Operation and Planning of Power Distribution Systems

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Lecture - 33
Energy storage systems

So, in this part of this lecture I will basically talk about this energy storage systems and this is the last part of module 7. In the first part of this module we discuss these different types of distributed generation systems and the impact of distributed generation units on the distribution networks ok. So, here we will talk about this energy storage system.

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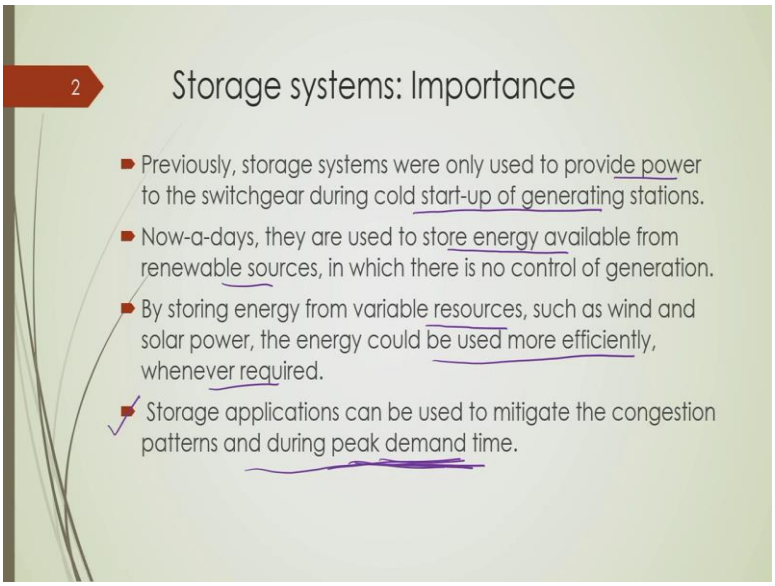

Let us see, what are those things. So, energy storage system is basically thought about only battery in previous days. But nowadays there are different forms of energy storage systems and for power system engineers these batteries are very very important thing; particularly those who are working in power generating station and also power distribution substation. Because this battery provides or energy storage systems provide a critical yet very important part that is, this power during black out condition or power during cool start condition ok.

So, we need electrical power in order to start any unit during cold start when the unit was not operating, any part, any parts of the unit is not operating ok. So, energy storage

system was only used to provide back this power or emergency power during cold start, cold startup of generation units ok.

But nowadays, these energy storage systems, are used to store energy available from the renewable sources and thereby to provide whenever this network demands that. In fact, I already discussed in my last lecture this most of the renewable energy sources are of intermittent in nature for example, solar photovoltaic, wind energy, I discussed in the last two lectures that how they are dependent on the weather condition ok.

So, therefore, their generation varies throughout the day ok. So, but again, for a distribution network operator as we know that our loads are certain entity which are also varying throughout the day. Therefore, it may so happen that there are some periods of time when generation is, this renewable generation units they generate very high amount, but load demand is very poor, load demand is very low during that moment.

Also, it may so happen that when load demand is very high this renewable generating, generation units are not generating much amount of energy. So, therefore, there might be mismatch and they are often, this distribution network operator, they often foresee this mismatch ok.

So, energy storage system will play an important role or vital role in order to store the energy when we have surplus energy from this renewable energy sources and also it can provide energy whenever there is deficit energy. That means, whenever our demand is very high, but renewable energy generators do not generate much amount of power ok.

So, therefore, storing energy from these variable resources could be used more efficiently whenever required ok. So, storage application can be used to mitigate congestion patterns and during peak load demand time. So, the storage can be efficiently used particularly during peak demand to meet that peak demand ok.

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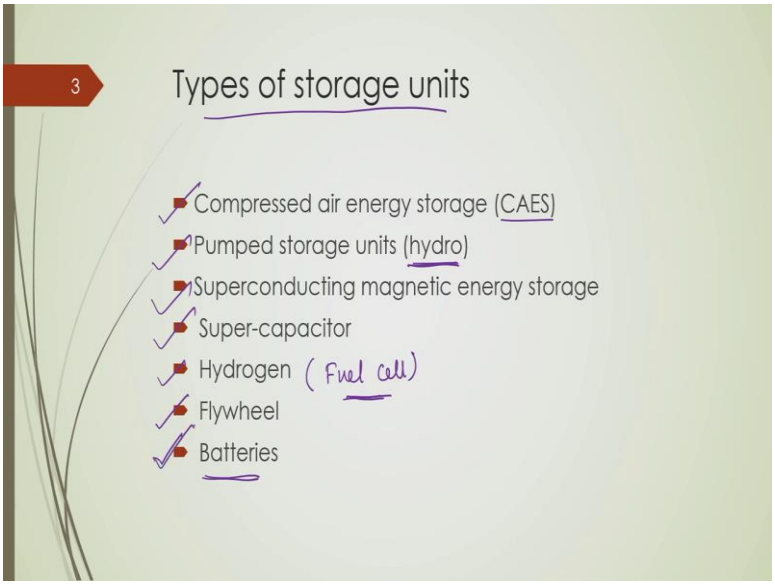

Now, there are different types of storage units ok. As I said, we only thought of these batteries which are the only type of storage, but nowadays we have different types which include compressed air energy storage CAES. What is this? I will come to that then pumped storage units; this is a kind of hydropower station I will also come to that. Then, super conducting magnetic energy storage, super capacitor hydrogen energy which is a type of storage nowadays which is in the form of fuel cell I will also discuss what fuel cell is; how it operates; and how efficiently we can use it. And also, another type is flywheel; then of course, we have batteries.

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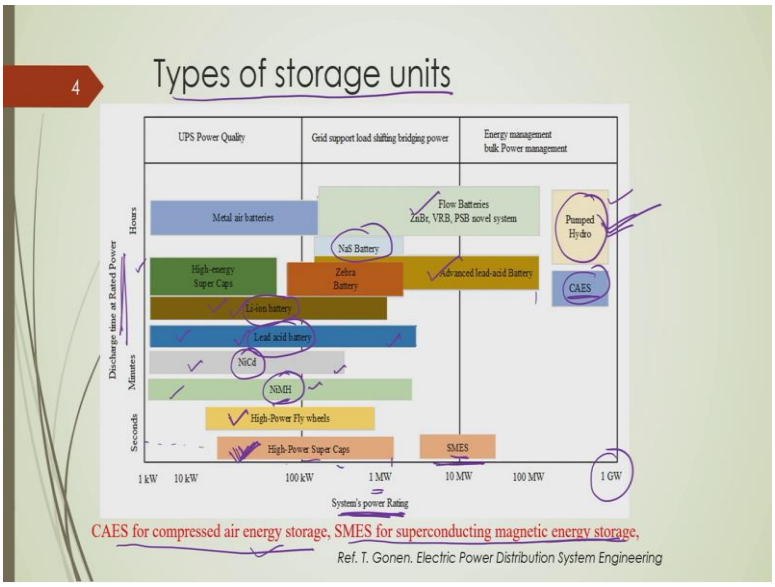

Now, this figure will give you a glimpse of idea that what are the different types of energy storage systems and also how they are different to each other in view of this power rating as well as discharge time or rated power ok. So, if you look at the bottom you can see this super capacitor it is capable of providing up to 1 megawatt of power for a few second only.

That means, it has very high-power capacity, but its discharge time is very very less. So, super capacitor as we know that it is a special type of capacitor which can be rated very high value, in the range of kilowatt or even megawatt. But discharge time is less; it means that its power density is very high, but energy density is not much high.

So, it can be used whenever we need this for a few second when, whenever we need support for this amount of power for a few second ok. Similarly, super conducting magnetic energy storage is another type which can provide you several megawatts of power for a few second. It is basically a typical type of storage unit and fly wheel is also another type; it is a mechanical type of storage, it is really used, but it can provide a megawatt range of power for a few second.

And these are the different forms of the battery, nickel cadmium, NIMH stands for nickel metal hydride and also lead acid battery we know and lithium-ion battery finally. So, if you look at this battery, they have different features; this nickel metal hydride it can provide up to megawatt of power for a few minutes ok.

Similarly, nickel cadmium as well, it can provide you some few kilowatts of power for a bit higher time than this metal hydride. Lead acid battery all we know; we use in our day-to-day purpose; this can be also used to provide power in a range of megawatt for a several minutes. And finally, we have lithium ion which we use in our mobile laptop etcetera. This is, as you know, the latest type of this battery which is extensively used in various applications, I will come to that ok.

Now, there are other forms of battery as well which are called flow batteries which are similar to fuel cell, higher this electrolyte is used, it flows from one part to another part. Also, we have advanced lead acid battery where capacity is much higher, that is up to 100 mega watt and so and, its discharge time is also close to 1 hour and even few hours.

Similarly, this is another form; that is called compressed air energy storage CAES where, you know that, air is compressed and stored in some place mostly underground. Specifically, these salt mines, exhausted salt mines are used to act as a compressed air energy storage system where air is stored in a compressed form.

And then it is released to provide combustion to the gas turbine unit ok. And it is found to be an efficient form of energy storage ok. Because, as we know that in gas turbine generation unit, we need compressed air and there used to be a compressor there ok. So, instead of that we can use this compressed air energy storage to have an effective combustion of this gas turbine unit ok. There are other forms of battery called sodium sulfur battery and also there is another type of storage which is called pumped hydro.

This pumped hydro is a special type of hydro generating station where we have two water reservoirs, one is on the top of a hill, another is at the bottom. So, in normal hydro we have only one reservoir at the top as you know, this hydro energy we generate by utilizing this potential energy of the water.

So, we need some storage of the water and also, we need some head or differential height from this top reservoir to the ground where we have this power generating station. Now this differential height is called head. Now similar to this hydropower generating station, in pumped hydro we have also a reservoir on the top of a hill and another reservoir at the tail race, we call it tail race where we have this generating station or generator turbine unit located near to that ok.

And the difference between a pump storage unit and a normal hydro generation unit is that in hydro generation unit we discharge water from this top reservoir whenever we require generation ok. But here, in the pumped hydro we also pumped back this water from the down stair to the top hill ok.

And thereby we can utilize this water whenever we need this higher amount of power or whenever we have a peak power demand. So, this is a very very important type of generation system which is used to meet this peak load demand ok.

So, during off peak time or during night time when power demand is very less our thermal power generation units which generate, which could generate a huge amount of

power. They are used, for they are used to generate a lesser amount, much lesser amount of power than what they could generate.

So, those time when we have the sufficient amount of power or energy capacity available, we can utilize this to run this pumped storage unit to pump back the water from the tail race point to the top reservoir ok. So, that is, when we have the deficit amount of power; that means, when our demand is much higher than our generation capacity, we can release that water to meet this peak demand ok. So, advantage of this pumped hydro is that it can provide giga watt of power.

And with a very very long time maybe 4 hour, 5 hours and so, but this construction of this pumped hydro is a costlier part; it is very costly and it needs various large amount of spaces; it needs various other environmental aspects to encounter ok. But other than that, it is also used in some part of the world and other types of batteries they can also used as the storage ok. So, let me discuss these different types of storage units one by one.

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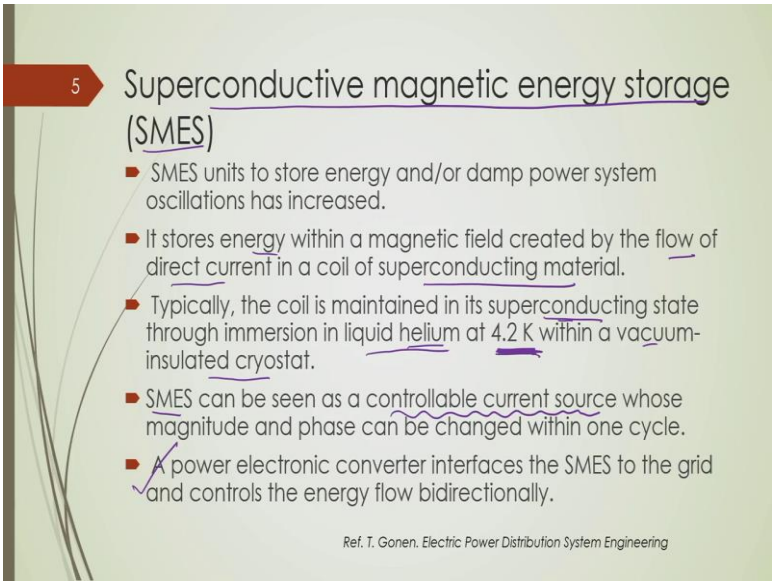

So, first of all, super conducting magnetic energy storage system, SMES, it is basically a type of magnetic energy storage by flowing of direct current in a coil of superconducting material. And that superconducting material is immersed in a liquid helium at a temperature or as low as 4.2 kelvin, look at this unit of this temperature it is not degree Celsius it is basically kelvin. So, you can understand that how much cold it is ok.

So, when a superconducting material is immersed in liquid helium in a vacuum insulated cryostat chamber. Then it can store some amount of electrical magnetic energy and thus this form of this energy storage, that is SMES can be used as controllable current source, can be used as a controllable current source whenever we require it. But of course, this SMES needs to be connected with some power electronic converter inverter systems so that we can use this controllable current for a specific purpose ok.

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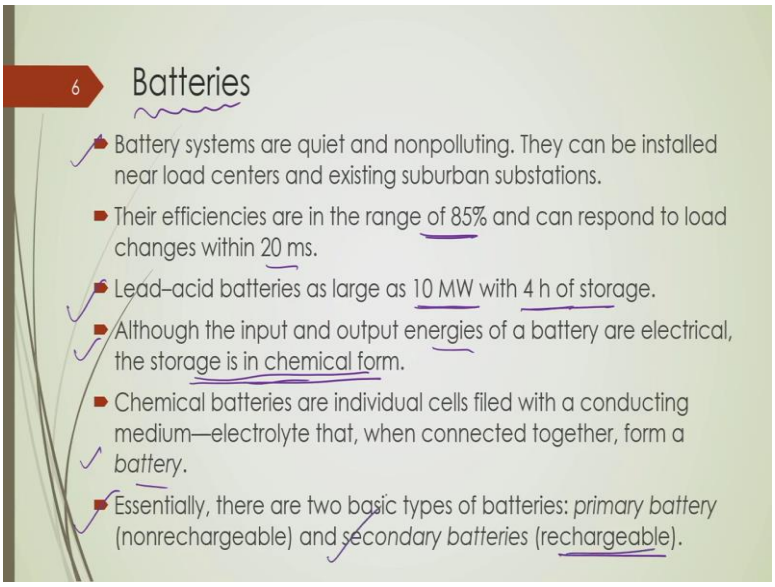

Now, as I said, these batteries are all very old and matured form of energy storage. But we have different forms of battery and we are still in search of the most superior form of the batteries which we could use for power storage or energy storage in the utility level and with the economical way ok.

So, batteries are some of the special types of energy storage system with efficiencies almost very high and it can respond to this load changes almost instantaneously. And lead acid battery in the advanced form can be used as a storage to provide power in a range of 10 megawatt for a duration of 4 hours ok; and you know that although this input output energies of the battery are of electrical.

So; that means, battery can be charged with electricity and it is discharged as also in the form of electrical power, but its storage is in chemical form ok. So, that chemical process gives you the energy storage as well as energy charging and discharging ok. So, we have some electrolyte and we have some electrodes which constitute a battery probably, you

know there are two types of battery; one is non rechargeable, another is rechargeable. But here we are talking about rechargeable batteries only, that is secondary types of battery.

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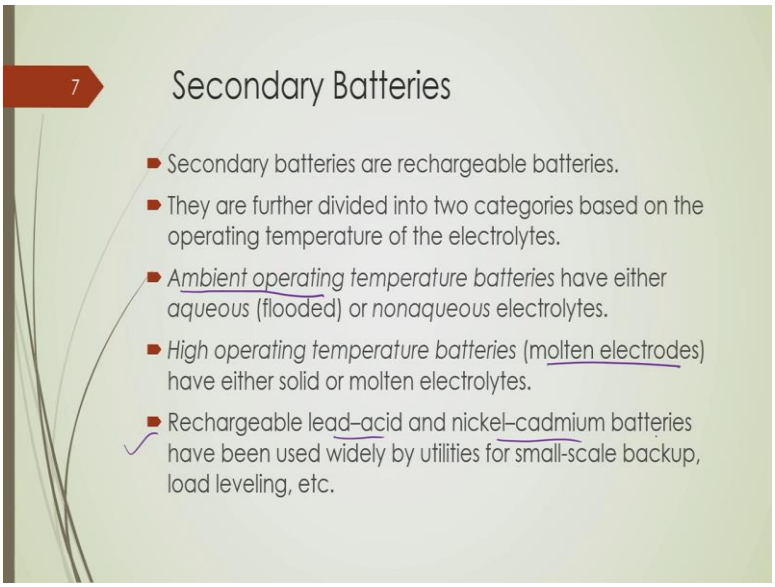

So, in the secondary batteries which are of rechargeable, the ambient temperature is another important aspect. It operates in the ambient temperature, and high operating temperature batteries also are available; they are of molten electrolyte form and rechargeable lead acid and nickel cadmium batteries are also used for utility level energy storage.

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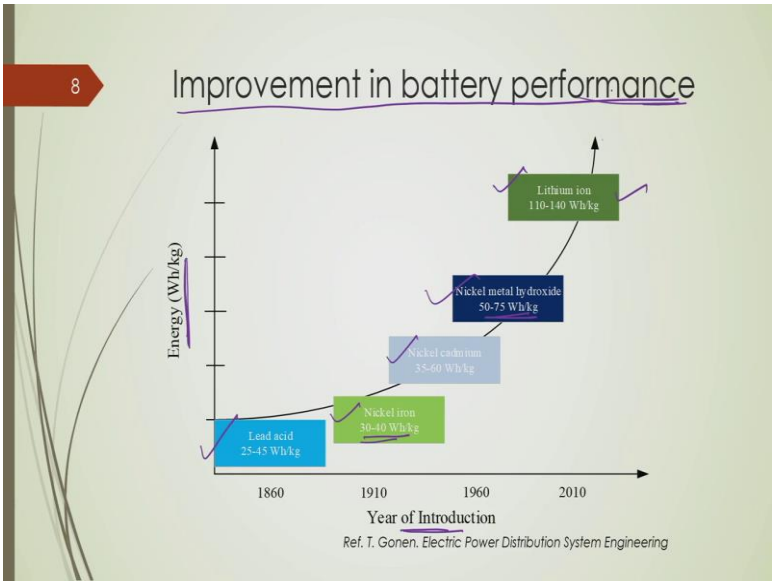

But of course, this price etcetera is to be considered in order to select that a particular type of battery for a specific purpose; this figure provides a good information to show the improvement of battery performance or it provides an evolution of battery technology ok. So, here you can see in this axis it is energy density that is energy per unit mass and here it is the introduction of a specific type of energy.

So, as we know, lead acid battery is the oldest form used for at least two centuries then we have nickel iodine with a superior form of energy density. Then we have nickel cadmium then we have nickel metal hydride with higher value of energy density and then we have at present a lithium ion which is having the highest value of energy density till today ok. Until this technology is increasing and we are in also search of a superior form of this battery with cheapest possible cost.

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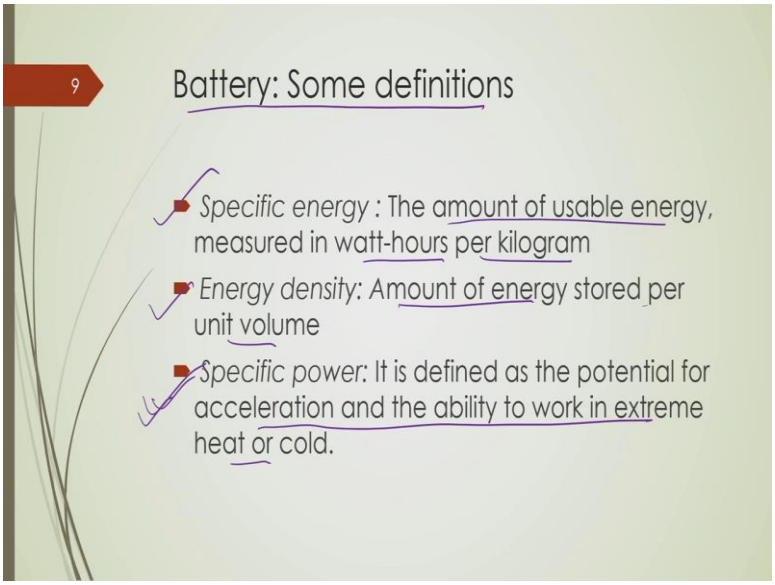

Now, there are some definitions, as I was talking about, one is called specific energy, one is energy density another is, but specific power ok. So, specific energy is amount of usable energy measured in watt hour per kilogram ok. So, whatever I talk about here is not energy then it is basically specific energy and energy density is amount of energy stored per unit volume.

And then we have also specific power; it is defined as the potential for acceleration and ability to work in extreme heat or cold condition. So, this specific power is in terms of watt or kilowatt megawatt.

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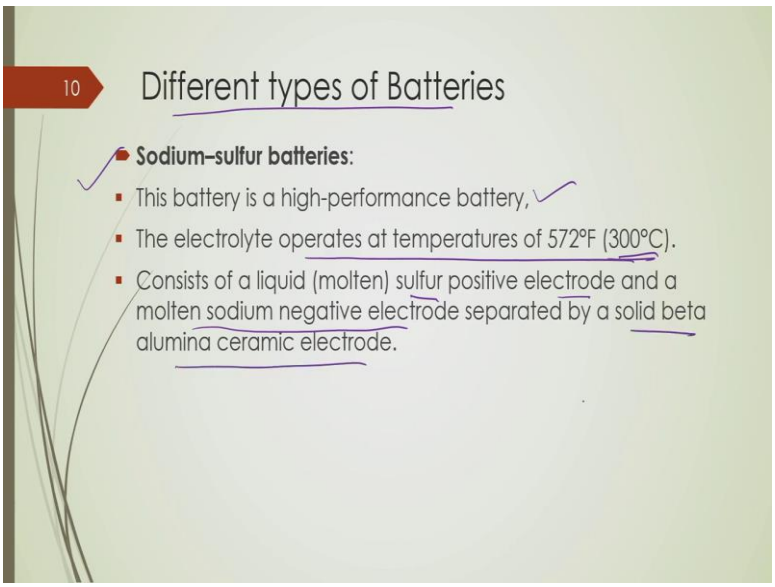

So, there are different types of batteries; one is as I said, one is sodium sulfur high, its performance battery in which operating temperature is very high around 300 degrees Celsius. So, therefore, lots of heat will be generated that heat can be utilized ok or can be managed otherwise; there would be a problem ok. So, it consists of liquid sulfur positive electrode light and molten sodium negative electrolytes separated by solid beta aluminum ceramic electrode ok.

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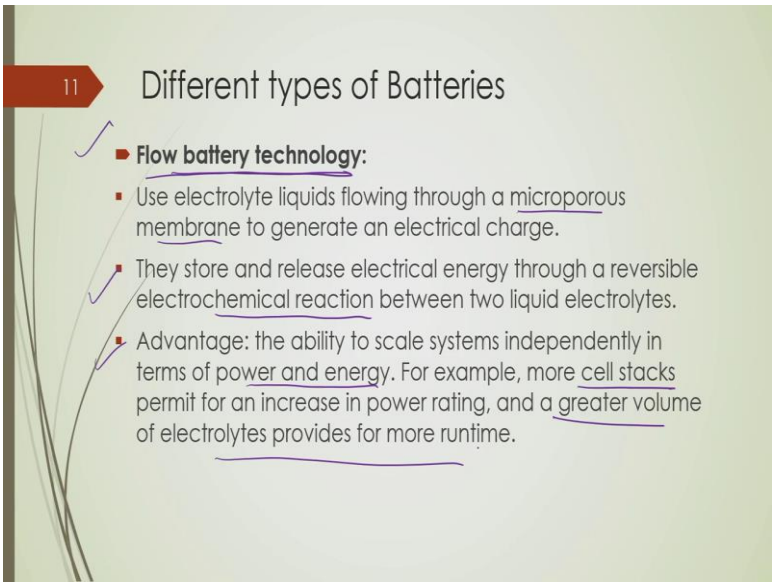

And there is another type of technology, battery technology which is called flow battery technology in which the electrolyte is liquid and it is flowing through a micro porous membrane to generate electrical charge. In fact, this is similar to fuel cell type of storage; I will come to that and this form of this battery can store and release energy through reversible electrochemical reaction and the advantage is the ability to scale system independently in terms of power and energy ok.

For example, more cell stacks permit for an increase of power rating and greater volume of electrolytes provides more runtime. So, scalability is another advantage for this type of energy storage.

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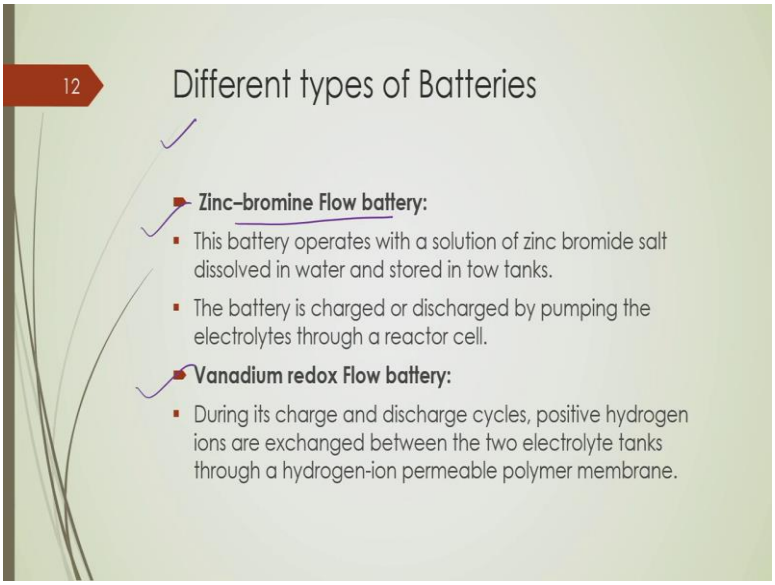

Now as I said there are other types of battery one is called zinc. In fact, different types of flow, flow battery technologies. One is called zinc bromine flow battery; another is called vanadium redox flow battery. So, they are of different characteristics.

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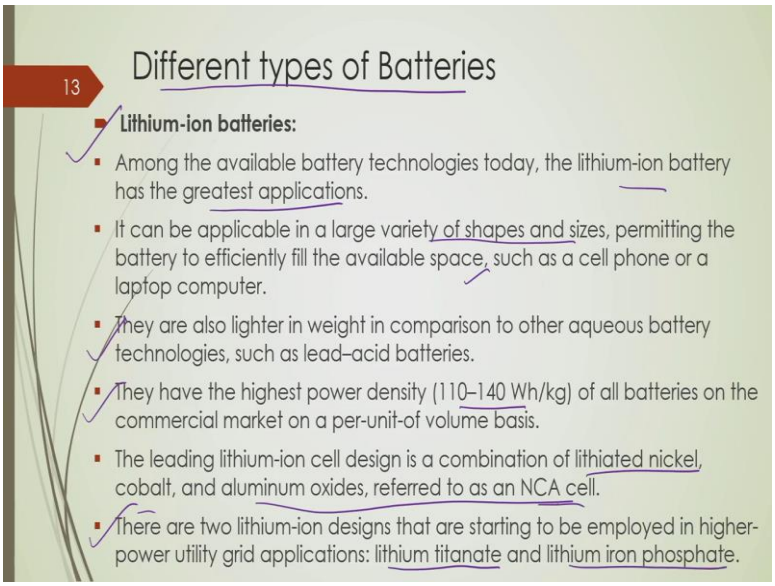

But also, as we know that we have these lithium-ion batteries with as I have shown you with the highest value of energy storage per unit mass. So, it is a special type of technology which we use nowadays in various applications, which include laptop mobile etcetera ok.

So, it has some greatest application nowadays and it has variety of shapes and sizes permitting it operate to efficiently in a particular space ok and also its one advantage is that it is of light weight and highest power density ok, it is energy density; now leading lithium-ion cells design in combination of lithiated nickel cobalt aluminum oxide referred to as an NCA cell. And there are two types of lithium-ion battery, one is called lithium titanate, another is called lithium iron phosphate ok.

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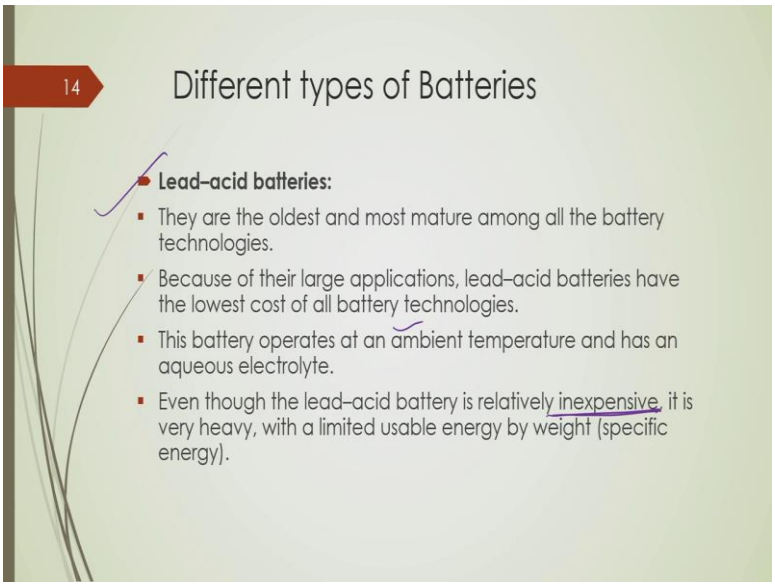

And finally, we have different types of lead acid batteries which are oldest and mostly mature technology among all the battery technologies. And they are also used for high power application ok. And basically, their advantage is that it is they are, it is in a form of inexpensive battery technology. So, it is the one of the cheapest forms of this energy storage ok.

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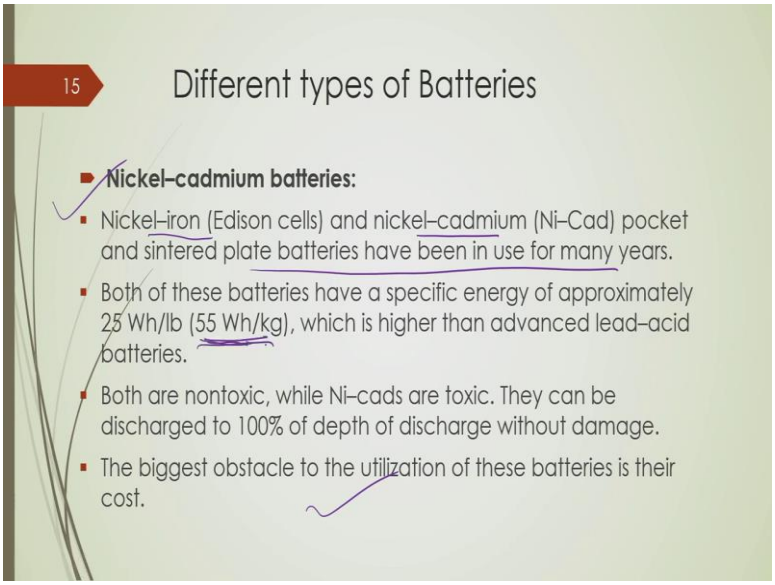

Also, we have nickel cadmium batteries where we have nickel iron and nickel cadmium pocket and sintered plate batteries have been seen for various years of application. And these batteries biggest barrier is their cost, but they are having good value of energy density that is watt hour per kg.

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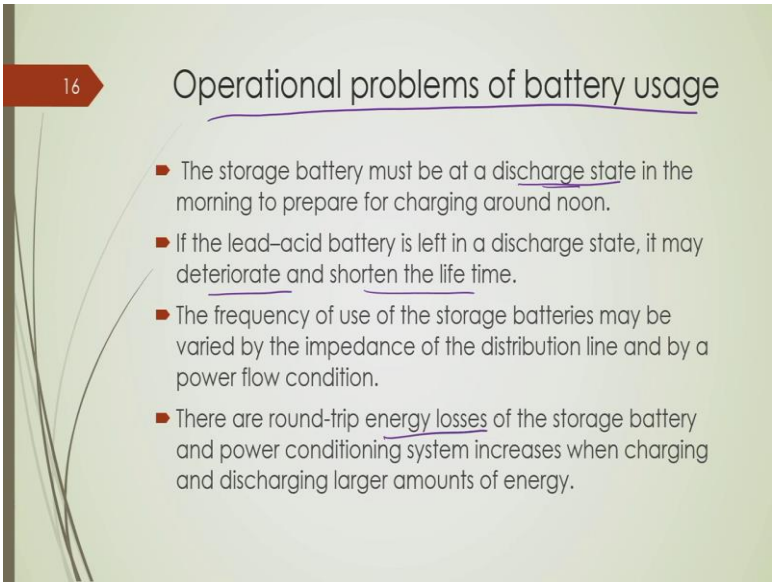

And also, we need to know that what are the operational problems we have in battery storage; one is called the discharging of the battery this is in fact, charging discharging of a battery is a research problem. How efficiently you can charge a battery during when we need to charge this for when we need to store the energy and also how efficiently we can discharge ok.

So, based upon that, there are different works reported in the literature and the students can go through this paper. The different forms of the, different types of this battery charging discharging often these are considered to be optimization problem and by solving this optimization problem one can find out the optimal way of charging discharging of the battery.

But there are some features that you know, one needs to understand that battery deteriorates with time and it has shortened, it can shorten this lifetime if you cannot offer charge discharge by following a specific way. And also, there are some losses this battery will encounter.

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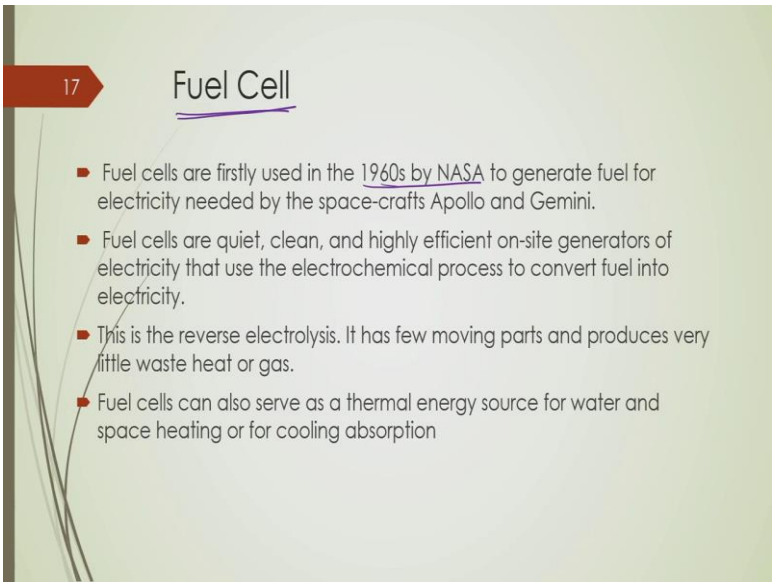

Now finally, I will talk about this fuel cell technology, it is not a battery, but it is a specific type of energy storage system. Why I am calling this storage? I will come to that, but this technology was firstly, used in by NASA for the space mission 1960s and after that it is in development stage for various applications and there are various forms of this fuel cell.

The advantage of the fuel cell is that it takes hydrogen as an input fuel and the byproduct of this fuel cell if you provide input as pure hydrogen the byproduct of this fuel cell is only water and some amount of heat. So, it is a form of clean type of energy generating system or energy storage system ok.

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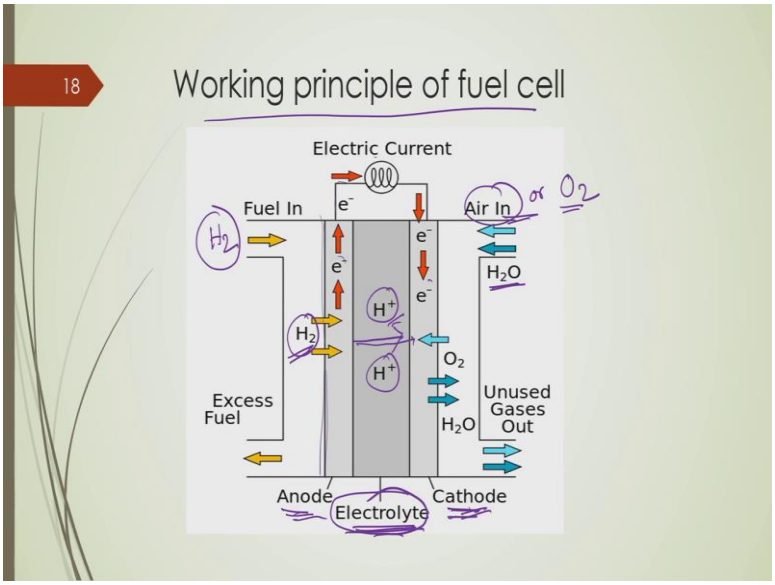

So, how this fuel cell works, let us see this is schematic how this fuel cell works. So, here you can see there is an anode and there is a cathode which is separated by some electrolyte membrane ok. And in the anode, we pass hydrogen, we passed hydrogen from in the anode site and then the cathode we passed air or sorry we passed air or oxygen ok.

So, when this hydrogen is passed through this anode, there is a porous body here which is having some catalyst which used the hydrogen to split into a proton and an electron that you know. So, this proton they can, this electrolyte membrane it is made in such a way that this proton can easily move through this electrolyte membrane as you have shown in the figure, but it resists the electron to move ok.

Now, if you connect these two anode and cathode with some electric wire then this electron will pass through this wire and thereby it will create a flow of current ok. So, that is in very simplistic way of understanding the, this working principle of fuel cell. Now when this electron will go to this cathode, there is, a we have passed this air or oxygen at this cathode side.

So, it will make a chemical reaction with this oxygen and also this H plus ion will penetrate this electrolyte membrane it will reach in this anode side and thereby it will create H 2 O that is water and some amount of heat ok. So, this is the basic working principle. Now depending upon what type of electrolyte membrane is used we have different what materials basically used for this electrolyte membrane. And also, what

type of fuel whether we are passing pure hydrogen or a gas which is, which is having hydrogen atom. So, based upon that, we have different forms of, different forms of fuel cell ok.

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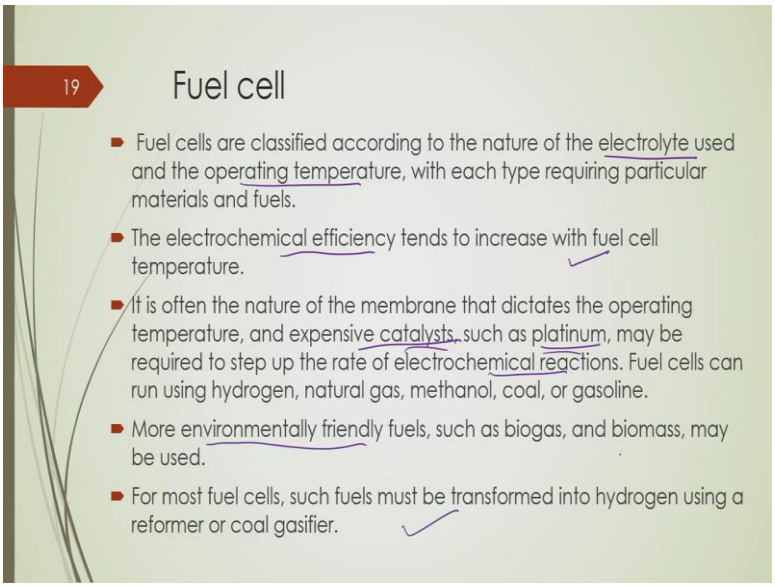

So, fuel cells are basically classified according to this what type of electrolyte membrane is used and also what is the operating temperature. In fact, as I said at this anode, we have you know by product of hydrogen H 2 O that is water as well as heat. So, this heat will create some temperature rise and based upon how much temperature rise will take place we have different classification ok. Or we have different forms of the fuel cell, they are having different operating temperature.

We can also identify that based upon this operating temperature we can also identify that for which application it is suitable for ok. Now as I said, this electrochemical energy tends to increase this fuel cell temperature. And as I was talking about this catalyst is basically used platinum to increase this step up this electro mechanic electrochemical reaction.

And since it is having only by product of H2O and heat, it is environmental friendly and, so, that is why you know fuel cell will be upcoming technology in various applications ok.

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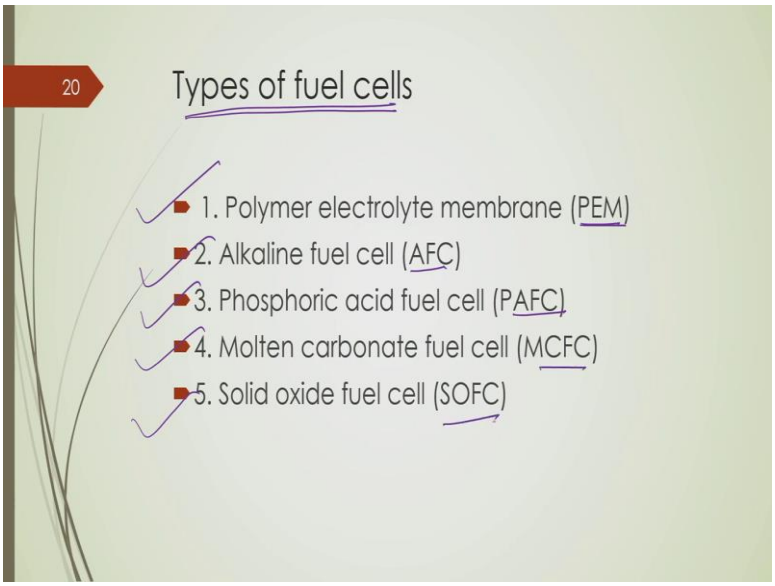

And as I said, based upon different types of this electrolyte membrane we have different forms of fuel cell which include a polymer electrolyte membrane fuel cell, alkaline fuel cell, phosphoric acid fuel cell, molten carbonate fuel cell, solid oxide fuel cell. So, they are often called by their acronyms PEM, AFC, PAFC, MCFC, SOFC ok.

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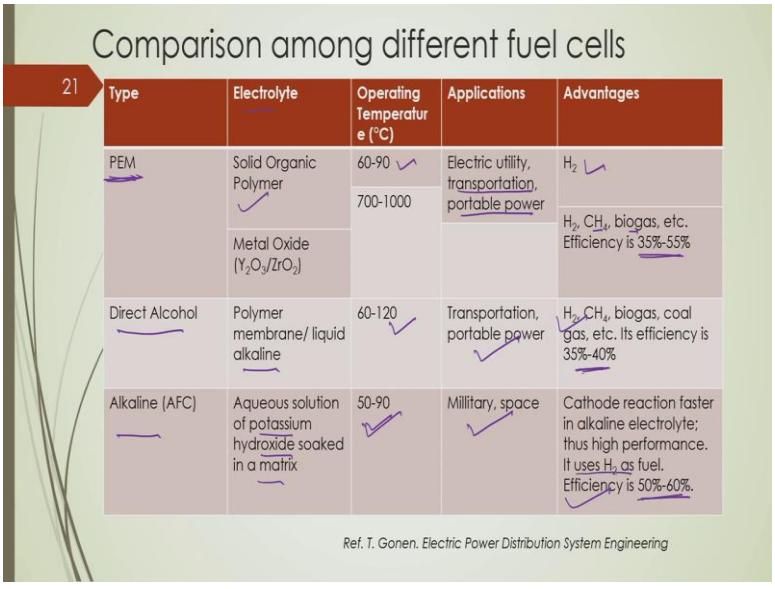

So, this table will give you a glimpse of this idea about the difference among these different forms of the fuel cell. Let us first with this PEM that is polymer electrolyte membrane fuel cell or sometime we call it proton exchange membrane fuel cell ok,

where electrolyte is used as solid organic polymer and it is operating temperature is very less, 60 to 90 degree Celsius. And therefore, it is suitable for transportation application or portable power ok.

Here we need only pure hydrogen as the fuel or sometimes we use some methane or biogas and its efficiency is 35 percent to 55 percent which is in fact, not as such bad ok. Now this is a direct alcohol fuel cell where polymer membrane or liquid alkaline is used as electrolyte membrane; operating temperature is higher than this PEM fuel cell. This could be also used for transportation application or portable power here, similar forms of hydrogen or methane biogas etcetera can be used as a fuel, and efficiency is similar to p m fuel cell even it is less than this PEM fuel cell. In alkaline fuel cell that is AFC temperature rise is similar to your PEM fuel cell, electrolyte membrane is used as aqueous solution of potassium hydroxide soaked in a matrix. Due to lower operating temperature, they can be used for military or space application and its efficiency is very high, 50 to 60 percent. So, it is used hydrogen as a fuel, pure hydrogen.

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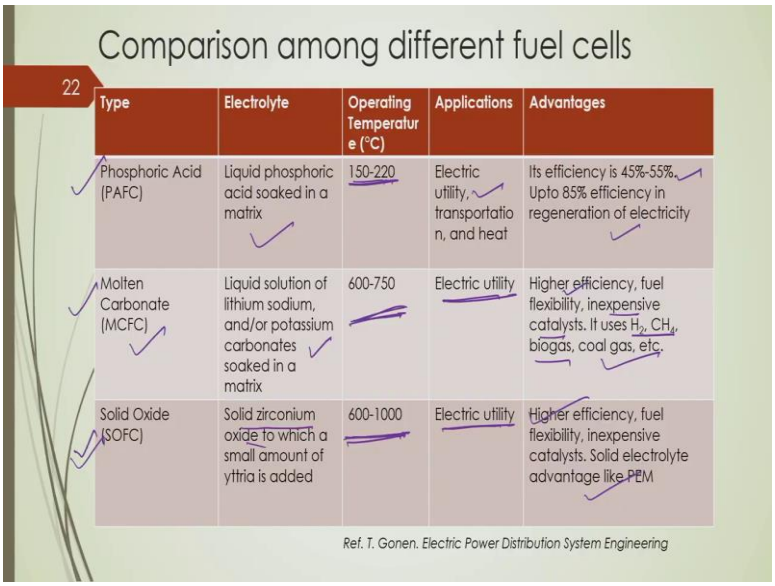

Similarly in phosphoric acid fuel cell, this electrolyte membrane is used as liquid phosphoric acid soaked in a matrix, operating temperature is higher than PEM fuel cell that is, 150 to 220 degree. So, therefore, this higher operating temperature enable is used for electric utility for power generation and storage.

And efficiency is also very good and up to 85 percent. if you can use the regeneration of electricity from this heat available. In fact, this is another advantage for these three part types of this fuel cell where operating temperature is pretty high. You can utilize this heat for cogeneration ok and that is why this form of fuel cell are suitable for utility application ok.

So, in molten carbonate type of fuel cell liquid solution of lithium, sodium or potassium carbonate soaked material is used as electrolyte. And therefore, since it is operating temperature is very high 600 to 750 with the use of proper heat management it can be used for electric utility application.

And it can use any type of fuel which includes hydrogen methane, biogas etc. It is having higher efficiency and inexpensive catalyst. In fact, this major barrier for deploying this fuel cell is that its initial cost or its investment cost because till today they are not manufactured in a mass scale so that this price will drop down ok.

So, therefore, still today this fuel cell, fuel cells are basically costlier. And because of that, because of this they are expensive, not many fuel cells are used for utility applications. But two important things which basically influence the cost or price of this production of fuel cell is one is this electrolyte membrane. Another is the catalyst used that is, platinum as you know, platinum is the costly metal.

So, that is why you know still today this is not used in utility scale. But it could be used in future and hydrogen technology would be an upcoming form of this powering the whole world not in terms of this utility application, but also in terms of this change in transportation application ok.

So, solid oxide fuel cell is having very very high operating temperature where electrolyte membrane is used as solid zirconium oxide ok. And because of this high operating temperature it is not suitable for transportation application, but it is suitable for electric utility application. This, having higher efficiency and the solid electrolyte membrane is an advantage ok.

Now, before I stop this part of this lecture I should clarify that why I call this fuel cell technology as a form of energy storage. Because you know that as we have seen that the

main fuel that we use for generating power in fuel cell is hydrogen ok. And the byproduct of this fuel cell is the electricity along with water and some amount of heat.

Now whenever if we use this fuel cell, another major challenge is to have the availability of the fuel for example, the hydrogen ok. So, hydrogen production is again a costlier item and that needs to be done in economical way so that the whole thing would be economical ok.

But one can always think of that this form of this energy is in terms of storage. Because whatever of this H 2 O we are getting as a byproduct of this fuel cell that from this H 2 O. We can again generate hydrogen with the electrolysis process. Now, if we have that provision along with fuel cell then this could be used as very good storage system. Because whenever we have surplus power, we can use it to generate hydrogen and to store it and whenever we have deficit power we can take, we can run this fuel cell to generate electricity and we can use it ok.

Now, this generation of hydrogen and generation of electricity can be done efficiently. If we have, if we can overcome some initial you know production cost of this fuel cell also, there are some sort of technological challenge in terms of production of hydrogen and also its storage.

So, these three things are very important; one is production of this fuel cell in mass scale that will be only possible if it can be extensively used in various applications. Number 2 is the production of hydrogen it is also a type of costly item and number 3 is the storage of this hydrogen.

So, when this technology will match three aspects, this fuel cell technology or hydrogen technology would surpass all sort of different forms of energy products ok.

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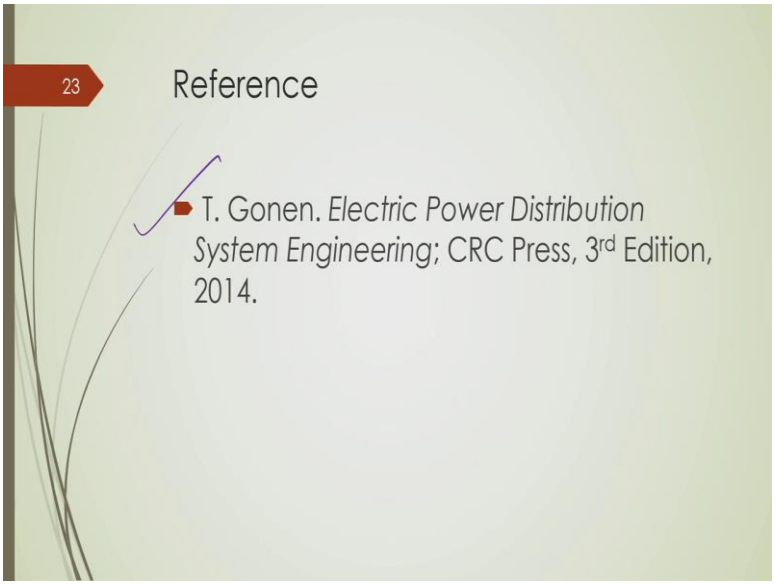

So, this form of the lecture I also prepared from this Gonen's book, Electric Power Distribution System Engineering and with this I complete this module 7 ok for this course and we have only 1 module left that is module 8.

Thank you very much for attending.