Non-conventional Energy Resources
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Lecture – 38
Supercapacitors

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Hello, in today's class we are going to look at a topic called super capacitors and this is form of you know energy storage device, that people work on and speak about in more recent times. And there are specific applications where, this is the kind of device that makes a lot of sense and in some places it may not be a device that can be used separately many times it may be used to augment a battery so to speak. So, it's an interesting kind of device. So we will go over it and there is a lot of research that goes on in it and a lot of applications that people are increasingly finding for it.

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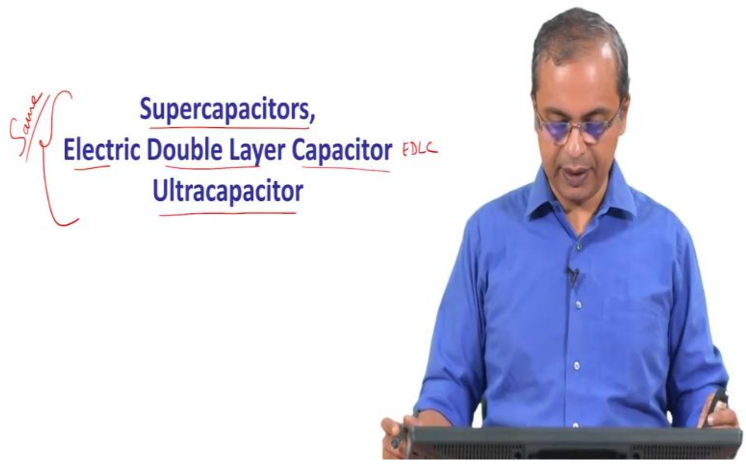

So in fact; if you look at the popular literature, if you read general articles on energy and so on you will see a few different terms that are being used you will here see a term of super capacitor you also see this term electric double layer capacitor, electric double layer capacitor and you also see this term ultracapacitor. So, these are the terms over and above just a capacitor. So, capacitor is something that's different, but I mean in some sense this is these 3 terms, that you see here so this is EDLC something like that.

So, super capacitors, electric double layer capacitor, ultracapacitor they all refer to the same thing okay. So, this is what you will see in the literature, but this is basically what it is that they are essentially the same. So, we will call it super capacitor for the course of this class and then, we will I mean this is just something that you have to keep it your mind.

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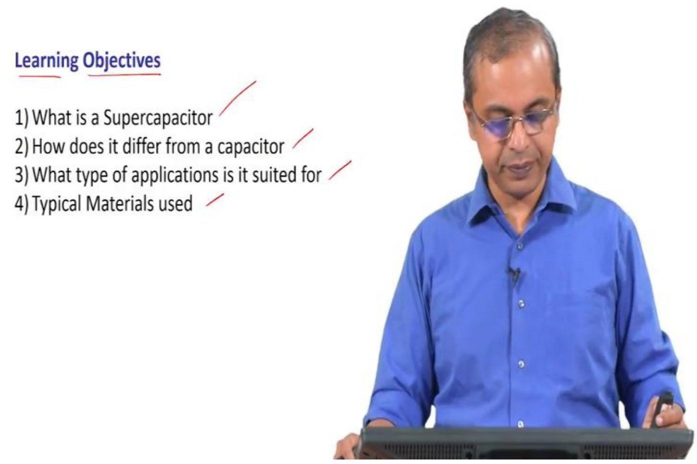

So, our learning objectives for today's class are of course, to first understand; what is a super capacitor? What is it that is you know since you are already aware of a term called capacitor? What is a super capacitor? What is different about it I mean, why should it be? When considered as something you know as separate from a capacitor so to speak.

so yeah, how does it differ from a capacitor? And what are the applications it is typically suited for what kind of applications it gets used for and what are typical materials used for the supercapacitor. So, these are some of the learning objectives for our class and within this context of these learning objectives we will look at the content of the class.

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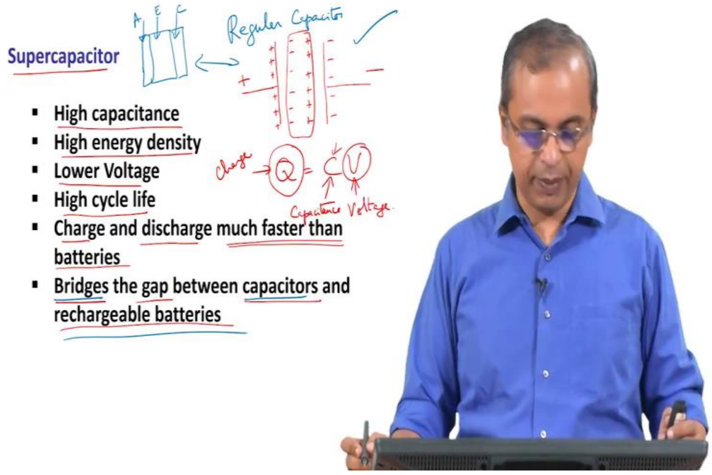

So, a supercapacitor is nothing, but a capacitor that has very high capacitance. So, I mean you can make you know from different manufacturers you can get capacitors of different capacitance, but just because something has slightly higher capacitance doesn't make it a super capacitor we will see that you know the; you are looking at several orders of magnitude difference in capacitance.

So, see when a capacitor is simply 2, parallel plates 2 metal plates right and there is some dielectric material in the middle could even be air, but you typically have at some dielectric material. So, you charge this up a supplier you attach this to some battery and you charge it up so you will get positive charges here. And you get negative charges here and corresponding, you will get the opposite charges here lining up with this positive charge you will get negative charges from the dielectric you will get positive charges here.

So, this is how it stores up the charge in the capacitor and then you can later release it and then you can get the; you know charge back to you. So, the charge that is usually there is given by C V, where V is the voltage you applied and C is the capacitance and this is charge. So, this is voltage in volts capacitance in Farads and charge in coulombs so this is what you will get so this is the relationship.

So, we are talking of capacitors where the; you know capacitance value is very high. So, therefore, for the same voltage you get very high amount of charge that is being held there so this is something that we look at it has high energy density.

Generally, relative to you know and other options that; you have the voltage, that it can give you is a little low, cycle life is very high. We will talk about this as we go through the other option; I mean details of the super capacitor. Generally cycle life is high, high in the sense we are looking at you know again several orders of magnitude that, that's the point that you have to remember as we look at numbers you will see it is not just high by a relative sense of you know a factor of 20 percent, or 30 percent, or even 100 percent. We are looking at difference both in capacitance in cycle life etcetera of several orders of magnitude so to speak.

Basically, it charges as well as discharges much faster much faster than batteries. So, that's the key that you have to understand that it charges and discharges much faster than batteries. And, therefore there are applications where the battery where the change in circumstance is kind of fast and you want something to store that energy quickly.

So, there a battery will not be able to do the job although a battery can store energy, it needs some time to pick up that energy, but supposing you are delivering that energy is so fast that you know you don't have that time you have only a few seconds in during which you delivered a whole amount of energy and you want the battery to hold it the battery is unable to pick it up.

Super capacitors are in a very good position to pick it up so that is why the super capacitor is interesting. So, in a sense it bridges the gap between regular capacitors and rechargeable batteries ok. So, this; what I have shown you here is a is a typical regular capacitor.

So, we will see that some more again anyway, but this is a regular capacitor. So, this is not what we are doing here we are talking about super capacitor and it the super capacitor bridges the gap between these kinds of regular capacitors and rechargeable batteries where you have you know an anode a cathode and an electrolyte so you will have. So, this is a regular capacitor the rechargeable battery will have anode, electrolyte, and cathode ok.

So, this is how we have the rechargeable battery and then you go again you charge it discharge it etcetera. So, between these two is where the super capacitors end up coming so we will we will look at that.

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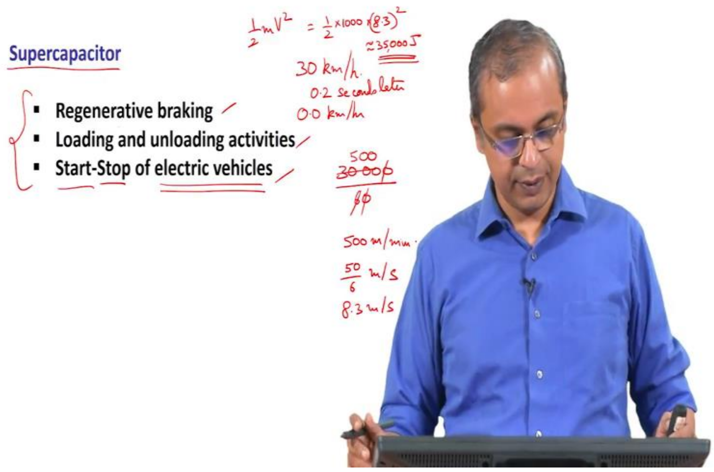

So, some for example, I just mentioned to you that you know it is ideally suited for conditions, where the circumstance is changing fast and you need the energy to be handled rather quickly. So, for example, if you look at regenerative braking okay so regenerative braking is the braking that is these days being done in electric vehicles? In fact, you could do it any in any other vehicle also, but generally since the electric vehicle is set up to run everything operationally using electricity the scheme of you know any energy that is any energy transaction that is happening people try to convert that to electricity.

So, normally in a regular car you press the brakes, the brakes just become hot okay so they become very hot and essentially that's what they are doing they are converting your kinetic energy into heat and releasing it.

So, there is a lot of friction that is put there it converts the kinetic energy of the car into heat and then throws it out into the atmosphere; so that's, really what is going on? So that is why you know when you are going on hilly terrain and you are climbing up and climbing down and so on your brakes can heat up very extensively; if you are continuously using the brakes. So, that's why we keep telling you use a gear lower gear and enable the gear to help you slow down your vehicle rather than just keep on pressing your brake you have to press the brake if you need it, but basically this is what is happening.

So, when you keep the when you keep pressing the brake you know continuously; you know you know say one hour downhill drive that really heats up the brake to the point that they may fail. So, you have to be careful with your brakes, but that’s what is happening in a conventional vehicle in a conventional car that is exactly what is happening.

Now, in electric cars the idea that you know when you try to generate electricity back from something that is; moving it slows down whatever is moving. So, you are using that energy that is there in the rotational process to generate electricity by just the way a dynamo would work in a in a you know cycle that you had except that there also the dynamo is pressing to slow down the cycle, but you don’t want it to slow down the cycle.

Here, you are consciously using this electricity generation process to brake the car to enable braking for the car so that that comes to home. So, regenerative braking as you can imagine is something that’s happening in fractions of second’s right. So, fractions of seconds to a second is, what you see traffic you are driving and traffic you need to hit the brake you hit the brake immediately you don’t hit the brake over several minutes you hit the brake instantaneously.

So, the breaking process occurs over a fraction of a second so that’s; what I meant by saying that? The time scale is very small in that time scale in that fraction of a second the entire energy that was there in the car the kinetic let’s say a car was traveling at say 30 kilometers an hour ok. And half a second later not even half a second maybe 0.2 seconds later, you have the car at 0 kilometers in hour ok. So, whatever was the weight of the car so, if you look at half m V square. This much kinetic energy was available.

So, if a car is about so this is half into let us say a 1000 kilogram car. So 1000 kgs you have and V is 30 kilometers an hour, so that is we have what we have 3000 you know 30000 meters in so you will have 30000 in 60 minutes. So you basically have this goes this goes 500. So, you have 500 meters per second per minute per minute and you divide this by 60 so you will have whatever 50 by 6 meters per second so, that’s the speed.

So, roughly about what is it 8 8.4 8.3 meters per second that's the velocity it is traveling at. So, you have half into 1000 into 8.3 square so this is the amount of energy that the car has in joules so that is quite significant. So, this is about 64 so about 30, 35.

So, you are looking at 35000, about 35000 joules so 35000 joules you have. So, this is 64, 64 by 2 is about little more than 64, so I will I am just assuming say it's 70, 70 divided by 2 is about 35 and 35 into 1000 so 35000. So, you have to 35000 joules of energy in a car that is; traveling at 30 kilometers an hour it travels about 8 meters every second and you are you are essentially in a 0.2 seconds you are bringing it to a complete halt.

So, in 0.2 seconds this much energy has to be stored somewhere a battery will not be able to pick up this much even though it is maybe a battery pack inside it will not be able to generally it takes time, it takes a lot of time for all the reactions to happen for the electricity to be picked up by the battery. So, a battery typically is unable to pick up 35000 joules in 0.2 seconds ok.

So, you need something else which can pick up this 35000 joules in 0.2 seconds, if you want to really do regenerative braking. So that's the kind of you know quick transition that which a battery cannot handle that a super capacitor handles okay so, that is the point that we want to understand so that is one application.

Similarly, loading and unloading so you load something on some you know loading process of adding a weight to something and then removing the weight from something. So, you need suddenly a fair amount of energy to lift something up put it somewhere and then release right. So, again you need a huge amount of energy being delivered shortly in a short duration of time, you have to pick this object up every is sitting quite. Suddenly you pick up this object which could be you know 500 kilograms, 1000 kilograms, whatever pick it up put it up into some shelf.

So, this may be happening in some storage warehouse or something, so that kind of a thing where you have a machine which goes and does this it goes and picks up a package lifts it off the ground puts it into shelf releases comes down. So, that has to you know suddenly give you that energy in this matter of a fraction of a second again, that is; something that a super capacitor can deliver to you. Also we spoke about regenerative braking and that that comes to the stop part of an electric vehicle, similarly start part of the electric vehicles, suddenly you want to start the car right.

So, in fact if you look at what all people are doing to you know optimize the energy usage for a vehicle which is you know a major aspect associated with you know running clean energy, environmentally friendly energy, and so on a usage of energy. right now they have they are implementing and you know the operational characteristic of a car in such a way that when you come to a halt for any reason even let’s say traffic has halted and you just come to a halt, because the vehicle in front of you is halted you just stop your car at that instant it will switch off the engine automatically you don’t have to do any such thing.

So, for example, in Indian conditions we are often told that if you come to a traffic light and you see that it is going to take some time you switch off the engine and that way you can save a lot of energy because a massive amount of energy is wasted just waiting for the traffic light to change traffic signal to change right.

So, most of the time we are advice to switch off the car and many of us sometimes we do it sometimes we do not do it and so on so lot of energy is wasted. So, the modern day electric vehicles actually do it automatically. So, the moment it senses that the velocity is 0, it instantaneously switches off the engine it’s completely it goes to sleep for several seconds.

The moment you start it will; immediately start that’s the beauty; of it you don’t have to you know give it any you don’t have to give it even a second to start almost instantaneously it is start. For it to almost instantaneously start again that much amount of energy has to be delivered suddenly all of a sudden you have to deliver this massive amount of energy to get this you know maybe 1 ton or 1 and a half ton car to start moving again almost immediately so, that is again done by the super capacitor.

So, both starting as well as stopping when you stop picking up the energy in a fraction of a second is done by supercapacitor. When you start again delivering of a lot of energy in a fraction of a second is done by a super capacitor. So, like this you can think of a variety of interesting end uses where the super capacitor is quite unique in it is ability to handle that task.

So, the battery can take care of the general operation okay the general operation of the device can be handled by the battery, but the transitions when you go from one operating point to as a distinctly different operating point could be from start to an accelerated starting point or from an accelerated, I mean a high velocity to certain stop those kinds of transitions which are drastic transitions occurring over a very short period of time, that is; where the super capacitor really makes a difference which the battery cannot do. So, like it's a good combination to have a; some set of super capacitors, and some set of batteries which are appropriately matched for a particular end use.

So, that the user experience as a user you buy a vehicle and you use it your user experience is very enjoyable you don't see problems you don't go back and complaining saying that you know I used to drive a petrol powered vehicle. Now I got this electric vehicle every time I try to start it struggles for a fraction of a second and then starts or a lot of energy is getting wasted I am not seeing enough benefit from it and so on. So, all those things are not that you will get all those benefits by having this combination right so that is what a super capacitor is capable of doing ok.

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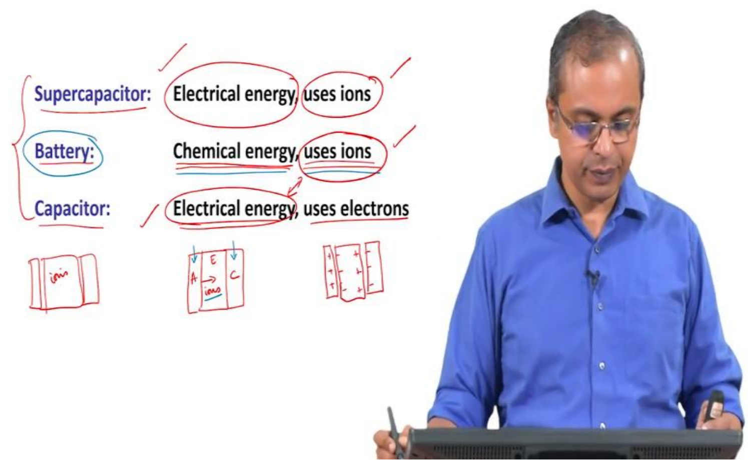

So we have 3 terms here we have a super capacitor, we have a battery, and we have a capacitor. So, we will spend a little bit of time trying to understand; what is the difference between these 3? So, primarily if you look at battery we is; we know that it is an electrochemical device ok.

So, the energy that is stored there is stored in the form of chemical energy, chemical energy meaning you have a reactant sitting on one electrode and another reactant sitting in another electrode. So, chemical reaction happens it’s an electrochemical reaction sure this so there is a charge transfer between electrolyte phase and the electrode phase.

In the end there is a chemical change that has happened to some constituent right so some compound has formed. So, we saw a lead, lead could become lead sulfate or lead oxide could become lead sulfate cobalt oxide could become lithium cobalt oxide, so many chemistries we saw for batteries.

So, but bottom line being there is a chemical change and that chemical change cost you to this electrochemical reaction is the manner in which the energy is stored. So, in a way you are storing it in the form of chemical energy the energy that is being stored is to being stored in a form of chemical energy right and to do this process you are using ions.

So, you have so for example, in a battery you will have the let me just put it here. So, you will have as we just saw anode, cathode and this is the electrolyte and you have some ions going across right. So, that is the process by which the activity happens. So, there is a chemical energy that is stored here.

So, chemical energy is stored here, chemical energy is stored here in the form of whatever reactants are present and then the ions move across and enable the process to happen. So, ions are moving and chemical energy is being stored. So, this is the idea with respect to a battery.

Now with respect to a capacitor we are actually storing electrical energy so meaning you have a flat plate another flat plate and then in the middle you have a dielectric ok. So, you store electrical energy so well as I said you have all these charges here you have minus charges here you have plus, plus, plus, minus, minus, minus.

So, you don’t have ions you have electrons basically and the energy is being stored and as in the form of electrical energy there is no chemical change that’s happening we will discuss that some more, but there is no chemical change that is happening the super capacitor uses this aspect of it that there is no that it’s electrical energy that is being stored that is the aspect that in which it resembles a capacitor, but it uses ions and in this process it resembles a battery.

So, it picks these two concepts so that’s what you have here it uses ions and it stores electrical energy ok. So, you have similar thing you have some electrode structure some something in the middle and another electrode structure and then you have ions here okay and that’s how the super capacitor is functioning.

So, we will see that functioning a little bit in more detail in just a moment, but this is how the three of them differ. So, the super capacitor uses ions the just away battery does and it stores electrical energy just the way capacitor does okay so this is the idea.

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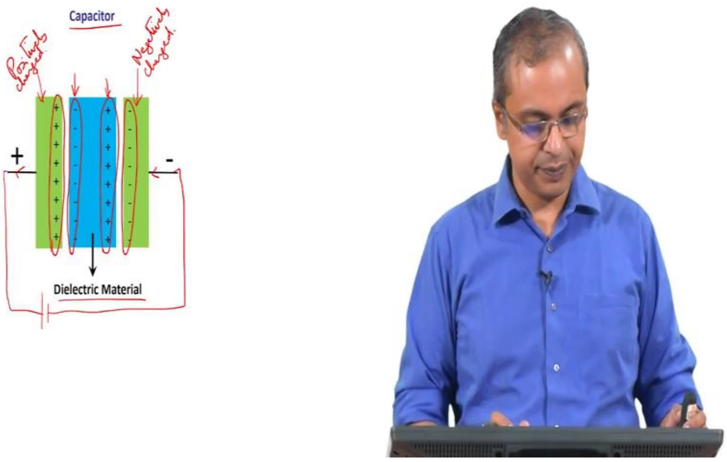

So, as I said if you look at capacitor this is how a capacitor schematic of a capacitor would look you would have two parallel plates.

So, one plate here, and one plate here which would be your electrodes to which you connect an external battery. So, you connect this to a battery. So, this is the positive positive and then I connect it here negative comes in ok.

So, then in the middle you have a dielectric material which is what which is shown here and then as you have supply electrons to this side and you take away electrons from here. What happens is this becomes positively charged, this becomes negatively charged, and then correspondingly the dielectric material the side of the dielectric material that faces the negative electrode becomes positively charged, and the side of the dielectric material that is facing the positive electrode becomes negatively charged.

So, overall there is charge neutrality there's just the same amount of positive charge as there is negative charge etcetera. So, you have charge neutrality and the also you should remember that this charge that you see here in the dielectric material is more or less in one region it's a flat region. So, you are looking at flat regions here.

So, in a very flat region you have a negative charge collecting on this surface of the electrode, similarly a flat region here both the electrodes are flat smooth surfaces here you again you have positive charge that is being collected. In the middle in the middle you have the dielectric material there also on the surface of the dialect material on one side you have positive charge on the other side you have a negative charge. So, this is the way in which the capacitor is functioning okay and in this process charge is stored energy stored you can reduce the energy depending on your requirement.

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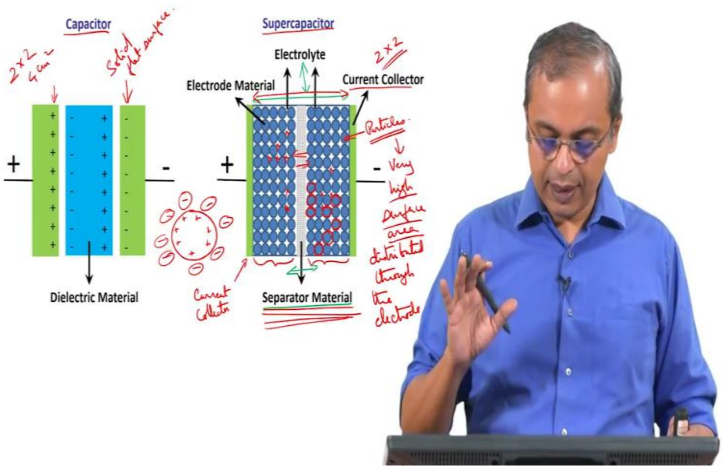

Now, if you now look at a super capacitor some of these ideas are being carried over, but and there's a lot of change so that is what we are trying to understand here so this is the super capacitor. So, again you can see here there is something like an electrode, but here the electrode simply serves as a current collector so this is like a current collector and so this side also you have a current collector okay and important difference that you have here is you have a porous electrode. On both sides you have an porous electrode and we will talk about that in just a moment in the middle you have a separator ok. So, you have something called a separator.

And, then in this entire region that you see here this entire region; that you see here from here to here you have electrolyte this electrolyte ok. So, this is what we are looking at in the course context of a super capacitor, so the point being that the current collector essentially enables electrical contact for the external circuit with these particles.

In this case it is particles but we will we can look at other options available, but this is basically particles. So, we have a structure where you have lot of particles that are present and therefore, because it is particles and not a solid object like this is not a this is a solid flat object okay, solid flat surface because it is a solid flat object here you have particles. So, you have very high surface area that is divided and distributed ok.

So, you have very high surface area that is now distributed through the electrode. So, it is not a flat surface it is not a single flat location where the charges represent when you talk about the charge, but anyway these particles are present and there’s an electrolyte that is present the electrolyte that is present over the extent entire extent of this region that that I just marked here between this current collector and that current collector you have electrolyte. So, this electrolyte actually penetrates into these particles. So, all these gaps that you see here all the gaps that you see here are all filled by the electrolyte everywhere ok.

So, all the gaps that that you see here so even here whatever gaps you see between the particles are all filled by the electrolyte so the electrolyte permeates into these porous into this porous structure. So, it’s important that the electrode actually be a porous structure the way we have shown here in a schematic, but the specific purpose of it being a porous structure is to ensure that this electrolyte that we are talking about has penetrated into that structure and it is present throughout that structure.

So, now whereas previously; you just had this flat surface. So, therefore, whatever was the geometric area was the area of the electrode so if it is you know 2 centimeter by 2 centimeter electrode, that’s a 4 centimeter square electrode right. So, if it is 2 into 2 so that’s 4 centimeter square electrode.

Here, even if your current collector is 2 into 2 that is; only the current collector area only is 4 centimeter square right actual surface area of the electrode is the surface area of each of these particles. So, you have to calculate the surface area of each of these particles and the total surface area that you get by a totaling up the surface area of all those particles is the surface area of the electrode.

So, therefore, this has an extremely high surface area very high surface area relative to this regular capacitor. The super capacitor relative to the regular capacitor the super capacitor has a dramatically different amount of surface area you are looking, at several orders of magnitude higher surface area relative to the regular capacitor and we are utilizing that surface area by enabling this electrolyte to penetrate throughout it and of course, you don't want the you know positive electrode to directly come in contact with the negative electrode right.

So, otherwise you will short circuit the thing if that short circuit the concept of a short circuit is the same here also. So, you don't want a short circuit between the positive electrode and the negative electrode that is why we have this separator material. So, the separator material will be sitting in the middle it is a non conducting material it is basically also soaked in the electrolyte. So, that the electrolyte is continuously present throughout the structure.

And separated materials are essentially the same kind of separator materials that you would use even in a battery. So, you have the separator materials which are non-conducting you know maybe polymer based materials which are porous so it's a porous structure. So, you can have electrolyte going in all directions through that structure and it fills that whole structure.

So, so though those are the things you have done you have put in a separator material which was not there in the capacitor you have put in a porous electrode structure not there in a regular capacitor and this electrolyte is distributing itself throughout this porous structure ok.

So, this is the way in which the structure of a super capacitor differs from that of a regular capacitor. So, as you can see at least at a structurals level and keeping in mind that there is so much more surface area there is a huge difference between what a capacitor is what a capacitor is and what a super capacitor is ok. So, this is the point we have to remember.

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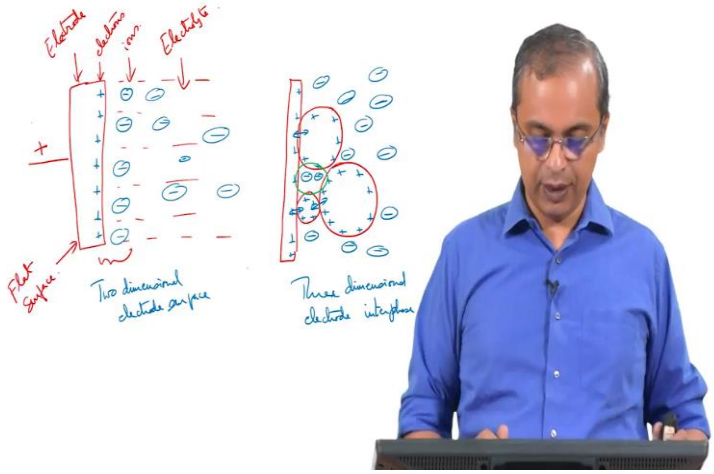

So, now, I will also point out that when you put an electrode in contact with an electrolyte. So, this is the electrode, and this is the electrolyte and let’s say; I connect this to the positive, positive of a battery ok. So, when you do that let’s say so you get a bunch of positive charges here ok. So, that part is still the same now the electrolyte contains ions okay so, the ions actually have you know they will have.

So, let’s say I have negatively charged ions so those ions are now affected by the presence of this charge that is there on the electrode. So, naturally just the way you would expect in all these circumstances the opposite ion gets attracted to this electrode. So, what happens though is that it doesn’t necessarily just form a single layer here ok, initial models used to suggest that it will also form a single layer, but because it’s an electrolyte and because you know there is thermal energy associated with it and there is movement of the electrolyte simply because of thermal energy that is present there etcetera it does not form a single layer it actually distributes itself some more.

So, much deeper into the electrolyte also you will have this region that is affected by this by the electrode ok. So, so this is how the electrode electrolyte interface operates. So, we even here there is the notion of a double layer capacitor here, but the second part of the layer is not necessarily a flat structure it is a little bit more distributed structure that’s the point we have to keep in mind. And you should remember that you should also notice that on this side you have electrons and on this side you have ions.

So, on one side of the electrode electrolyte interface on the electrode side you have electrons on the electrolyte side you have ions ok. So, when you look at this structure of the super capacitor what is different here relative to what I have drawn here is that the in the electrode in this case I have drawn as the flat surface.

Whereas, in a super capacitor we have one flat surface which acts as a current collector and just for you know to wake for clarity sake I just only draw say two or three particles. So, I have a large particle I have a small particle and I have one more large particle something like this right. So, then the charges so you put a positive charge here, this positive charge because these particles are electronically conducting is also the positive charge that distributes itself here ok.

Then the negative charge gets distributed in this intermediate area is all con containing electrolyte. So, all here you have electrolyte all over this place. So, you have negative charges collecting here ok. So, this is how the now you have sort of extended the electrode into the system you have extended the electrode into a larger region as supposed to a flat.

So, what was two dimensional has suddenly become a three dimensional structure right so that is what you have done. So, this is two dimensional, this is three dimensional. So, the electrode electrolyte interface is three dimensional it is distributed into into a larger region and that is how you know electrical contact has been made here, the electrical contact is there, electrical contact is here, electrical contact between these particles is then that’s how the positive charge that you put on the electrode goes to all of those particles and then the electrolyte is you know it has permeated everywhere and that is very important.

If the elect so for example, if the electrolyte were not here so supposing this region there is no electrolyte then in that place there is no charge this charge will not have this charging will not happen right. So, it is very important with the electrolyte penetrate everywhere once it penetrates everywhere you can do this.

And of course, you are like I said you know the this separator is also very critical because the separator is not there then you will have a short circuit across this which is also not something that you want you definitely don’t want the that kind of a situation ok.

So, that is how the super capacitor you know suddenly creates a situation where you are having a much higher surface area and because you have much higher surface area and the charging process you know so fundamentally depends on that surface area that you know the amount of charge it holds goes up in a big way.

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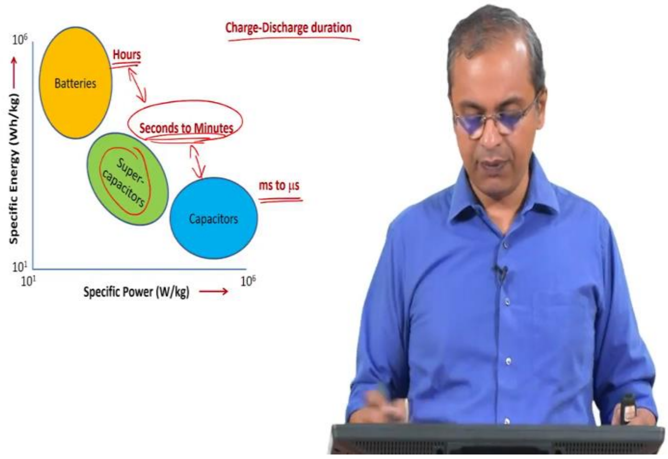

So, if you compare this is a this is the kind of plot that you would often see where they are comparing different kinds of power sources available to you different kinds of energy sources available to you.

So, if on your x axis we have specific power okay in watts per kilogram, so that is specific power and on the y axis we have specific energy, watt hours per kilogram so or joules per kilogram. So, if you see in in comparison between batteries, super capacitors, and capacitors batteries which usually will have a lot of charge that they can hold, but are relatively lower amounts of current that you can draw will have high amount of energy okay so they are up on this axis.

So, they are up on this axis high amount of energy, but they are unable to deliver this at very high currents, so they are actually low on the power axis. So, they are on this side of the power axis. So, you go up vertically and move towards the; I mean closer to the y axis that's where the batteries sit.

So, this is the general direction in which the battery will go the capacitors on the other hand go the other way. So, if I capacitors are in this direction they are they don't have much they don't have ability to hold a whole lot of charge because it's just a surface you know just a little bit of charge who held on the surface, but that whatever is there on that surface it can release really fast.

So, therefore, in terms of power which basically relates some voltage, but significantly depends on the current that you can deliver you can deliver a high amount of current for a fraction of a second, so that's a capacitor the super capacitor is somewhere in the middle it has a little better specific energy than the capacitor, but it also has a little better specific power than a battery.

So, it nicely bridges the gap between a capacitor and the battery in it's ability to deliver power as well as hold energy and in this process it can enable supporting both a capacitor and a battery in specific applications where each one of them can individually perhaps not do it so that is the way you may want to look at it.

So, for example, if you look at charge discharge duration required for charge and discharge if you look at capacitors they typically require anywhere from a milliseconds to microseconds to charge or discharge okay so milli seconds to microseconds is all it takes to charge or discharge the capacitor and so that is a very tiny amount of time and it is able to do the job that quickly.

Batteries on the other hand take hours to charge and discharge we are quite familiar with that because all our mobile phones operate that way when even though many of us may not have used an electric car it's still not that common electric cars typically take several hours to charge.

We usually in fact the normal operating scheme for an electric vehicle is that you bring it home you leave it on charge overnight, and then when you leave it on charge overnight next day you can drive for it maybe 150 kilometers or 200 kilometers something some range will be there 100 kilometers, 150 kilometers something that range happens the next day, but overnight you need to charge. So, you are charging for some 8 hours, 10 hours etcetera.

Mobile phones also of course, these days they have faster charges and what not, but still you are looking at you know of the order of hours to charge a mobile phone completely. the super capacitors on the other hand again in the middle as opposed to milliseconds to microseconds to charge it takes several seconds to minutes to charge. Several seconds to minutes to charge and it also just requires several seconds and minutes to discharge.

So, whatever energy it stored it takes up that energy over this space of a few minutes and then you can deliver it back in few minutes. So, from a few seconds to a few minutes it will deliver that energy back. So, what it is doing in terms of time is significantly better than what the battery does the battery requires several hours to do it's delivery of charge or discharge this is doing it in seconds or minutes, but it is holding much better charge than a capacitor ok.

So, capacitor clearly is doing you know several orders of magnitude better than a battery in terms of time, but because it doesn't hold much are there is not a whole lot you can do with it even though it gives you that whatever it holds it gives in you know microsecond, but it gives you such a tiny amount in microsecond that you cannot really do a whole lot with it you have to put a huge number of capacitors to even run something for a you know couple of minutes so that is not going to help you. So, this gives you a nice mix of you know the timing which is just seconds to minutes, but the charge is distinctly higher than that of a capacitor.

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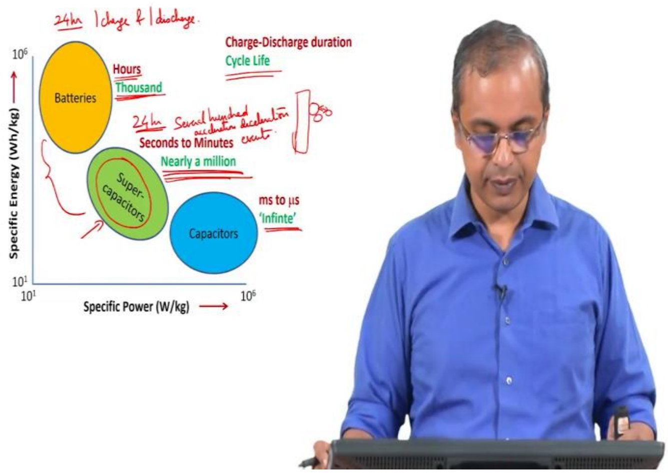

So, for example I also in the same context in terms of cycle life; if you look at cycle life you can see that capacitors are almost infinite in their cycle life you can keep on cycling a capacitor for all practical purposes it nothing will happen to it. Because, you are really not doing any significant change to the material it just remains whatever it is so nothing much is happening to it.

So, it works for you know millions of several millions of cycles it will run essentially it's infinite from for our practical applications. Batteries on the other hand good batteries I am not even talking of ordinary batteries good batteries will probably give you about a 1000 cycles.

So, what is the real reason for this restriction where a number of reasons are there usually what is happening, because there is a lot of chemical reaction that is going on electrochemical reaction that is going on across the interface and a few different things happen for?

For one thing for example, at lithium ion batteries for example, you will have an eventual degradation of the electrolyte that may happen, but more importantly the electrode itself is changing from one phase to another phase you are having some reaction that occurs. So, some chemical that is there in the electrode changes to some other chemical. So, there's a there's a change in you know one reactant becomes some product and so in terms of a phase one phase becomes another phase each phase has a different you know specific gravity and. So, it's volume will be different.

So, invariably if you look at battery electrodes their dimensions even though you don't see it externally you are seeing the same battery that is there. Internally the dimensions of those electrodes could be changing, they could be swelling, they could be getting compressed, etcetera.

So, there's a lot of structural change that happens at that level it is not something that's visible to us, but at the level of those particles it is a lot of structural change that is happening the crystal structure level there is a lot of change that is happening so that puts a lot of stress at that you know size scale. So, many of those particles that are present in that electrode can break, can you know deform or a particularly if they break off they may lose contact with the rest of the electrode. So, you have an electrode, and you have some two particles there one particle here and another particle here.

So, this particle the second particle may at some other particle may break away from the electrode and so now, this is no longer in contact. So, if it’s no longer in contact it is no longer in a position to participate in the reaction ok. So, so all these things happen in a battery so because there is swelling there is a change in dimensions of the particles etcetera lot of damage happens to the electrode over a period of time ok.

So, it happens over a period of time. So, normally that is the reason why by the time you have done up say a 1000 cycles, the battery does not behave that well it doesn’t behave that particularly well and then eventually you give up on it get yourself a new set of batteries.

On the other hand super capacitors are only charging on the surface there is nothing there is no chemical reaction that’s happening. So, there is no species chemical species in the form of ions no ions are entering the electrode structure I mean the sense if you go back here and look at these particles, if I take an individual particle here the ions just come to the surface.

So, for example, if I say so, this is let’s say it is positively charged here, the ions come to the surface, but these ions are not entering the particle this holding position just around the surface they don’t enter the particle. So, in the particle nothing is happening the particle doesn’t swell, does not contract, nothing happens it just stays more or less intact.

So, therefore, in many ways it is undisturbed by the cycling process and therefore, if you go down here it is also in a position to give you a million cycles, a million cycles is a lot I mean in the in the context of you know electric vehicles and so on. So, million cycles works out very well because even though you know if you are doing a let’s say a battery that is running the electric vehicle is charged once overnight.

So, you do one full charge and then the next day you run for 150 kilometers and you do a full discharge. So, if you used a battery for a 24 hour period of a electric vehicle you do 1 charge, and 1 discharge, but if the braking is a regenerative braking which is using the you know super capacitors and you also let’s say you take the assistance of super capacitors to help in the acceleration and deceleration and so on of the vehicle.

then especially in conditions where there is high traffic and heavy traffic and so on let’s say typical Indian conditions where there is a lot of start of the car stop of the car you know you have to slow down the car, accelerate the car and so on.

In the same 24; 24 hour period you may have I mean several 1000, several 100 to a few 1000, charge discharge you know acceleration, deceleration events right. So, you have several 100 to a 1000 maybe a few 1000 acceleration deceleration events. So, a charge discharge of the battery happens only once, but the acceleration deceleration of the vehicle happens several 100 times maybe 1000 times it happens.

So, therefore, it makes sense that you use some device which can handle I mean you would really will utilize this the fact that it cannot be it can be cycled a million times is really useful to you and the fact that the battery can be cycled only if I mean a thousand times is still for you.

So, a 1000 times if you can charge and discharge a battery that already means 1000 days you can use the battery so; that means, that that is over 3 years right, something like around 3 years you can run the battery, but a million times you are charging and discharging ability to run this 3 orders of magnitude more becomes necessary because you may in fact, use it a few 100 times each day.

So, you will have to multiply it by a few 100 and then that the million really works out comfortably for you right so that is; how these two taken together are really useful for electric vehicle applications. The battery super capacitor combination.

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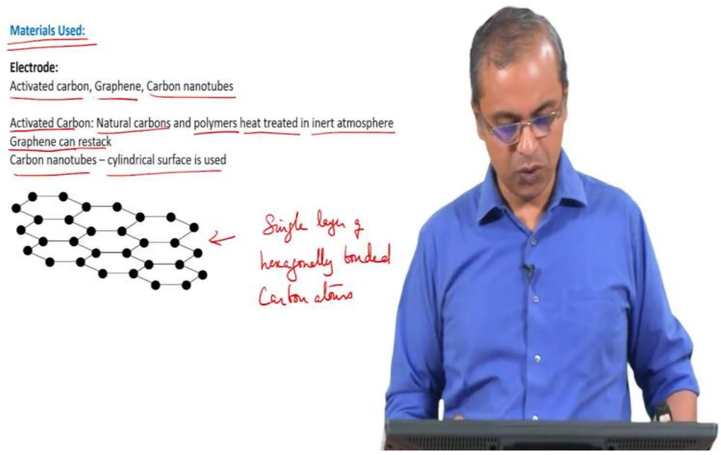

So, let’s look briefly at the materials used for this super capacitor, as I said in general the idea is that there is no reaction as such happening on the electrode it is just a highly porous structure which can interact very well with the with good electronic conductivity which can interact well with the electrolyte.

So, the electrode electrolyte combination is typically critical usually people are using things like activated carbon, carbon nanotubes, and Graphene this is these are the kinds of materials that people are actively researching and working on.

So, activated carbon for example, is simply natural carbons that you get from you know let’s say sawdust, or you know some waste material from the agricultural sector, and then or you can take polymers artificially derived polymers and then you heat treat this in an inert atmosphere. So, you remove all the other species from it you will get carbon that carbon is typically called activated carbon it has high surface area so that is what is this activated carbon.

Then you have graphene graphene is like this it’s a single layer of hexagonally bonded carbon atom. So, this has very high surface area because you just have a single layer of atoms and you have high surface area.

So, if you put lot of graphene particles together you have a lot of a very high surface area with which the electrolyte can interact, but the only issue is that the graphite is actually much more you know stable kind of a structure. So, if you give it enough chance the graphene will realign and form restack and start forming graphite. So, you have to keep that in mind so you have to do something to stabilize it so to speak then of course, there are carbon nanotubes which are cylindrical in structure.

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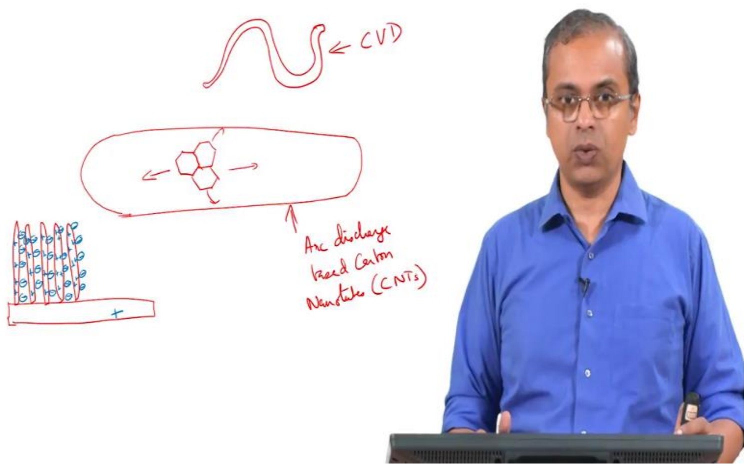

So, they essentially look something like that, A long cylinder we can end cap this side and an end cap that side and in this you have all those hexagonally bonded carbon atoms right. So, this is how you have the structure.

So, you have hexagons like that and then you get the so this hexagons are there all over the surface. So, this continuous in all directions and this is how you get this structure you get cylindrical structures based on how you generate this the nanotube you can get it straight the way I have drawn it or you may even get highly curved coiled tubes like that ok.

So, you will have you know some extremely coiled tubes also you can form so usually the CVD, CVD based synthesis of chemical vapor deposition based synthesis of a carbon nanotubes, which is the typical kind of carbon nanotube you get when you commercially buy it when you go to you know some internet site where they sell carbon nanotubes and you purchase it mostly they are providing you chemical vapor deposition synthesized carbon nanotubes that will give you extremely coiled structure.

If you look under an electron microscope you will see the structures that look extremely coiled whereas, if you do arc discharge based carbon, nanotubes or CNTs as they accord then you get this straight structures.

So, this straight structures or the coil structures you can use in an electrode. So, so for example, if this were your current collector you could line all of these up on top of them ok. So, I have just drawn some for example, so if you look at it charge wise let’s say this is positively charged so all of this will get positive charge, all the surface of this will get positive charge and correspondingly you will get negative charge in all the all the negative charge ions will come around it.

So, like this you will get right. So, you get all this negatively charged ions which are collecting in the gaps between these carbon nanotubes, because you have the charge that has been built on the carbon nanotube and the positive charge is sitting in the carbon nanotube. So, this way you now have a very three dimensional structure over which you have a lot of charge that has been held together ok. So, this is how you take flat structure and generate a lot more charge and store it in this structure.

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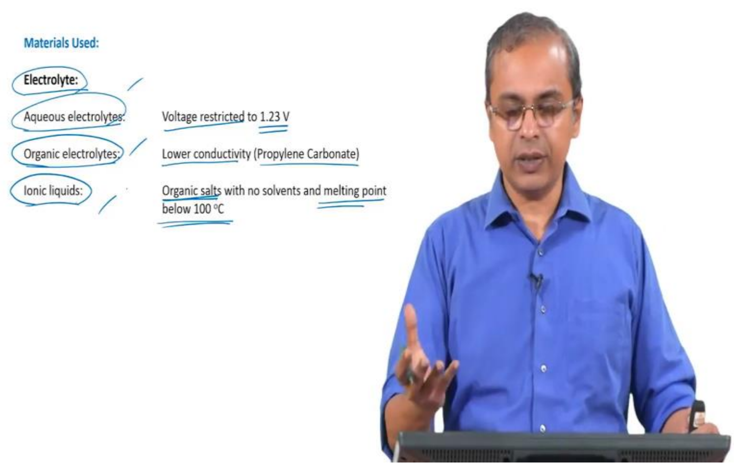

So, in terms of electrolytes; so, that is the main thing the electrode. The electrolytes are usually of three kinds aqueous electrolytes, organic electrolytes, or ionic liquids. Generally, aqueous electrolyte means water is I mean by the by using the term aqueous we mean water is present, if water is present it breaks down at a at 1.23 volts, into hydrogen and oxygen.

So, it means if you are using an aqueous electrolyte the voltage of that capacitor cannot be more than about 1 volt. So, if you go more than 1 volt you are increasing the chance that the electrolyte will break down so voltage gets restricted. therefore, the actually the more commonly used electrolytes are these on organic electrolytes almost half of what is out there consists of in terms of product is organic electrolyte based structures.

They have lower conductivity are usually propylene carbonate is the solvent used and some salt is used there lower conductivity, but still if you see some better stability under some circumstances so that is used. More recently people have been really looking at I mean a researching these things called ionic liquids, where you are taking an organic salt and you are not putting any solvent in it ok.

If you put a solvent you have to do a lot of purification of the solvent and so on to remove any moisture present etcetera. Here you put no solvent the except that you pick an organic salt which has a melting point that is less than 100 degree C so that you can just keep the capacitor at that temperature and you will have a liquid electrolyte, but the liquid electrode is basically a molten salt, so that is; how we operate this material the super capacitor.

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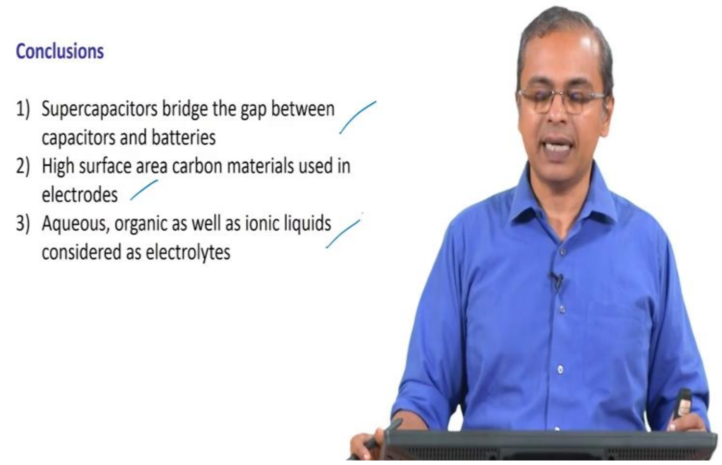

So, the electrodes used are carbon based either activated carbon or graphene or carbon nanotubes and the electrolyte used is either an aqueous electrolyte or an organic electrolyte or an ionic liquid so this is basically what is used. So, that's our discussion on super capacitors both what is what is special about it? How is it different from a capacitor? How a difference how it differs from a battery and what are the applications it can be used for what are it is capabilities and; what are some materials that are used to create this super capacitor?

So, in conclusion super capacitors bridge the gap between capacitors and batteries so they actually offer you a; you know a new realm of operation which neither the battery would offer nor the capacitor could offer so it gives you a good mix of the positive aspects of both the battery and the capacitor. It is typically based on high surface area carbon being used as electrodes with the charge being distributed into ions in the electrolyte ok.

So, the ions in the electrolyte; distribute the charge and hold the charge and that is how the electron ion combination helps you hold that charge and typically you have aqueous organic as well as ionic liquids which are being considered as electrolytes for super capacitor. So, that's our summary for of super capacitors and it is an interesting topic has a very nishe application in you know specific technologies such as electric vehicles and as you know something that you will keep hearing about more and more.

Thank you.

KEYWORDS:

Supercapacitors; Energy Storage Device; Electric Double Layer Capacitor (EDLC); Ultracapacitor; Battery; Capacitor; Applications of Supercapacitor; Difference between Supercapacitor and capacitor; Structure of Supercapacitor; Materials used in Supecapacitor; Activated Carbon; Graphene; Carbon Nanotube(CNT); Ionic Liquids

LECTURE:

The difference between a Supercapacitor, Capacitor and Battery is discussed in detail. The structure and the materials used to fabricate a supercapacitor and its capabilities are listed and explained along with their applications.