**Energy Resources and Technology**
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**Lecture - 37**
**Energy Storage**

There are still some topics to be covered in this course and the most important being the problem of energy storage.

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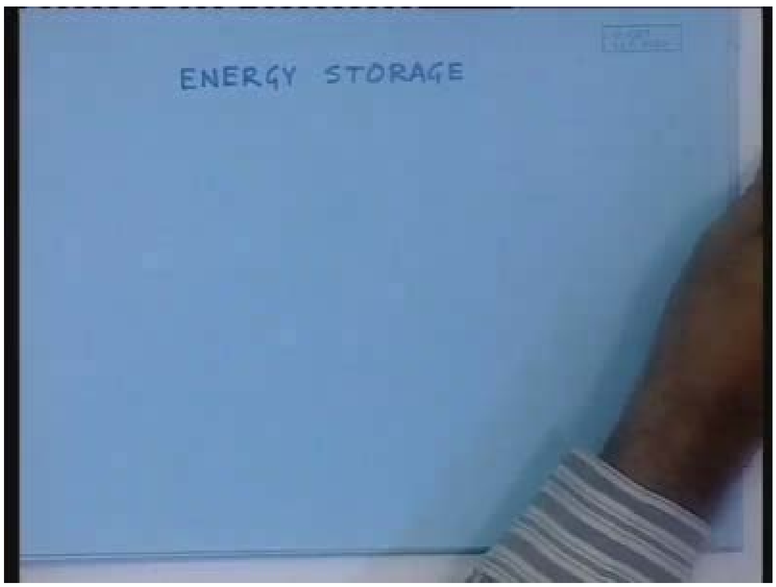


As you have seen, most of the non-conventional energy resources are intermittent in nature. For wind, whenever there is a great amount of wind flow, you have a great amount of generation. But when there is none, you have none. So, it is for solar energy, so it is for tidal energy, everything, most of these things are intermittent and there is also the problem of the load on a power system being variable over the day and I have already told you that that produces a lot of problem, because most of the standard power plants cannot vary their generation or cannot start up, cannot stop, very fast. So, that produces some problem.

Most of the conventional thermal power plants would be very happy if they could run at constant power output all through the day. Very happy means their production will run smoothly, their life will be higher and at the same time it is also true that, if a power plant has to produce say 20% of its rated capacity, then the efficiency goes down as a result of which even though the power output is 20% only of the rated capacity, the core input is not 20%, it is more. So, one wants to run the power plant as far as possible, at a constant load as far as possible. But nevertheless, meeting the peak demand then becomes a problem.

There are a few ways people have thought of, but essentially the most convenient remedy to the problem should be if we could somehow store the energy. Now, electricity cannot be stored, right. Electricity is produced and immediately it has to be consumed. Normally, there is no storage of electricity. But, if we can have some storage of electricity, then we can have at least a partial solution to this problem. That is why there has been a lot of emphasis on energy storage and a few different types of possible ways have been found. For example, it is not difficult to see that the energy storage medium that we all know, batteries, that is, that is good for small power applications, all right, but that would not be good for very large kind of energy storage. For example, the energy that is produced by a power plant all through the night being stored to be supplied during the peak hours that is something where the batteries will not be very good. So, what to do in those cases?

There are a few suggestions for that, but let us clarify the different types of requirements. One, where we would like to store the energy, store the produced electrical energy during the off peak periods meaning late night or so, to be used during the peak hours that is one type of requirement. The requirement is that you should have a very large energy storage capacity and the power rating, energy and power are two different things. A huge amount of energy can be stored, but if it can be given only in a, in a short time then the power rating is high. If the power rating is low then even if there is a large amount of energy storage it can be only given out over a large period of time, thereby the power rating would be low. So, they are two different things.

For that kind of applications, we would need something that would store energy, huge amount of energy, but at the same time, power rating should also be of the order of hundreds of megawatts. What to do then? There are also energy storage requirements for your cell phones, right; milliwatts that is also a requirement. So, for different types of requirements, you need different types of solutions. There are also requirements, where the energy storage may be not very large, but you might need to give it out within a very short time.

For example, suppose in the morning a whole industry switches on, a whole industry means some megawatts of power. Suddenly there is a demand. How can that power be met? Obviously, immediately the moment it switches on he gets the power. Where does he get it from? Immediately, the coal input cannot be increased. There has to be a lag, there has to be a feedback loop which will take time to operate. So, obviously that cannot be the solution. So, where does he get it from? He gets it the moment he switches on, gets the power. But, that comes from the kinetic energy of the generator rotors, which means the kinetic energy falls, which means there is slowing down and then that is fed into the, that is fed into a feedback loop, the frequency drop is sensed and the frequency drop then gives the input to change the steam input, steam input is increased, the moment the steam input is increased the steam has to be generated anyway, so there has to be an increase in the coal input and so on and so forth. A chain reaction occurs; that takes time.

So there is, normally you will find that whenever that kind of event happens, there is a dip in the frequency which is undesirable. Now, if you can have some kind of a fast storage that means the storage quantity is not very large, the amount of energy that is stored may not be very large, but that can be given out within a very short time, say within a second, so within a second the energy can be pushed into the system, so that the rest of the system that changes the steam governor, that increases the coal input, all that has its own time to react. That is another kind of requirement, a requirement where the energy storage requirement is not very large, but the power requirement is large.

There can also be requirements of storage like the modern electric vehicles. Nowadays, there is a great amount of research on electric vehicles, because gasoline or petrol is becoming very expensive. You know the reason, we have done a great deal of study on that and what kind of storage would you have. We will have to tackle all these problems.

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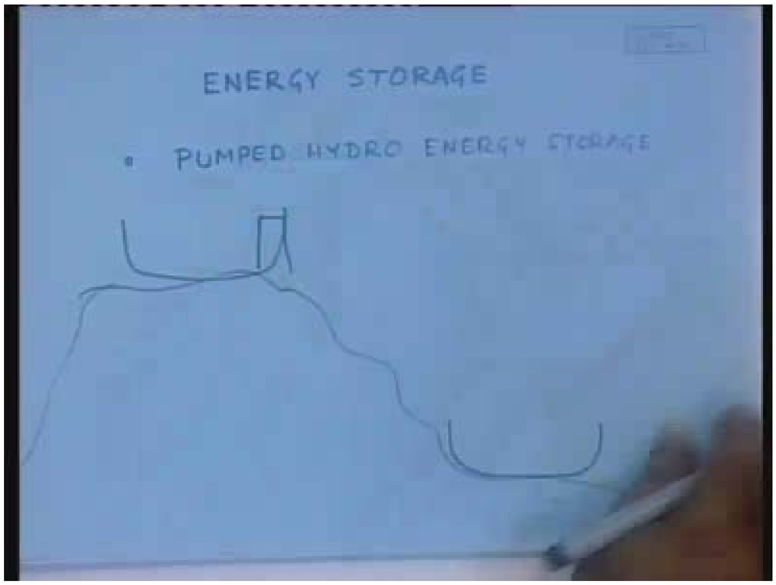


Now, the various types of energy storage that has been proposed or in various stages of actual application in various places are, pumped hydro energy storage. Here, the concept is similar to that of a hydroelectric power plant which means that either an existing hydroelectric power plant or one that you create, where there are two reservoirs at two different heights. So, this may be on top of a hill or something like that, right. So, you might imagine that there is a hill. Normally, you do not really make, you know, coal runs like this. These are the essentially large reservoirs. So, you have a, let me draw separately.

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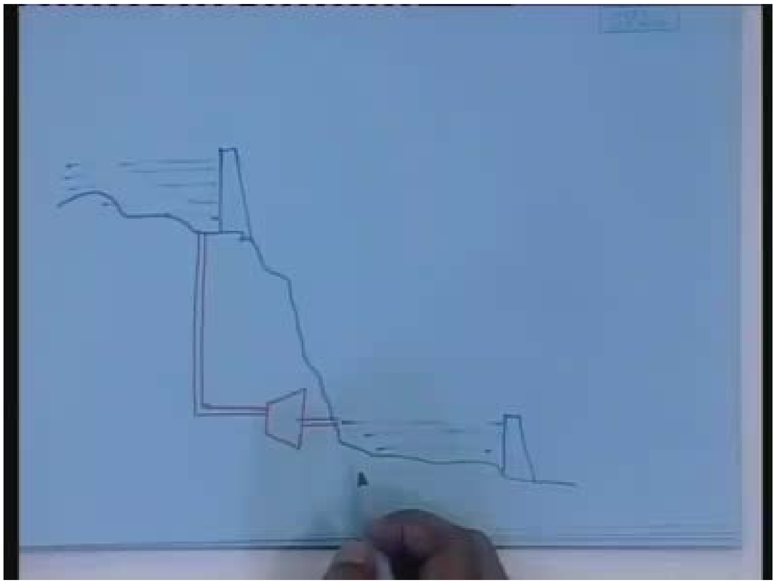

Suppose you have a, some kind of a hill terrain like this. So, you construct a dam which encloses some amount of water and here you have another dam like structure which encloses another amount of water. So, you can then have, normally this is done through the sink and then that goes through a turbine to this. So, during the night time when, I mean I have drawn it this way, because this is normally this way that means the whole thing is situated at least the pipelines are situated inside the hill. During the night time, one would pump the water up using a motor and this turbine would then work as a pump.

The same thing can work reversibly as a pump or a turbine. There are some turbine designs for that. For example, the Francis tube turbine is normally used for this kind of a purpose. So, during the night you would pump it up, as a result of which the energy that was surplus that is used in order to store it in the form of kinetic energy, in the form of potential energy, then during the day time, during the time when there is a huge load demand, then this can be allowed to flow back and you have this device running as a turbine. So, this shaft has to be a reversible pump turbine and it is to be connected to an electrical device that is both acting as a motor as well as a generator, depending on whether you feed power into it or take power out of it.

Student: Sir, …. turbine power is a constant, turbine power rating is a constant?

Turbine power rating is constant but its power output actually depends on how much water you feed into it. So, the opening of the valve that determines how much power actually it will be able to produce. Its rating is fixed and with the amount of electrical machines that you have learnt, you know that all machines, all electrical machines can be used as motors as well as generators. So, there is nothing like a special motor or special generator, all machines are both. Likewise, in mechanical engineering also, most of the turbines are both. You can work reversibly as pump as well as turbines. So, that is the essential concept.

You might ask, how much, how much energy can be stored? Huge amount, huge amount really; there have been pump storage plants of the power capacity of 1000 megawatts in various places and as of now, there are at least 500 pump storage plants all over the world. So, it is a, it is a large scale used system, proven technology. In India, well in West Bengal itself, because West Bengal is deprived of hydroelectric power, it has most of the power generation from thermal power because it has proximity to the coal source and we do not have much of hydroelectric source, only we do get power from the Chukha hydroelectric power plant in Bhutan. The advantage of hydro is that you can vary the output very fast. So, whenever there is a power demand, we buy it from Chukha, but that falls short of the requirement. That is why the West Bengal state electricity board is now installing a pump storage plant in Purulia, in the Ayodhya Hills. If you visit that place anytime you can see that. Right now it is under, in the final stages of construction. So, this is one concept of energy storage.

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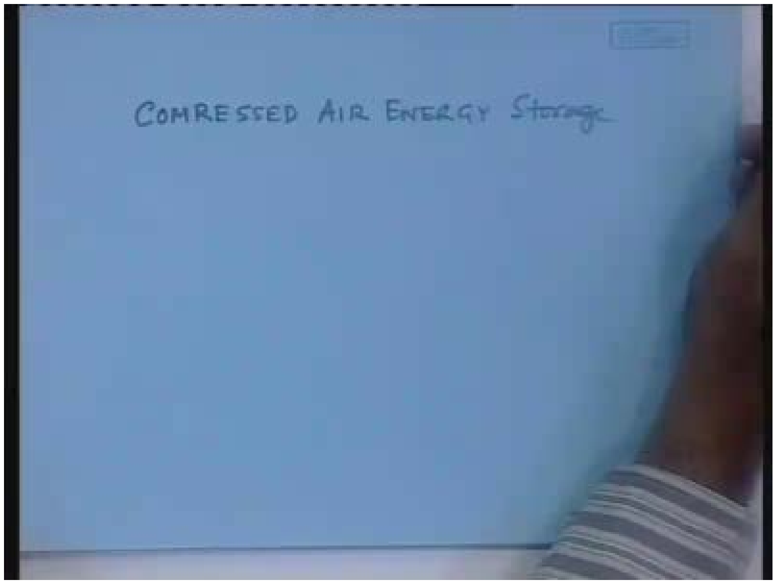


The second concept of energy storage that is not as widely used, but nevertheless that is very widely applicable that is called compressed air energy storage, compressed air. Here, the idea is instead of storing the energy in form of the potential energy of water here, you use air and since there is no question of potential energy of air, so you can, you can store in form of the pressure. Naturally, you would need to reach a very high pressure and not only that, you would need to compress a large volume of air. So, you will need a chamber, where you can store large pressure air as well as the large volume of air. Can you make such a thing, a huge chamber?

It will be prohibitively expensive, because even if you want make a huge chamber, then the more, the larger it is, the difficult, the more difficult it will be to make it withstand very large pressure. So, you never do that. Instead, we often take a very simple trick, abandoned mines. The mines that had been used are now abandoned, they can store a large amount of ah air and at the same time, since it is all the sides enclosed by rock, you will have a complete enclosing and therefore, thereby you can do that. So, that is the idea that is pursued. Mostly people like, for this purpose compressed air energy storage, the salt mines. In the salt mines normally what do you do? You simply pump in hot water that is mixed with the salt and that is pumped out and that is dried. That is how salt is produced out of salt mines.

It is not that people get down there with spades and they, no, it is normally dissolved and taken out, as a result of which a cavity is created which is very smooth, without any crack. So, it has that advantage. Normally, if you have any other type of mines, there will be seepage, there will be cracks through which the air can go out, but salt mines are very good for that purpose. So, the first installation was in Germany. There was a salt mine in which they had the compressed air energy storage. But before I go into the concept, probably I did not talk much about the gas turbines, did I? No.

I need to take about it, so let us understand it first. The idea is similar to the jet engines. Do you know how the jet engines function? Studied in school how the jet engines function, jet aircraft engines? There the idea is that first air is compressed. Air is compressed by means of some compressor. Air is compressed to a high pressure and then that is mixed with fuel. Normally, if it is gaseous fuel it is fine, if it is not then the normal liquid fuel, what is known atomized by means of very fine droplets, it is injected into it and burnt, as a result of which, as the temperature increases its pressure also increases much and then there is a stage of turbine and the turbine and the compressor are connected to the same shaft, so that a part of the power that is generated by the turbine goes into the compressor. So, that is how the whole thing works and the jet goes out. That is the essential concept.

So, you would like to draw it something like this.

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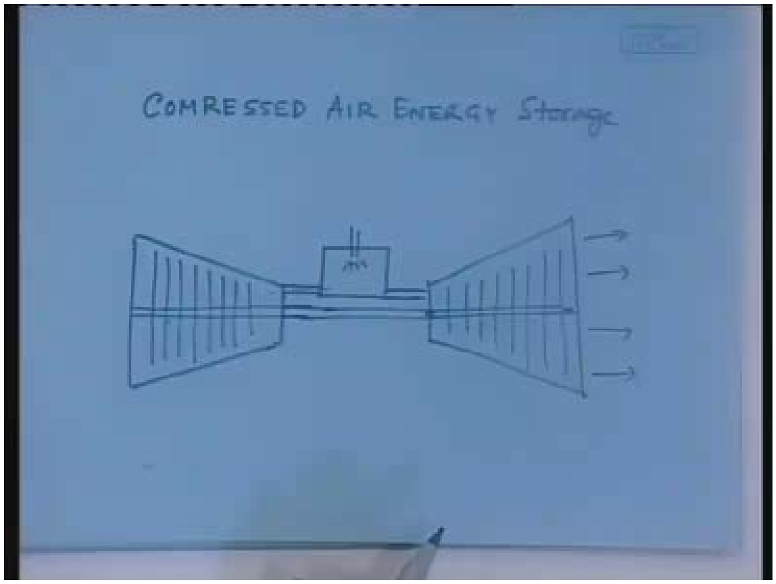


You have the, so this is the side from which it comes. It is compressed and then it goes into, the whole thing is connected; then this one goes into a chamber. I am drawing only schematically, it is not exactly the way it is. I am drawing schematically, so that you understand what it is. So, this is where the fuel is injected. So, here you have the same shaft connected and I will draw it like this. There are the blades of the compressor, so there are compressor blades. It rotates and by rotation it compresses.

So, as it moves the principle fluid, in this case air, moves in. It is compressed and that compressed air goes into the combustion chamber and then from here it goes into the turbine. The same shaft is then connected to the turbine and you have these stages. Here also there are those blades that extract a part of the power out of it and the same power feeds the compressor and then air goes out at high speed; essential concept of a normal aircraft engine.

Now, you would notice, sometimes you might hear of the, the talk of gas turbines being used for electrical power generation. Gas turbines in that case would be only this system, essentially. One uses abundant or presently unused simple aircraft engines, nothing more, where you have the same system. Only thing is that in the aircraft you need the gas to go

out at high speed, in case of gas turbine where you are generating electricity you do not need that and therefore, in case of gas turbines meant for electricity, this turbine part will generate much more than, much more energy than that is necessary for the compressor part. That is true because, here the compressor is having to compress cold air,
while here there is a heat being injected, as a result of which much more energy is available to the turbine. So, you get more energy out of the turbine than the compressor, essential concept.

About 20 years back, there were many gas turbines in India. But nowadays these are being phased out, because the fuel has to be the liquid fuel and the liquid fuels are very expensive in India, so these are slowly being phased out. Again, with the increased availability of natural gas in the western region, these are again coming into the market, because you can also use natural gas that is relatively widely available. So, that is the concept of the gas turbine. It has the advantage that it can start very fast, within a minute it can start, as a result of which these are very well suited for supplying the peak power.

Now, where they use the compressed air energy storage, essentially after this stage, after this stage that means here is a stage that, here is a stage that compresses the air. That stage the air is pumped into the cavern. As I told you, the container is nothing but an abandoned salt mine, a cavern, so it is pumped into there. So, there the pressure increases and it is used, this compression stage is used during the night time.

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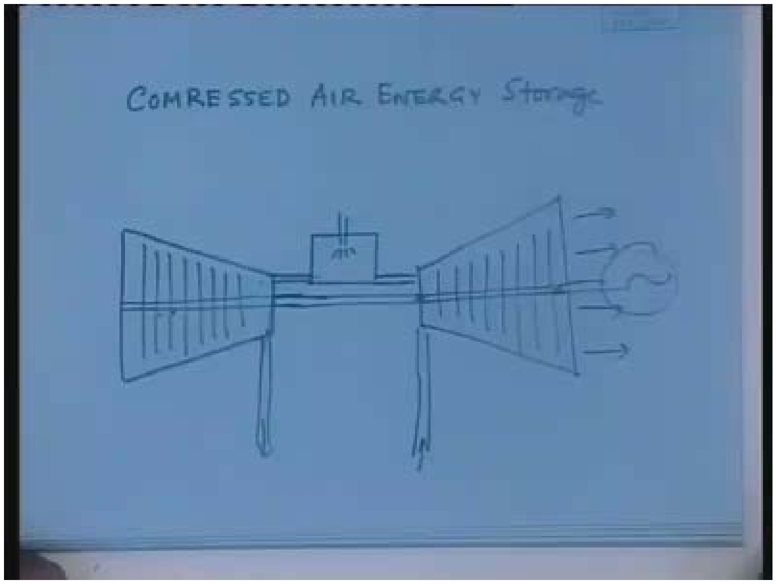


That means normally there will be a generator connected to it. The generator would then at that time act as a motor that will connect to the shaft and that shaft will, this part will work and that will produce compressed air, the compressed air is pumped in. During the day time when you need the power, then again this was how it is going in and during the day time from here it is again taken out, that compressed air runs the turbine and runs the generator. Do you understand? In a normal aircraft this happens, but happens at the same time, compression as well as the power generation happens at the same time, while in this concept the compression happens at the night and the power generation part happens at the daytime, thereby we have effective storage of energy. Do you understand the concept then?

How much can be stored? In fact, again huge amount. These are good for that kind of load leveling purpose, where the peak power is supplied by this kind of means; where the peak of the power station goes up, at that time you run this turbine. There are a few problems you might easily notice, that in the compression process the temperature of the air goes up. If you simply inject that into the cavern, it will be hot air into the cavern and obviously hot air contains, take up more space than cold air. So, it will make sense, in order, if you can cool it before putting it down into the cavern. Then you will be able to store much more amount of air with a given amount of energy.

Here, normally the air that is stored in the cavern would be cooled and therefore, the cold air would be coming out, right. Cold air obviously would not be able to produce as much energy as is possible for hot air. So, you might either put a small combustion chamber here, put in some amount of fuel to heat it up, is possible. But at the same time, what is normally done is there is a heat exchanger. So, before it goes in, it is cooled by means of the air that is coming up. But there is a problem still, because when this fellow is going, this fellow is not coming up. There is a time difference between them and because there is a time difference between them, there has to be some kind of storage of heat, so that when this fellow goes in, it gives out the heat to something which again gives out the heat to this fellow when it is taken out and this is normally done, this can be done by, you know, large containers containing pebble beds, so that if the air passes through, then that absorbs the heat and then that contains the heat, keeps the heat and then when this one goes up, when you allow the air to come up from the cavern into the turbine, you pass it again through that pebble bed. So, that is the standard concept of energy storage. How much can you recover in case of the pumped hydro energy storage?

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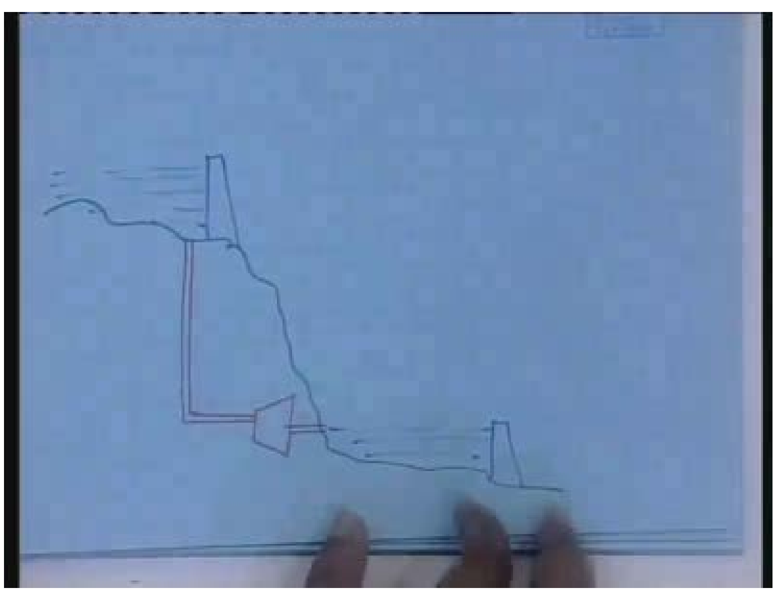

In case of the pumped hydro energy storage, it is not difficult to see that there are the normal inefficiencies involved in the turbine, in the passage; there would be. But, in addition there would be evaporation from there, seepage through here, as a result of which the water that is pumped up, a part of that may be lost, right. So, that results in some additional inefficiencies. So, overall efficiency would be of the order of say, 80%, normally taken to be 70 to 85%, but you can say on an average it might be about 80%. In case of compressed air energy storage, it would be of the same order, more or less of the same order. Now, is the concept understood? These are the ones that are considered for large scale storage.

There is another energy storage means that is considered for large scale storage, but it is not yet come to that kind of use. That is magnetic energy storage where energy is stored in magnetic fields. You can of course store energy in magnetic fields. So, what will you have to do?

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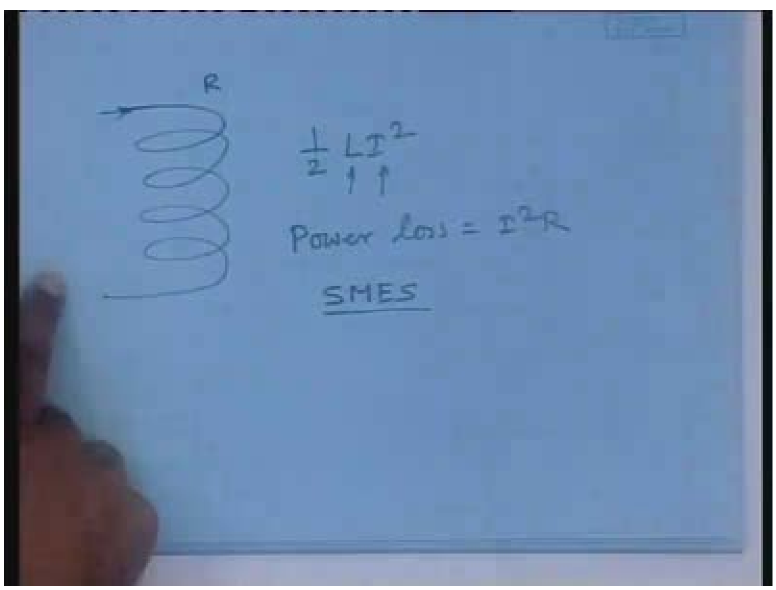


You have a say, solenoid and as the current is set up how much energy is stored in it? Half LI square, so half LI square is the quantity that is set up. Obviously, that depends on how big L is and how big I is. In order to have L and since it is more dependent on I, therefore you would like to have a large amount of energy, like large amount of current going through of the order of say kilo amperes or even say, mega amperes. Now, if large amount of current goes in, obviously this coil has some resistance. If the resistance is R, then how much is the power lost? I square R; so, power loss is … So, if power loss is I square R, you can easily see that the more the I, the energy storage will go up, all right, but the power loss will also go up. So, you need to avoid that.

The way to avoid that is now the technology is now available to us by means of superconductivity. So, normally this kind of magnetic energy storage is, superconducting magnetic energy storage called SMES, superconducting magnetic energy storage. So, there are some materials which when cooled to a temperature close to zero degrees absolute, they lose their resistance altogether. That means resistance actually goes down to zero. It is not close to zero, it is zero. So, this term will then vanish and therefore, you will be able to store energy for a very long time and you would also be able to reach very high values of the I and that is the concept that is very hotly being pursued these days. So, superconducting magnetic energy storage obviously requires some means of cooling to a temperature that will be very low temperature.

Normally, it is done by liquid helium, so that there has to be a liquid helium refrigeration system that produces liquid helium and that liquid helium is, the whole thing is contained in a container called a Dewar. Inside it, there is a liquid helium bath and inside that the whole, it is called niobium titanium wire which becomes superconducting, at that particular temperature that is immersed. At that temperature the coil becomes superconducting and so, if you have, if you apply a DC voltage, remember if you apply a DC voltage what will happen?

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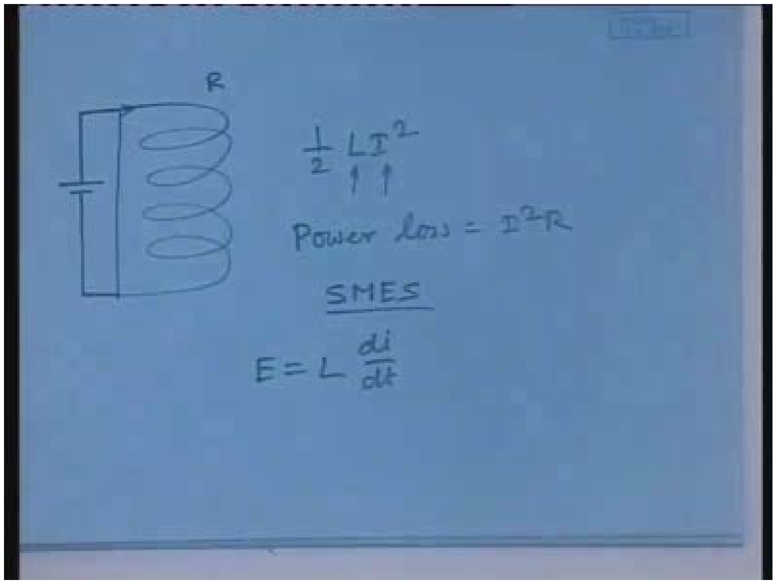


Say based on your idea that you have learnt in the first year electrical circuit course, if you have zero resistance and inductance and a DC voltage applied to it, what will be the behaviour of the current?

Student: …

No, no, not very high, how will it change? E is equal to L di dt. So, E is equal to L di by dt. So, you can see that di by dt will be a constant. So, I will rise linearly, I will rise linearly and so, as you apply the voltage here, the I will keep on rising linearly. When it reaches the value that you want to be stored, that means depending on the I there will be certain amount of energy stored in it, when that amount of energy is stored you simply short it. If you short it through a superconducting switch, that also contact has to be superconducting, then what happens? The current keeps on going through. Since there is no resistance, it will not decay, it will remain here and it will be, it will be properly stored and when you want to take the power out, what do you do? Taking the power out means the current has to reduce. If the current has to reduce, how can you make the current reduce? By applying a negative voltage that is the only way. If the voltage is zero, the current remains the same. If the voltage is positive, however small it is the current will rise, right and if you make the voltage negative, then the current goes down and thereby the amount of energy that drops here will go out into the system. So, the actual system description would be something like this.

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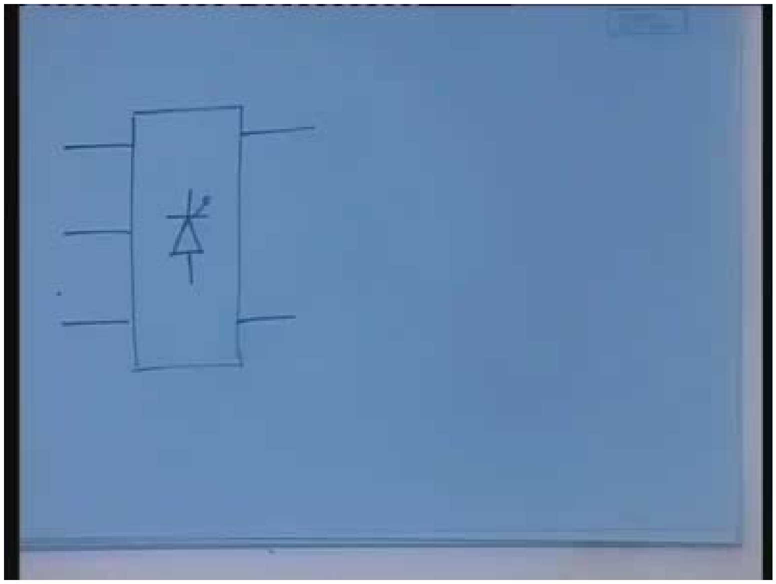

You have the three phase line coming and there would be a power electronic interface, whose details I am not going into, but essential property is that it should be some kind of a power electronic interface which will apply a DC voltage to this side, which will apply a DC voltage to this side and that DC voltage will be variable. Not only that that its polarity should also be variable. What is the shape of that? Will it be a solenoid? A solenoid means where you have wound like this. If it is a solenoid, the magnetic fields go like this, come back, as a result of which, if it is a solenoid structure, imagine that I have got a solenoid structure here. There is solenoid and I am passing say, megawatts, mega ampere current through it.

Nice, no problem, but now suppose I am trying to take the energy out which means the current will decay, current will fall. I am taking the energy out or I am pushing the energy in current will rise. If there is a current there will also be a magnetic field, there is a magnetic field established. The energy is stored in the magnetic field really. If the current is changing, the magnetic field will be changing, all right. If the current is changing the magnetic field will be changing and if there is a magnetic field changing if you are standing close by, what will happen? Your body is a conducting material and it is in a changing magnetic field, so there will be voltage induced in your body. So, that is considered to be somewhat unsafe.

That is why the solenoidal structures, they are easy to wound. They are very easy to wind that is why they are used all right, but they are used in relatively smaller energy storage elements. These smaller energy storage elements, remember here there is no limit to the power that you can take out. That depends on the rated capacity of the power electronic converter, nothing else. How much current it can carry? So, power level can be very high. 100 megawatts is no problem, but the energy storage of course will be dependent on the current and that has to be limited and so, these kind of use, this kind of systems, smaller some 30 mega joule, 40 mega joule kind of systems are used for, when I told, no …

There are requirements in a power system. In order to stabilize a power system, short term requirement that will give power for may be 10 seconds, but megawatts of power. For that kind of purpose, there are a large number of such small superconducting magnetic storage elements that have been installed in the US. They are working fine, they actually stabilize the system. Larger energy storage elements, where you know the power that is produced during the night would be stored as huge amount of energy that will be stored, they have been planned. But, then in that case, you cannot really have solenoidal construction.

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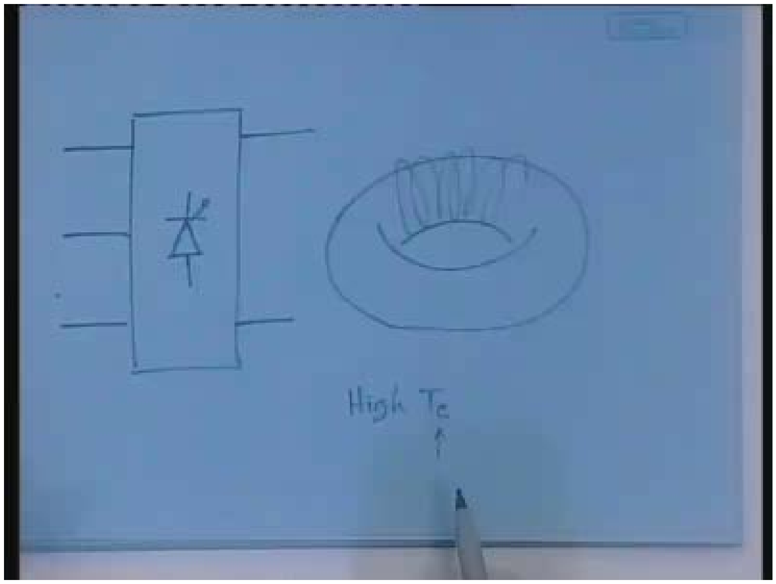


It has to have its own structural strength and that will be possible only if you can make a toroidal structure, so this wound like this. The advantage is that the magnetic field is confined, magnetic field is confined and the whole thing has a larger structural strength. With that kind of current flowing two nearby conductors will have a lot of force between them. That force is rather difficult to contain, unless you have this kind of construction. So, this is a very stable and mechanically stable construction, toroidal construction. So, that is where people are going to for larger size.

Nowadays, there is another development. Earlier, say 20 years back, the only superconductor we knew of that can be commercially used was niobium titanium wires. But, in the late 80's, there was a development when it was found that it is possible to make relatively high temperature superconductors. The low temperature superconductors, when you hear that particular term, you know that these are to operate at liquid helium temperatures. While you will also hear the term high TC superconductor where the critical temperature, TC is the critical temperature, that high TC, the critical temperature at which the superconducting transition takes place that is relatively high. When that is true, then you can also use liquid nitrogen temperature.

Liquid nitrogen is much easily produced, readily available. Nitrogen is in the air, so you can readily have it and liquefaction of nitrogen is rather simple. So, the whole cost goes down. But at the same time, those high temperature superconductors still have some problem that at high magnetic fields, their superconductivity may be lost. So, you cannot really have a large magnetic field with those superconductors. So, you are actually paying for the advantage that you get in terms of the simpler cryogenics, in terms of paying for not so large system. So, some of the smaller systems that are being installed these days are high TC superconductor, the high TC superconductor. This is the critical temperature at which the transition takes place.

These materials are ceramic in nature. That means metal oxides, yttrium, barium, copper oxide is the material that is normally used these days. So, Y, Ba, Cu O n, that means the number of oxygen’s are variable. So, this is the essential concept of the superconducting magnetic energy storage. When I said that some mega joules of energy is stored, for example 30 mega joules, is it a large number or small number? Mega sounds large, right; joule is a very small quantity, so mega joule is not really a large, large quantity, so remember that. 30 mega joule is relatively small system. 10 mega joule, 20 mega joule, 30 mega joule, these are small systems that are used only for those 10 seconds, 20 seconds kind of requirement, to satisfy that kind of requirement and whenever there is a requirement for larger amount of energy storage, people are doing research on installing magnetic energy storage of that capacity. But, it has not yet come into commercial practice.

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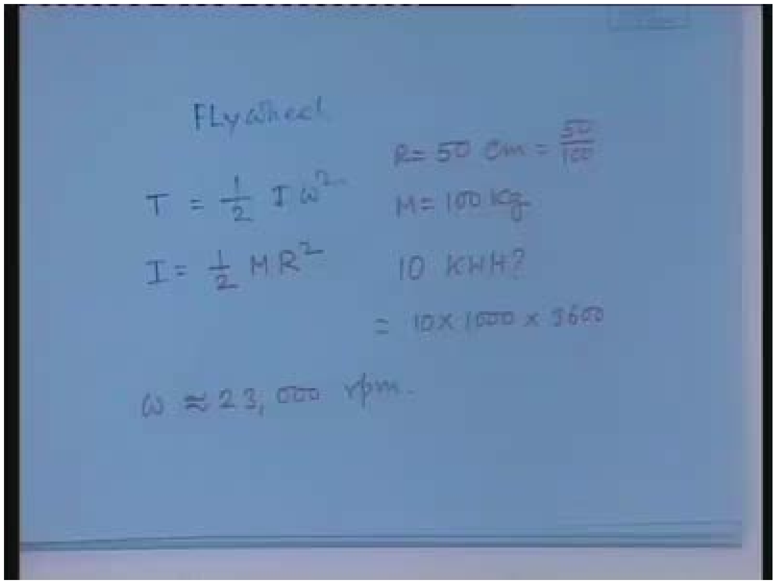


The fourth is flywheel, flywheel energy storage; energy storage in kinetic energy of a rotating thing. You might have doubt, how much energy can it store anyway? So, how much energy can it store? Half LI square?

Student: I omega square.

I omega square, yes. Notice the same kind of expression, I omega square and what is I?

Student: …

I is

Student: …

Yes, but that is for a rotating disc.

Student : Half M R square.

Half MR square. Now, this half is not really half for everything. This half depends on this, the structure. For example, it is half for a circular disc, but if you have some, some other kind of thing, for example a bicycle rim kind of thing where it is connected by spokes, then it is 1 really. So, there can be various construction, but let us consider it as a disc. Let us try to understand. Suppose there is a, does anybody have calculator? We can quickly do some calculation to find out what will be the requirement? You have?

Student: Mobile phone.

Oh, mobile phone; make sure that it does not ring, while it is in action. Suppose you have a disc of 50 cm radius and the mass is say, 100 kg. Then at what speed does it have to rotate in order to store, for example 10 kilowatt hour? Can you calculate? 10 kilowatt hour, do you understand how much it is? Normally, an electric heater is about a kilowatt. It takes about a kilowatt hour, it is, it is rated at 1 kilowatt, so 1 hour it takes. So, you will be able to cook for 10 hours using this energy. To give you some idea, you will be able cook for 10 hours using this energy. So, it is a very small system. Can you see? 50 centimeters is only this much, not large. So, tell me how, what speed should it rotate? Using these two expressions, you can do that.

Only you will have to do in the proper units. Kg is okay, 10 kilowatt hour is 10 into 1000 watt hour into 3600 watt second. That is what you have to use, right. So, substitute and tell me how much, what will be the speed of rotation? You have to find omega. Omega will come out in radiance per second, convert into …

Student: 24 …

Yeah, approximately, 24? Nahi, nahi, nahi, nahi; it is not in proper unit … After you find omega, after you find omega, then you have to divide by 2 pi, revolution per second, then revolutions per minute, then you will be able to figure out, how, what kind of speed you need? So, you will need omega at

Student: 5

5, what?

Student:

Nahi, nahi; completely wrong, no, no. Still wrong, get the units proper. 12000? Should be even more; RPM may karo. So, get it into RPM. It should be something like

Student: 720

Yeah, like that 23000 RPM

Student: …

Hai Na? Yeah, it should be around 23000 RPM. Convinced? So, this is a very high speed and you might have the doubt, is it achievable. Yes, it is very much achievable, it is very much achievable. Only thing is that the normal, this depends on the, depends on what? This fellow depends on the mass, but you see this is linearly proportional. The kinetic energy is linearly proportional to the I and I is linearly proportional to the mass. So, if you increase the mass, what is happening? It is only linearly increasing. Why? If you increase the omega it will be squarely increasing. So, it will be, it will take make more sense to have a light weight flywheel rotating at a very high speed. That is actually what we do.

So, we normally go for, not steel but some material that is lighter than steel, but has a larger radial structural strength, because there will be a lot of centrifugal force created and the centrifugal force will try to rip it off. So, in order to stop that from happening, you would like to have a very high tensile strength around the radial direction. In fact, carbon fibre reinforced materials are used for this purpose. Carbon fibers have very large structural strength. But, there is another aspect of the story. That is if this fellow is rotating and if you have air, then the air friction will itself slow it down. So, it has to rotate inside a chamber which is evacuated. So, you create a vacuum, so that it is not stopped by that; second point.

Third point is that if it is, how does it stand there? If it is standing on top of some bearing, all wheels run on bearings, so its capability, how long it will be able to store, all that will depend on the bearings and the bearings are after all making contact with each other. So, at this speed, the bearings will not be very good. That means they will inevitably dissipate energy and they will, that thing will slow down. So, this is also never used. In fact, we do reach speeds of the order of 50,000 RPM. Even experiments have been conducted with 1 lakh RPM, 100,000 RPM. How?

In that case, you cannot have anything but vacuum, all right, but you cannot have a normal bearing. In that case, a new concept is brought in, magnetic bearing. That means the whole thing rests on magnetic field, so that there is no friction at all and magnetic levitation are now very common concept. You have magnetically levitated cars and trains, you know. So, this is a very well tested and applicable concept. That is how the whole thing is done. That means you have magnets, this thing is rotating, as a result of which each part of that sees a varying magnetic field that will produce a current that will produce a voltage. The whole thing is conducting and therefore, that will produce a current and that current will produce a magnetic field.

By Lenz's law, the magnetic field will oppose the cause. So, it will try to repel. That is how the whole thing floats. But not only that, there has to be some arrangement to stabilize it. It floats means it can run away, so there has to be some additional coils to stabilize the motion. That means it will, it will be allowed to oscillate all right, but it will not be able to run away. If you go to the Electrical Department's Machine lab, you will find a system like that. Not a flywheel, but something where there is a magnetic levitation and the thing is stabilized. It is there, it is just there. It is used for, you know, advertisement where you see, you can see that something is floating in the air and it caters your eyes. But, the idea is very simple and that is what is used. So, you have the flywheel energy storage.

It has been found that this can be used for various purposes. When you want to pump in energy into it, all you need to do is to run the electrical machine connected to it as a motor, pump energy into it and when you want to extract the energy out, all you need to do is to simply run the electrical machine as a generator, nothing more and since all machines are reversible, so there is no technical problem about it. So, that is the essential concept of flywheel energy storage. People have run even cars using flywheel energy storage. There are many systems right in place, right now, where the flywheel energy storage is used for energy storage of the order of …

By the way, can you, can you tell me how long will it, will it run? For example, something is rotated at 23,000 RPM and left like that, using magnetic levitation and using vacuum? How long will it keep on rotating? Like 6 months; so, it simply keeps on rotating, there is no dissipation. So, it is a very stable and nice energy storage. Only thing people are worried about is that what if the thing somehow fails. A hugely rotating stuff, at huge speed is there inside, so there is a possibility that this may cause a, you know, big problem the moment the thing fails. There has not been any such occasion as yet, but there is a worry about that. That is why the construction often is such that, if it fails, somehow the centrifugal force gets the better of it and it rips. In that case, the whole thing will immediately disintegrate and will remain inside. It is not that some flying thing will fly away. No, it is not like that.

So, lastly, I would like to say before we conclude, that so far the energy systems in all over the world you can say majorly rest on the fossil fuels. Fossil fuels are used both as the source as well as the storage of energy, remember. But now, now that we are moving more and more towards the renewable fuels, we know that storage is a problem. So, one concept is now coming up in a big way. That is what if wherever we can generate a renewable energy we generate and using that we generate hydrogen.

All these concepts that we have talked off, mostly are site dependent, the generation will be at a place that is normally very remote, unwieldy or maybe inside, in the middle of a sea. There we generate hydrogen and then that hydrogen is used to power the whole economy. Hydrogen can be used to power say, cars. There is no problem. Right now, we have CNG. In place of CNG, you can use cars, you can use hydrogen, compressed hydrogen. Also, if you use hydrogen you need not use the internal combustion engine, because nowadays a concept is coming that is called fuel cells, where like batteries you have a similar electrochemical arrangement in which the feed stock is hydrogen and oxygen and there is an electrochemical arrangement in which they combine. The resulting chemical energy is extracted by means of electrical energy. So, you get electrical energy output.

Many of Japanese car companies already have in place cars that run on fuel cells. They are concept cars all right. They visualize that that will come into the market 20 years later all right, but nevertheless the technology is proven. Hydrogen can run most of the economic processes, because it is, it can be used for almost every purpose. So, there is a concept that is the concept of hydrogen economy, where using the different types of energy storage, different types of renewable energies, we produce hydrogen and that actually runs the whole economy. That is the concept that is coming for the future when we run out of petroleum and also coal.

As you have learnt, petroleum will last not until your active lifetime; it will not last. So, within your, before you retire, you will find petroleum is completely exhausted. So, you will have to encounter that kind of a time when we have to majorly, oh, he does not want to run on flywheels, is it? Yes, but you will have to encounter a time when these things become the order of the day. So, gear up and prepare for that time. That is all for this course, for that matter.

Thank you very much.