Energy Conservation and Waste Heat Recovery
Prof. Anandaroop Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 52
Energy Storage System – II

Welcome back and let us continue with the next lecture on Energy Conservation and Waste Heat Recovery. If you recall in the last class we started with energy storage and as part of energy storage techniques we started with mechanical energy storage. We had an introduction to the first type of mechanical energy storage which is pumped hydro storage.

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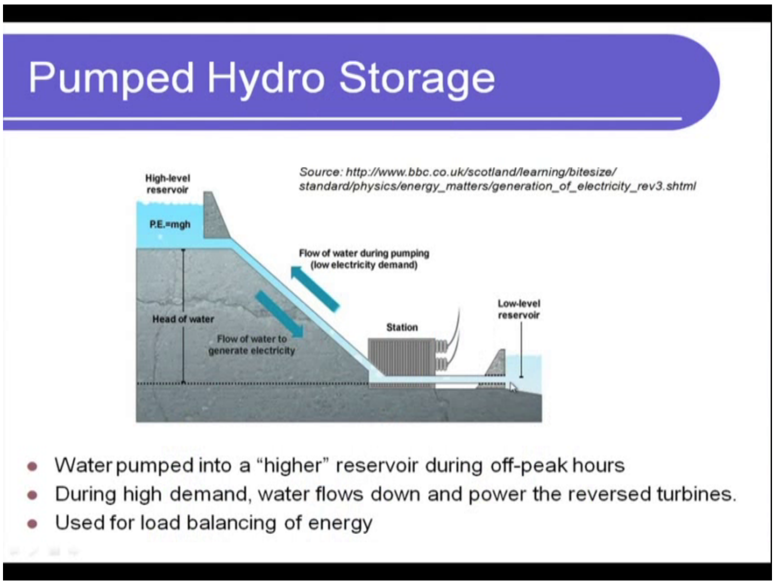

We looked at this schematic as we saw that pumped hydro storage what happens is we have two reservoirs at elevated levels. So, one is at the lower level if we and the other reservoir is at a higher level may be at the top of a cliff. So, what happens is during off peak hours let us say during night time when the demand is low and the and the supply is higher than what I require then the additional electricity which is generated is used to run a pump which is going to pump the liquid up or in this case water up from the lower reservoir to the upper reservoir.

So, by this means what happens? The water gains potential energy. So, this is the energy that is released let us say during the day time when the load is, when the load is higher than supply or the demand is higher than supply then this water from the upper reservoir flows down and hits the turbine as we recall that type of turbine is the Francis type of turbine that is used that can be that can function both as a pump for pumping it up as well as a turbine. So, that when the water comes down and hits the Francis turbine and makes it rotate we get additional electricity. So, this is an example of this in a nutshell is how the pumped hydro storage works.

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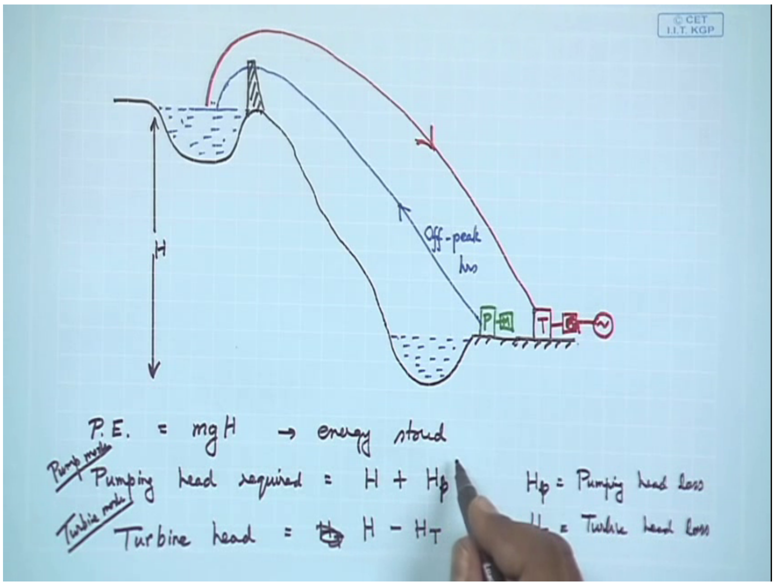

So, now what happens this is also a picture that we drew last time as to how a pumped hydro storage the schematic. So, let us do some analysis now. So, if I say that the height here the head that the water attains is H. So, therefore, the potential energy that we get or that we that is stored is mg H. So, this is the energy stored clear.

However what is the pumping head required, this is going to be H plus I would say H l where H l are the pumping or let me say H p is a pumping head loss clear. So, this is when you are in the pump mode. In the turbine mode what happens? The turbine will also have some loss there is nothing like a perfectly efficient or 100 percent efficient turbine. So, turbine head will be H T is also going or per prevent head is also going to be H minus H T all right and what is H T is a turbine head loss. So, therefore, if you look at it what is the turnaround efficiency the turnaround efficiency is going to be mg H minus H T over mg H plus H p, clear.

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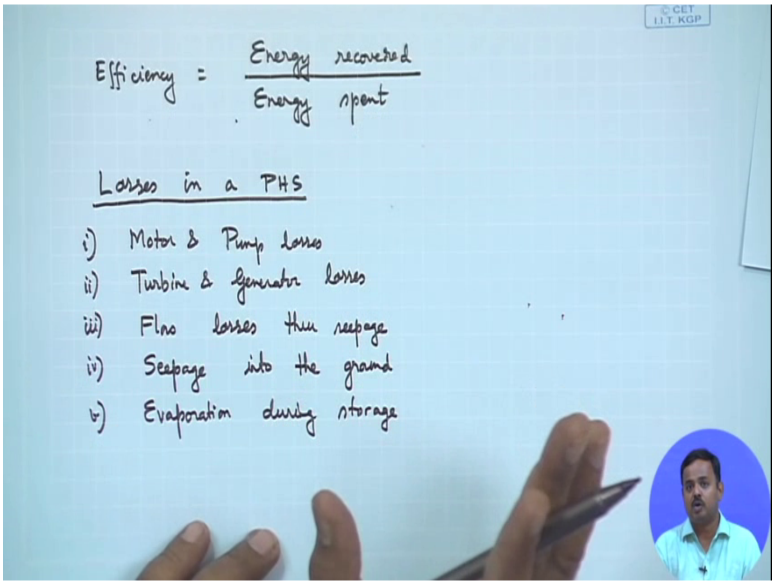

Now keep in mind; however, in this case or for example, for that matter let me just write it down efficiency will be energy recovered over energy spent and none of these are necessarily equal to energy stored. Energy recovered will normally be less than energy stored and energy spent will normally be more than energy stored right all right.

So, now let us say what is the amount of work energy that we can store is huge. So, the quantity of energy quantities of energy that we can store in pumped hydro systems is very large 1000 megawatts or even larger that is a lot of; that is a lot of power that is the reading. And this run depending on where you are storing it can run for several hours. So, we are talking about 1000s of megawatts, 1000s of megawatt hours, several thousand megawatt hours that is a lot of that is a lot of energy right. So, pumped hydro actually is the most common and the most popular type of mechanical energy storage across the world all right. So, we talked about losses which are we talked about pump and motor losses pump losses and so on.

So, let us talk about other losses in a pumped hydro system losses in a PH storage system, all right. So, the first one are the motor and pump losses and the second one we already goes hand in hand turbine and generator losses. Now, these are definitely the most intuitive and we know that. What else? There can be flow losses because remember it is flowing through some channels, its I mean the way I showed the schematic where two lines, but if you actually see here in this picture actually there are some I mean there are these flow channels that go up and then this may be even underground also or so therefore, the flow paths there can be some seepage all right. So, flow losses I would say let us say through seepage, clear.

There can be seepage into the ground especially from the top reservoir clear from the top reservoir there can be seepage into the ground because that is after it is pumped up it is staying there. So, something can seep in and there can be variation also during storage and so on.

So, these are some of the sources of losses and we need to keep this in mind and therefore, the efficiencies are never going to be 100 percent, but these are typically pretty high I am talking about when I say high I am talking about 75-80 percent, 80 percent probably is a good ballpark number for most pumped hydros storage plants clear. So, this is a very popular, probably the most popular type of mechanical energy storage that we have.

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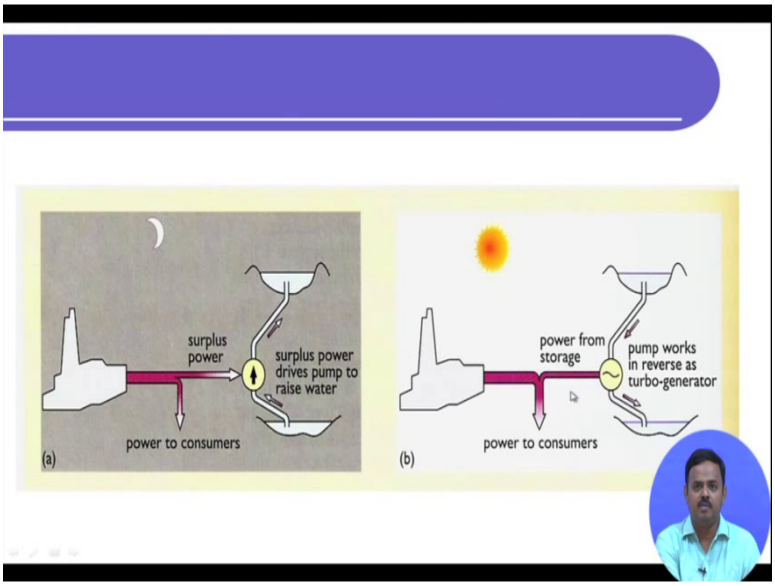

So, let us look at some of these, this schematic as you can see is what I am trying to show this is during the night time. So, what is generated from the power plant? Only part of it goes to the consumer and the rest of it is used for pumping the water up. And during day time of course, the entire supply from the power plant goes to the customer plus whatever is recovered from the stored energy also goes to the customer because this is when the peak load is and the peak load the demand is higher than the supply all right.

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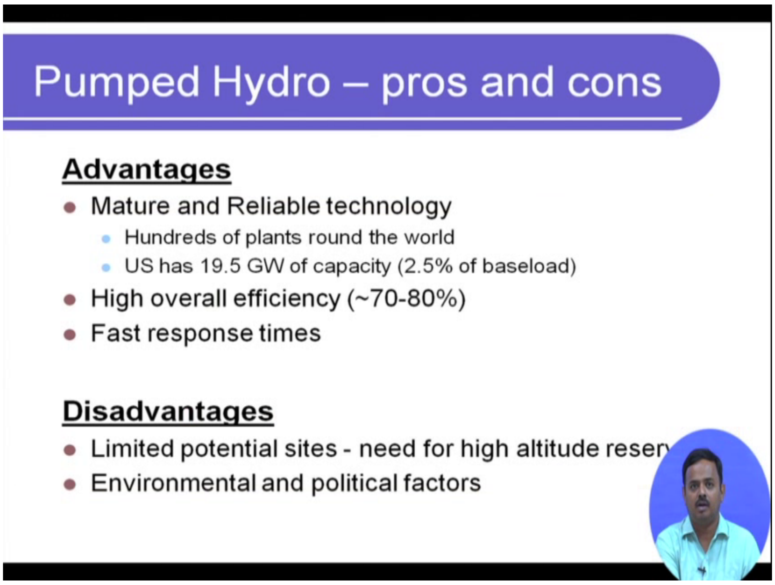

So, these are some pros and cons we have already discussed some of them. So, this is a mature and reliable technology there are hundreds of plants around the world, if you look at globally if you if you just search on Google you will see there are lots of installations across the world. So, this is definitely very popular. So, USA has almost 19.5 gigawatts of capacity that is a lot, 2.5 percent of base load is a lot. The high overall efficiency is 70 to 80 percent is it is quite fast because this is hydro and you can also you can control the valve depending on the demand you can control the amount of flow rate that you want to release right clear, all right.

What are the disadvantages? The potential sides are limited I mean because you need an high altitude area. So, you need a high altitude reservoir. So, you can only have it where you have hills. So, you cannot just for example, in the West Bengal plane in the Gangetic plain I cannot have a pumped hydro storage plant right.

Environmental and political factors are also there because you know just anyway I mean just installation of a power plant if you have to dig a reservoir and there also in this, this has some environmental impact. So, these also have to be kept in mind.

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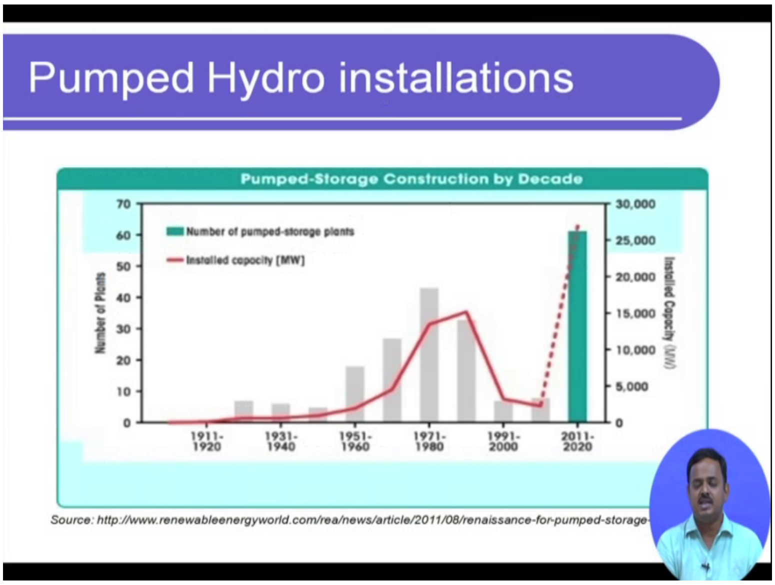

So, these are some pumped hydro installations across the world and you see how the popularity has grown from around 1911 in the decade of 1911 to 1920 there was none. Probably there was one I do not know, but after that it has slowly crept up and at around the 1950s, around 60s and 70s it is very high. Then slowly it is coming down because now you know I mean that is I mean there are only an hour limited as I said a limited number of sites where you can install them.

So, therefore, the naturally were whatever was available was probably exhausted by here. So, it saw a dip and again it is expected to raise because slowly especially now in the later after in this new century what we have we have seen is we have become more and more conscious about the reduced availability of fossil fuel. So, therefore, any we have become more conscious we have to become extra conscious about energy storage about having more efficient and newer plants about having new and renewable energy sources and so on. So, as a result there is again a renewed vigor on such energy storage on the and the focus has again shifted back to energy conservation to energy storage and therefore, several plants are due for completion in this decade.

So, this is a projected figure, we may not be hitting this 60 mark over here, but we will we will have several I mean a significant number of new installations in this decade that we are in.

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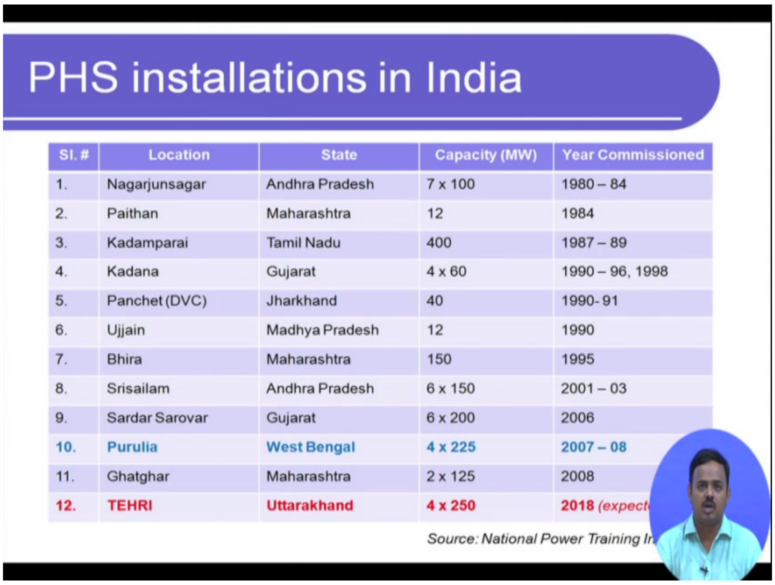

Sl. #	Location	State	Capacity (MW)	Year Commissioned
1.	Nagarjunsagar	Andhra Pradesh	7 x 100	1980 – 84
2.	Paithan	Maharashtra	12	1984
3.	Kadamparai	Tamil Nadu	400	1987 – 89
4.	Kadana	Gujarat	4 x 60	1990 – 96, 1998
5.	Panchet (DVC)	Jharkhand	40	1990- 91
6.	Ujjain	Madhya Pradesh	12	1990
7.	Bhira	Maharashtra	150	1995
8.	Srisailam	Andhra Pradesh	6 x 150	2001 – 03
9.	Sardar Sarovar	Gujarat	6 x 200	2006
10.	Purulia	West Bengal	4 x 225	2007 – 08
11.	Ghatghar	Maharashtra	2 x 125	2008
12.	TEHRI	Uttarakhand	4 x 250	2018 (expect

If we talk about PHS installations in India again of course, it is not like in the gigawatts range yet, but if you look at it in megawatts is not bad. So, the first one was in Andhra Pradesh it was in Nagarjuna Sagar in Andhra Pradesh and the capacity was 1700 megawatts quite a lot and this was done in the 1980 to 84. Also you will see that in India of course, recently there has been a change, but there has been this planning commissions every 5 years and that is when most of these installations are sanctioned. So, all these installations if you look at it look at the periods they coincide with some planning commission, right.

So, next one as we seen that the next one was python in 1984 and as you keep growing this is you can see that all these installations have happened. In West Bengal there is one which is which is a pretty high power this is the 900 megawatts it was it is in Purulia and it was completed in 2008 all right. So, you also have, have it here, but otherwise what you will see is there is a large there is a bigger concentration in southern and western India. However, that being said the one that is right now it is expected the one that is under construction is expected to be completed next year is in Thehari, Theohari Dam in Uttarkand the pumped hydro storage installation is in progress the hydroelectric plant is already there and there it is going to be the installation is going to be 1000 megawatts which is very high.

So, overall I have seen in India also this is quite popular there are 11 installed plants already and there is the 12th one that is coming up and there be maybe a few more over the next few years.

So, pumped hydro system is quite is very popular and a viable and proven reliable mature technology.

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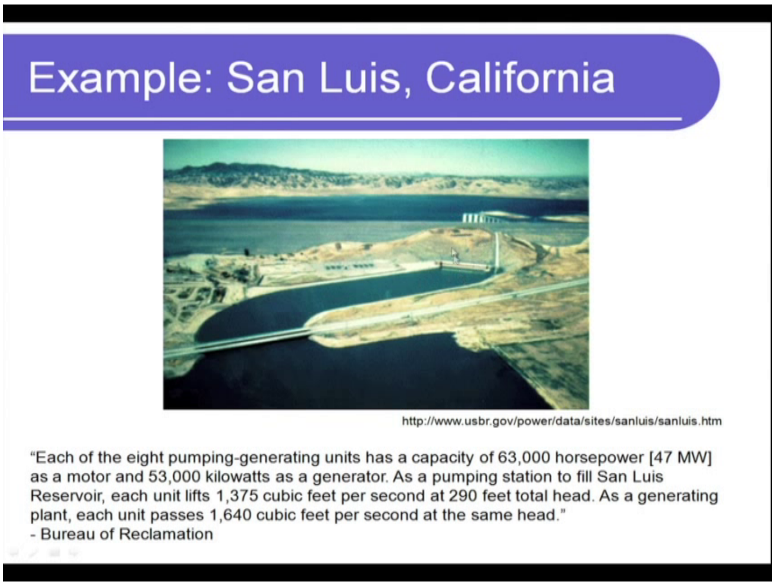

So, I am going to end this lecture by showing you a few pictures of pumped hydro installations across the world.

This is in San Louis California and here you can see that the two reservoirs you can directly see and this is where you are generating the, you getting the you are pumping the water up and gathering the potential energy which we are harnessing later, all right.

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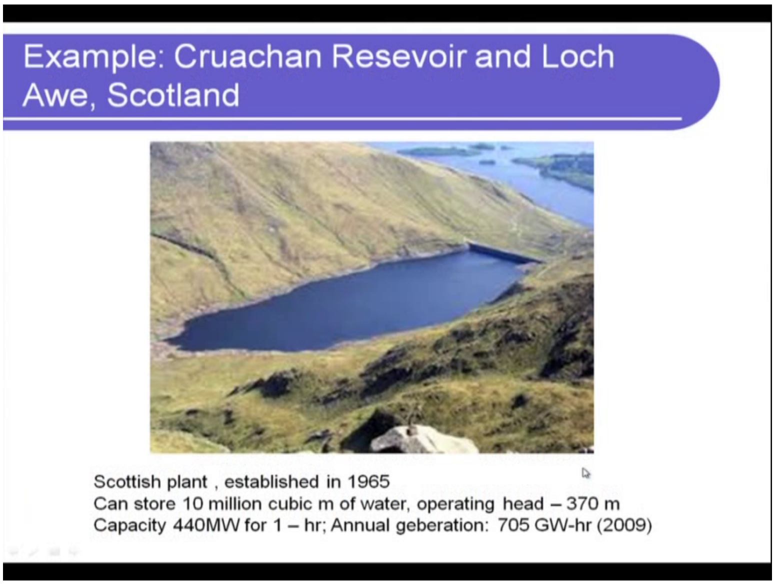

Next one is in Scotland Cruachan reservoir and Loch Awe, Loch in Scottish is actually lake and as you it established in 1965 it can store ten million cubic meters of water after operating ahead of 370 meters, almost 1000 feet or even more than that. Capacity is 440 megawatts for a 1 hour the annual generation is 700 watt 705 gigawatts hour this is again it varies from annual generation will vary from 1 year to another in 2009 it was 705.

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So, and the third one is in Germany in I even do not know if I can pronounce it correctly Koepchenwerk in Germany on the Ruhr river and here also you see the two reservoirs very nice, this is the lower reservoir this is the reservoir at the higher altitude.

So, that kind of brings us to the end of our discussion on pumped hydro storage and this is as I said it is a very popular and mature tech really reliable technology for energy storage a mechanical energy storage where water over hydro or whatever what energy stored in the as potential energy and release later for generation during peak hours.

So, with that what we will do now is we will move on to the next form of mechanical energy storage which is known as compressed air energy storage.

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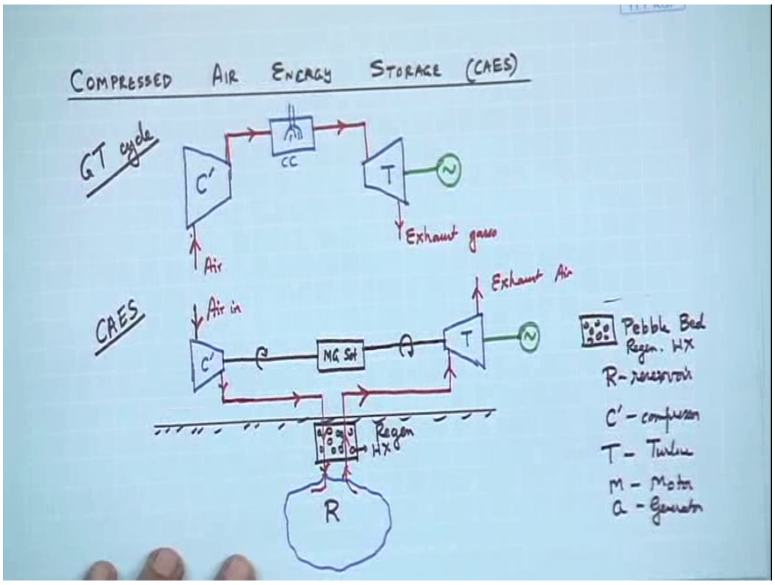

So, compressed air energy storage or CAES, what do I mean by this? So, as the name suggests over here look in pumped hydro the energy was stored in the form of potential energy in compressed air energy storage the energy stored is in the form of pressure energy in the form of pressure. So, what is it?

So, let us look at compressed air energy storage or maybe I should first just give you background of probably all of you know, but it is it does not harm to just recap something for gas turbines. So, in gas turbine what happens in the gas turbine cycle and you would have studied in this course itself. The first thing that we have is a compressor into which air is pumped or a or whatever air enters and it is compressed and when it comes up out it comes out at a higher pressure and because of the compression the temperature also is higher has to be right.

So, then what happens is the next one that it goes in a in a gas turbine cycle is the combustion chamber where liquid fuel comes in and the air and fuel is combusted and what leaves is the combustion gases at high pressure and temperature the temperature even further raises and it comes out in this form and which is next fed into a turbine, right. And this turbine rotates as a result and it generates electricity it is connected to a generator and it generates electricity and what comes over here are, the exhaust gases which is that a sufficiently high temperature still. So, this is air this gets compressed and so on, clear.

Now, in energy storage plant what happens is it is something similar what happens is in the sense that we still have a compressor which is used to compress air. So, let us draw that again. So, this is I would say this was a gas turbine cycle. So, in a gas turbine union in an aviation engine for example, in the air aircraft engines this exhaust gas is let go in the atmosphere and that creates the thrust as a result of which mine the airplane moves.

However, in the industrial turbines used in power plants especially if you are talking about combined cycle these exhaust gases actually form the source of heat for the bottoming cycle which you have studied before and that bottoming cycle can be a steam turbine Rankine cycle or if you are talking about even lower temperature, it can be an organic Rankine cycle, it can be a Kalani cycle and so on, all right.

So, in compressed air energy storage what happens is you have a compressor and here the air comes in sorry over here and it is compressed and comes out in the compressed manner but next what happens is then this one is not fed to a combustion chamber like in gas turbine instead what happens is I am going to draw something and then explain to you let us say this is my ground. So, what happens is this compressed air comes in and is stored in a large reservoir. Let me draw that over here, it is stored in a large volume an empty volume where this compressed air goes and is stored.

Next what happens is. So, what is this air at? This air is going to be because it has been compressed his volume is low lesser than what at least it was over here and it is at a higher temperature. Later on ideally what will happen is this compressed air is going to be released and when it is released where will it go it is going to go to a turbine which will be rotated it is a gas turbine more specifically air turbine and we will use it to generate electricity. So, this is air in, this is exhaust air all right and as before this is where I am going to generate the electricity all right.

And let us draw a few more other appendages I am going to have a motor generator set and which is going to have a shaft which is going to connect these two clear. So, this is how a compressed air energy storage works. Again to repeat what happens is you take air and you compress it in a compressor. So, that it is now at high pressure therefore, low volume and at high temperature which is now stored in a reservoir. So, let me name that as R and say that R is reservoir, C prime is compressor, T is turbine, M is motor, G is generator. So, all this good stuff all right.

Now, typically what happens is; however, there is a little variation to this there are several variations to this, but even in the regular case what happens is the air that comes after compression is at a high temperature. Now, if you put it in the reservoir what will happen or rather before that if you put it in a reservoir that h it will lose heat definitely, but if I can bring down the temperature at the high pressure itself then what happens the volume of the compressed air is going to shrink even further all right.

So, again I repeat what I am trying to say is the compressed air that is coming out of the compressor is already has been compressed. So, it is at it occupies lesser volume, but it is at a high temperature if I can cool down while keeping the pressure the same then what will happen my volume will be even lower because I have brought down the temperature. So, the volume required to store that air will be even lesser or in other words for a given volume of reservoir I can store more mass of air either way whichever way you look at it all right.

However, when it comes out of the reservoir and goes to the turbine I would like it to be at a high temperature because if that turbine inlet temperature is low the amount of work that I am going to get out of it is also going to be lower. So, what do we do? So, the way it is done is I have a heat exchanger here. So, I will have a heat exchanger over here. So, what kind of heat exchanger is the next question? So, before that, if there is a heat exchanger what happens this fluid the compressed air coming out of the compressor is going to lose heat and the air that is going to the turbine is going to gain that heat, but here there is a problem. The problem is these two are not happening at the same time these two are not flowing at the same time right. The compressed air is getting into the reservoir during off peak hours when I am storing energy whereas, the flow to the turbine from the reservoir is happening during peak hours they are not at the same time actually that is that is the whole principle of energy storage you store it at some time for a certain interval of time so that you can use it later. So, then what do we do?

So, I think the answer you already know because you have studied professor from P K Das lecture from Professor Das lecture you have studied heat exchangers and the two types recuperator and regenerator. So, therefore, I cannot use a recuperated in such a situation I have to use a regenerative heat exchanger. So, therefore, a regenerative heat exchanger.

So, what is the regenerative heat exchanger? It can be like a pebble bed. So, let me write that here pebble bed regenerative heat exchanger. So, what is this? This is a volume consisting of some pebbles or stones. So, these are materials that have high density and high specific heat typically that is what thermal energy storage that is how we do. So, what happens is when the heated air from the compressor is flowing through it, it will lose heat to this pebbles which is going to store it and, what comes into here with what comes in to the reservoir is high pressure low temperature.

And similarly when it is released it is made to flow through the same reservoir or through the same regenerative heat exchanger sorry where it picks up the heat from these pebbles this pebbles are good candidates for energy storage right. So, it picks up the heat from this pebbles and goes through. Pebbles is just one example we will see more examples later pebble we will list down other types of heat exchangers that can be used for this purpose. So, overall it is clear is it clear, how it works?

So, I will just summarize it over the next one minute and before we end this lecture. I have air coming in let us say room temperature low pressure, compressed to high temperature high pressure. And then and so therefore its volume is low it is further cooled down by passing it through a regenerative heat exchanger where it loses heat to let us say a packed bed of pebbles and then therefore, what comes out of the heat exchanger is air at high pressure, but low temperature and then it is stored in this reservoir R. Then what happens? During the peak hours the same air goes out and is made to flow through the regenerative heat exchanger, but it picks up the heat from that pack bed of pebbles, so now it is still at high pressure high temperature and it enters the air turbine gas turbine where it makes the gas turbine rotate, it generates electricity and exhaust air at definitely lower temperature and lower pressure then the inlet comes out, clear, all right.

So, this is the compressor mode during off peak hours, this is the turbine mode during peak hours. So, the extra energy that I have because my demand is low during off peak hours is used to run this motor generator set especially the motor which runs the compressor and during peak hours what I get from this turbine is in addition to what my power plant is generating. So, this in a nutshell is compressed air energy storage.

So, in the next lecture what we will do is again like before we are going to do a bit of analysis on this how do we solve for problems or how do we calculate the performance, the volume, the pressure etcetera for a compressed air energy storage and then we will look at some again some examples of installations across the world, all right.

Thank you very much and we will continue on this topic in the next lecture.