are planning to have that hydroelectric power plant that is after all using the water that has been received over a certain catchment area, so for every hydroelectric power plant or a for a every river there is a catchment area in which the rain coming in flows through and flows into that particular river, which you finally use for your hydroelectric power generation. So, you need to consider the catchment area also. The amount of catchment area and what is the rain characteristic, rainfall characteristic of that area.

For example, 1 cm of rain, how much water is that? You know that in every place, the meteorological department says that so much rainfall was there. In what unit is it expressed? Centimeters; so, how much water is that physically? Yeah, it has to be multiplied by the area. So, how does it translate? This will be about 10 to the power 4 kg per … So, this amount of water will be available, if there is a 1 centimeter of rain and in that rain, some amount of rain will go away as evaporation, some amount of rain will percolate through the soil, into the subsoil water, ground water. Only the amount, the rest, the rest of the amount will flow through the, found various channels into that river which will be available. So, you have to consider these aspects. How much of this amount will actually be available for power generation?

So, at the beginning of the study, suppose you are sent to a particular place where you are undertaking the study whether a particular site is feasible or not; there are a few stages of that study.

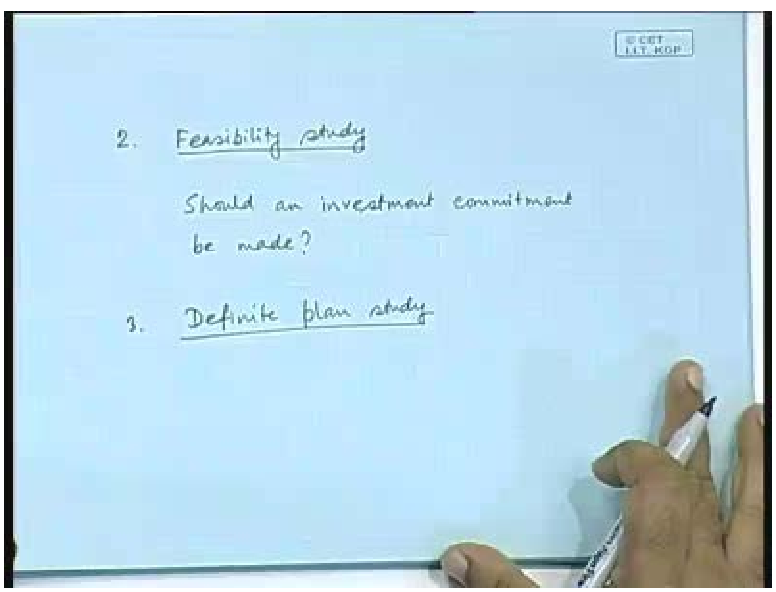
(Refer Slide Time: 23:58)



Number 1 - the stages - you see, a hydroelectric plant means a huge expenditure and one does not really make that expenditure unless you have a properly planned system and plan is naturally done in stages. First you have to decide whether you really go for a good planning or not. A planning means that also incurs expenditure, you have to do many measurements. So, the first stage is called the reconnaissance study, which is essentially a very preliminary estimate of whether a site is suitable or not. That means in order to actually undertake a feasibility study, in general, the feasibility study of a particular site is given to consultants which actually costs a lot. So, first one has to decide whether a feasibility study is necessary. At that stage, at this stage that is the absolutely preliminary stage, you go to a place and see that okay this may be a good place. This may be, will be dependent on a few numbers.

First you need to know the average annual flow. The discharge available during the low flow period that is more important, because we want a continuous power output. So, the amount of discharge that is available when there is no rain that is also an important factor that you need to consider and then the head. So, with this you can more or less make an estimate whether the site, whether you should really go for the site, but this is definitely not sufficient in order to make a plan for the actual installation. So, the next stage is something more detailed that is called the feasibility study.

(Refer Slide Time: 26:46)

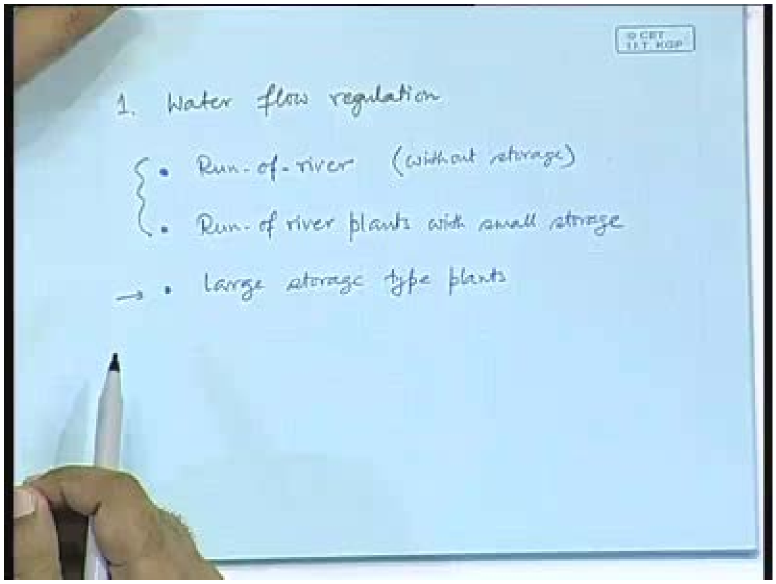


Stage 2 – I will, I will come to what exactly are the things necessary in order to make the feasibility study, but at this stage we essentially make the decision should an investment commitment be made, because this is a big investment. In every hydroelectric power plant it is basically the initial investment that is there. In a coal powered power plant, there is a continuous purchase of coal, in a hydroelectric power plant there is none. So, the initial investment is the main thing, main component. So, this decision has to be made. Now, this decision has to be dependent. In addition to the things that we needed at the stage of the reconnaissance study will be the variability of the rainfall or the availability of water during the year.

How that is used, I will come to that later, how actually that information is used, but in the feasibility study stage, you use that in order to make an estimate of supposing so much water is available, how much should be the actual size of the turbine? If it is small, then the investment is small, but then a small amount of water is used. If it is small, then the amount of the size of the dam that you need to create is also small. If it is large, then you need to create a larger dam, in order to have that water availability all through the year. So, at this stage we need to make the actual planning of how big should be the dam, how big should be the, how much should be the water retention capacity, how big should be the turbine, how big should be the penstock and all that and finally the third stage is the ….., so this is actually the complete detail planning of a system.

I will, I will come to the details little later. So, now let us come to the classification of various types of hydroelectric power plants. The classification is actually done from two angles. Number 1 - how big is the water retention capacity?

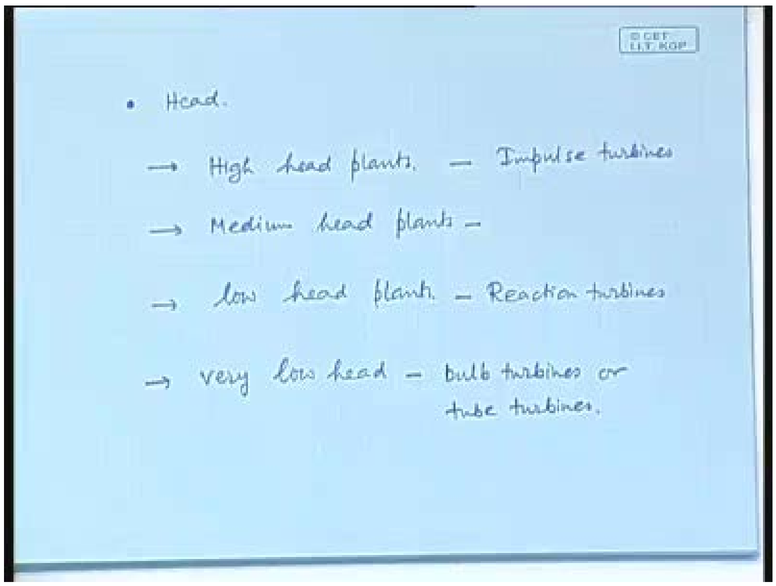
(Refer Slide Time: 30:08)



If you ask that question, number is water flow regulation. From this angle, there are three types of hydroelectric power plants, really. One are called the run-of-river power plants. This is … As the water comes you utilize it and do not store anything. Many of the micro hydel power plants that are situated in the Himalayas, for example, the ones that are now being installed in Assam, in Meghalaya, in Manipur, these places, these are of this type, really. You do not have much of storage capacity, when the water comes utilize it that is it. These have obviously less installation cost, but then obviously you do not have power generation some of the times, power generation varies. Then, run of river plants with small storage. Again, most of the hydroelectric plants that are situated in elevated locations you do not have scope of very large storage, so you have this kind.

Have you ever visited any of the hill stations? Most of you have, right. Have you seen any of these small hydroelectric power plants? Most of the hill stations have, because there are small rivulets, small amount of water available, even that is enough for generating power, because of the high head, right, very large head available and therefore, you can easily utilize that and the third type is the large, large storage type plants. For example, the ones that are in Maithon, Panchet these are of this type, right, in within West Bengal. Bhakra Nangal, the one that is now being at center of controversy, Sardar Sarovar basically the ones of Narmada, these things are the large storage type power plants. So, this is one kind of classification. The large power plants are generally of this type and these two are essentially the micro hydel, mini hydel or micro hydel class.

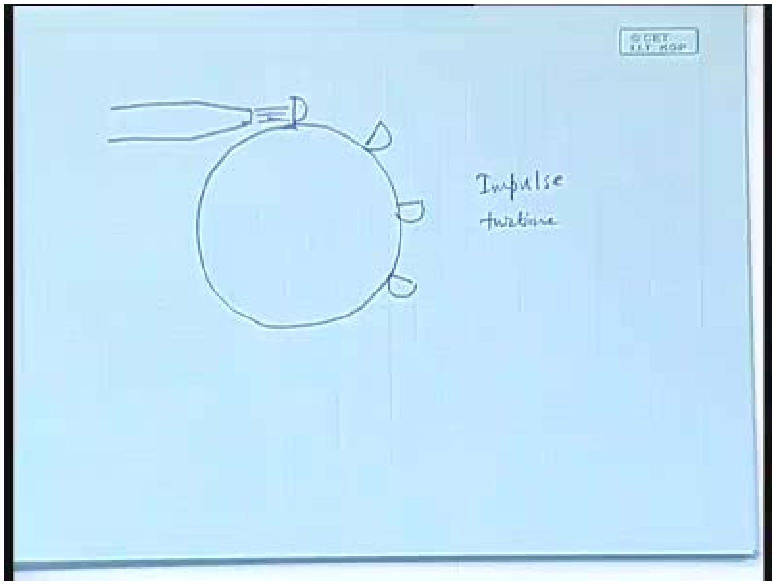
(Refer Slide Time: 33:25)



The second classification comes from the head. So, in this you have … These are generally in the upper reaches or regions? of the Himalayas, high head plants and you have the … plants and the ….Why is this classification needed? Because, in the high head plants normally you will have them in the upper reaches of the Himalayas or the hill terrains. You have a large head available and in such cases, it becomes advantageous to first convert that into the waters kinetic energy and utilize that kinetic energy. In medium, in low head plants, you cannot really convert into kinetic energy, right. If you put it in the nozzle, it will only fall, because low head, the pressure is low. So, in that case, you have to directly utilize the pressure without converting into kinetic energy.

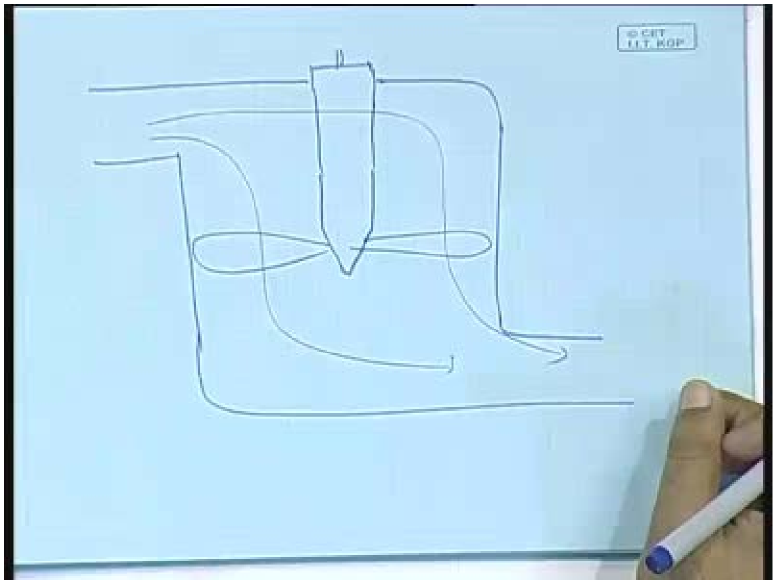
So, they, these three types require different types of turbines. That is why you have this different classification. Mostly these things will have a class of turbines that are called impulse turbines. So, here you have impulse turbines, where the water is first allowed to pass from a high head to the normal pressure, the atmospheric pressure through a nozzle and that is allowed to impinge on some, you know, cup like shapes that is placed on the surface of the turbine and the turbine rotates. These are the standard impulse turbines. These are, they have to use the reaction of the pressure directly without converting into kinetic energy. These are called the reaction turbines and in the medium head, you have certain special class of turbines that are meant for medium head, so called Francis turbines. But the point is that, if there are very low head power plants, then you have also the, then you have special class of turbines which I will deal with later when we actually deal with the subject of tidal power generation, which have very low head. Then, these are called the bulb turbines or tube turbines, but at this stage it will make sense to give you some idea about the structure.

(Refer Slide Time: 36:39)



For example, the impulse turbines, we will have the structure something like this. You have got a circular shape and you have got those cup like things and there is a nozzle which allows the water to come out at high speed and impinging on the wheel, on the cups which makes it rotate. So, this is the standard structure of the impulse turbine. The standard structure of the reaction turbine is something like a fan.

(Refer Slide Time: 37:35)

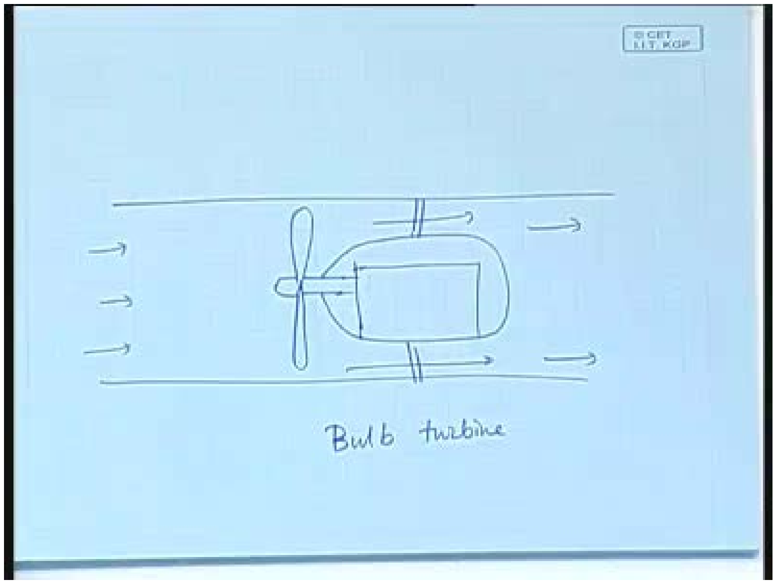


For example, you can imagine it is something like this and you have the shaft of the generator there. I am, I am drawing very simplified diagram just to give you an idea. In any book on the turbines, you will get a better picture of it, but presently I am trying to give you the essential picture. It is like a fan. So, as the water comes and flows, the fan rotates and therefore, you can see that the fan is always in touch with the water and you are not using the kinetic energy of water, really. You are only using the pressure of the water, flow of the water to make the turbine rotate.

So, this is generally used for the low head and for the medium head, there are a little bit of complicated construction, which is not subject matter of this course, because most of you will learn such structures in detail in mechanical courses. But, you see, here also you need this amount of head in order allow the water to pass through, because it is placed vertically and in very low head power plants which are placed almost in plain lands, there the amount of head available is only a meter or two. In those cases, obviously, you cannot have even this much of a height difference between the two sites.

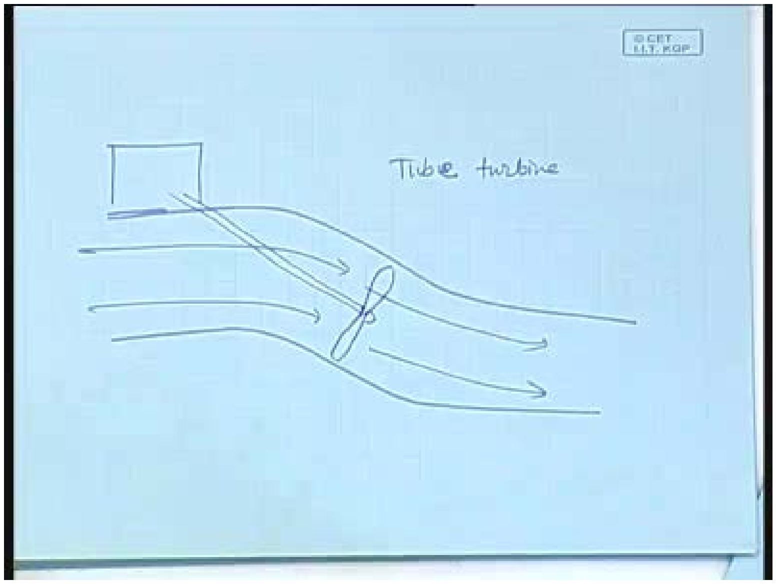
In those cases, you have as we called the bulb or tube turbines, where, here the problem is that the thing is placed in water. But, it has to be connected to the shaft which is placed, has to be placed outside the water, because it has to be, it has to house the generator; it has to be connected to the generator. So, the generator has to be placed outside the water. In this, this particular design, it is vertically aligned, so that the generator is placed up here. But, as I told you that if the head is too low, then you cannot have even that. In that case what you do?

(Refer Slide Time: 40:10)



You have a straight flow channel and you can have say, water is flowing this way. You can have the propeller kind structure like this, but then where to place the generator? Generator has to be placed in the same shaft which will be inside the water. So, one creates a bulb like structure in which the generator is placed. It is, this is completely water tight, so that water does not go in. So, that is why this is called the bulb turbine. For very low head power plants, you have turbines of this kind of shape. These are called the bulb turbines.

(Refer Slide Time: 41:34)



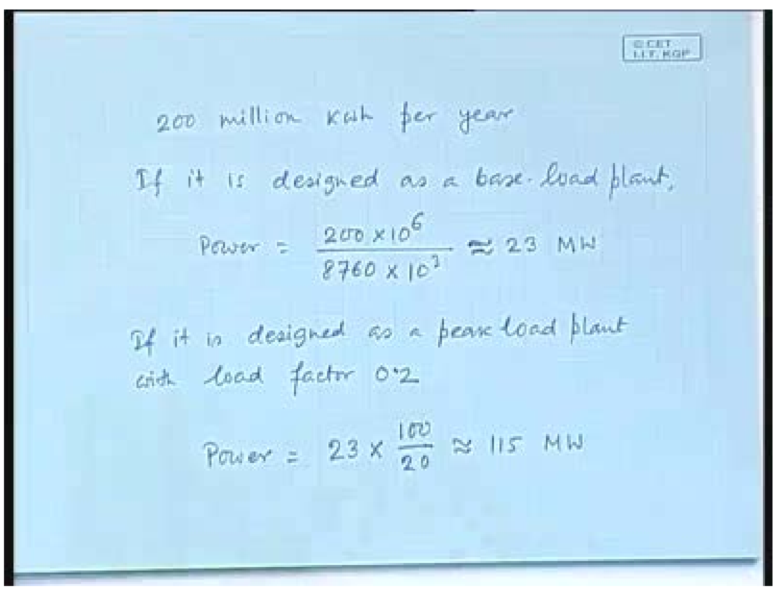
Tube turbines are the ones where you have the, you allow the water to flow through a channel placed like this. Place the turbine here and you make a shaft that goes up and place the generator here. There is another way to have it. So, this will be structure of the tube turbine, clear. That is why you had these three classifications of, these four classifications of the power plants depending on the head, because you need different types of turbines for this purpose. Have you copied the tube turbine? Now, as we have seen, the hydroelectric power can be used both as a base load plant as well as a peak load plant. So, you might plan it to be used as a base load plant, because you have got huge water availability, I want to use all the water, so that it is used as base load plant. You may also use it as a peak load plant, right.

What would be the difference? Suppose, in a particular place, you have certain quantity of water available all through the year and you have planned it to be a base load plant and in another case, you have planned it to be a peak load plant. What will be essential difference in the planning? It is that, in case of the base load plant, it will be running all the time. In case of the peak load plant, it will be running only for say, 20% of the day. Now, this is expressed in a quantity called the load factor. Load factor means load factor power plant means in the numerator, it is a fraction in which you have in the numerator, the amount of energy that is actually generated. In the denominator you have the amount of energy that could have been generated if it ran at full load for the whole time. Have you understood the …

So, in case of a base load plant, what will be the load factor? 100; 100 by 1, 100%. In case of a peak load plant it will be something like 20%. So, the load factor will be different. Often you will find, you will find referred, the load factor referred in literature on power plants like, this power plant ran at something like 0.6 load factor. What does it mean? It means that even though it could have produced so much power, it did not, because of certain reasons, either outage or some leakage or some, something due to which its actual total energy production was less. So, that was the load factor.

Now, suppose let us do a simple problem.

(Refer Slide Time: 45:16)

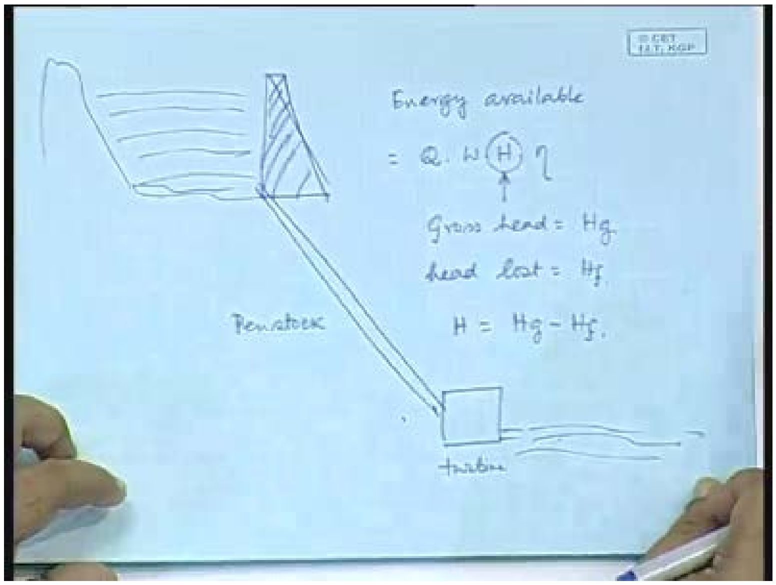


Suppose there is a dam that has a sufficient water capacity, water retention capacity, so that it can produce 200 million kilowatt hour per year. Suppose you have got a dam that retains sufficient amount of water, so that this amount of energy can be produced per year. In one case you are designing a base load plant; in another case you are designing a peak load plant. Now, if it is designed as the base load plant, what will be the power? This is the energy. What will be the power? So, if it is …, then the power, it will be 200 million into 10 to the power 6 divided by the number of hours per year which is, you know how much it is?

8760 is the number of years per and this will be expressed in kilowatt. You like to express in megawatts, so divided by … How much will it be? Because, you see, here the load factor is 1. So, this is just the total amount of energy divided the time. How much is this, can you calculate? It will approximately come to 23 megawatts. It will approximately come to 23 megawatts. Now, if …, check that, yeah, 22.8 something, right. As a peak load plant with load factor 0.2, then how you will calculate that, power? No, not; it will not be into 0.2. Yes, so this will now be, this will now be into 5, right. How? The same thing 23; now, this will have to be multiplied by 100 by 20. So, this will approximately be how much? So, you see, if you plan it as a peak load plant, it has, it has to have much more power capacity, which means the turbine should be larger, which means the penstock should be more, will have more diameter. So, all this will be necessary.

That means a peak load plant, if you plan it as a peak load plant, it will have larger investment. It will require a larger investment, but still most hydroelectric plants other than the areas where it is huge amount of water is available, other than those areas, things are designed as peak load plants. Why? Because, the advantage is, during the lean period you used it as a peak load plant, all right, but the same thing during the rainy season can be used as a base load plant, right; the same thing. You have already installed it; you have already installed it and during the rainy season huge amount of rain is available. So, the same thing you run as a base load plant, so that the amount of coal that you use will be less overall. That is why even though the power produced, the power necessary, power capacity necessary for a peak load plant is so much larger, still we use most of the hydroelectric plants as peak load plants. That means these are run only during a part of the day when the peak becomes, the load becomes, goes to a peak only at that time these hydroelectric plants are run. But in the rainy season, they run all the time. Is that clear? That is how most of the power plants run.

(Refer Slide Time: 50:38)



One more thing before we stop today that is the structure of the plant then would be that there are some hills and you construct a dam, so that water is stored here. Then, you have a tube running through, which is called penstock, the water that goes through and then, at some height below, you have got the turbine and the discharged water actually goes through the river. These are the essential components. You can understand the basic things from this. Now, you see that there are various types of, various ways of creating the dam. In very crude micro hydel plants, you can, this can even be simply some boulders placed with clay, but in most places you have got concrete structures. In any case, the point is that the amount of energy available, so, here is the turbine and this is the penstock.

The energy available is, as we have seen, it is Q times the unit weight of water which was …., so let us call it W times, we said the H, right, we had then missed out a particular issue that is the efficiency of the system, so the efficiency has to be multiplied. That is actually the energy available, but there is point here, here. Now, the difference in head from here to here is the available head. So, let us call it the gross head, let us call this Hg. But then, because water goes through this penstock, some amount of head is lost there, right, in the sense that after all there is some loss there and that loss, there is a loss in getting into the penstock, there is a loss in going through the penstock, there is a loss in getting out of the penstock and then in the nozzle. So, all these losses can be taken together as somewhat some kind of loss of head. So, the head lost let us call it Hf. Then this H is actually Hg minus Hf. So, the actual difference does not really translate into power. It will be slightly less and that less is the collection of the losses in all the systems, right. So, when you calculate this, we will have to take that into account also, clear. So, that is all for today. Let us continue with this tomorrow.