Introduction to Smart Grid

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Lecture - 23
Modelling of Storage Devices

Very good morning dear listeners, today we are going to talk on storage devices. As you all understand renewable energy integration to any power system requires reasonable amount of storage so, that the intermittency or the uncertainty associated with the renewable generation can be protected. For an example in any case for example, solar the maximum energy which is available to you during the day, and not necessarily that your peak requirement; peak energy requirement may fall exactly at the time of peak solar energy production.

And if the load is reasonably low during the maximum generation of peak to solar energy production, then the excess energy available to me from solar may not be utilized efficiently. If the system is integrated with huge renewable, and if the grid is hungry to observe all that is available to you from the solar then it is fine. But if your system is island it or not able to accommodate the solar energy at a given point of time, then we need to store those available energy from solar so, that it can be utilized during the second peak or during the evening hours.

Now let us look into the wind energy. Now the maximum energy available to you from wind is during late evenings, and as a whole the peak requirement in the evening hour do not fall in line with your maximum wind energy available to you.

Once again, the wind energy needs to be stored during midnight so, that that can be utilized during day peak. So, as a whole what I wanted to focus here: if you wish to integrate maximum percentage of renewable to your grid and if they are of solar or wind, you need to have storage technology in place so, that the investment being made for renewable integration is being justified.

Now always please remember God is not very kind to engineers and especially for renewable or smart grid engineers, because the peak energy requirement period unfortunately do not fall with the peak generation from both the renewable sources especially from solar as well as wind. So, let us focus how this challenge can be addressed by having storage devices and how to model and all the issues related to storage technology.

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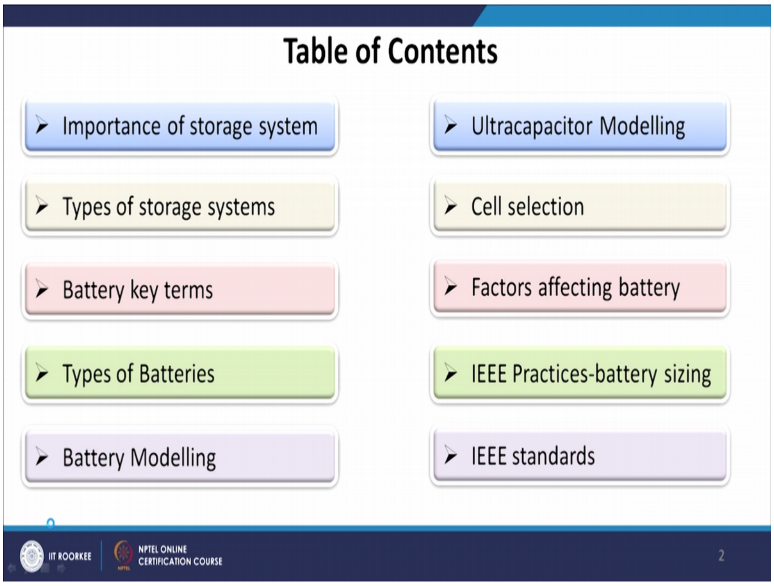

Now moving into these are the points we like to talk today; especially the importance of storage system and types of solar street storage systems, battery key terms, types of batteries, battery modelling, ultracapacitor modelling cell selection, factors affecting my battery, IEEE practices for battery sizing and finally, IEEE standards.

Now, what is the importance of a storage system? Now the first important one is during renewable energy excess as well as deficit.

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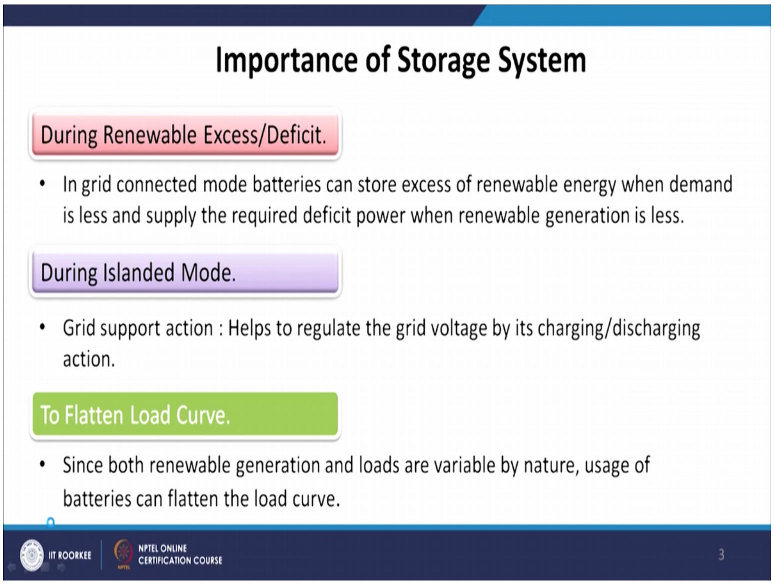

In grid connected mode batteries can store excess of renewable energy when demand is less, and supply the required deficit power when the renewable generation is less, As a whole what we wanted to say when the load is high the battery can provide, and as and when the renewable generation is getting reduced and if your load is more than that then still the stories can accommodate those excess demand.

Now, during islanded mode of operation in specific to remote areas, grid support action helps to regulate the grid voltage by its charging and discharging action. The associate characteristic of storage system is very important. It can certainly make your system healthy by appropriate discharge and charging action from the storage system. Now one more very important part that we need to focus today is that, if the load curve is ideally not very flat for any developed or developing countries across the world, the load curve is never being flattened.

The activity some of the countries do have multiple peaks and some of them have do a minimum number of peaks, but in general we do experience at least one to two peaks during the day. And because of that you need to have access install capacity to protect or to maintain or to meet those peaks, but during the rest of the day maybe for 14 to 15 hours a day, you need not efficiently utilize those generation which has been installed or available to you.

So, it is a very good idea if you can flatten your load curve so, that the install capacity is very close to your requirement peak and that is one of the most interesting phenomena can be achieved with help of storage technology. Since both renewable generation and loads are variable by nature, usage of batteries can flatten the load curve means you do your charging action during off peak hours and perform your discharge action during peak hours.

So, by this we can certainly increase your off peak hours, reduce your peak hour so, the load curve can be made flattened. Now one of the case study which is a very important in recent time I like to focus today you can see that.

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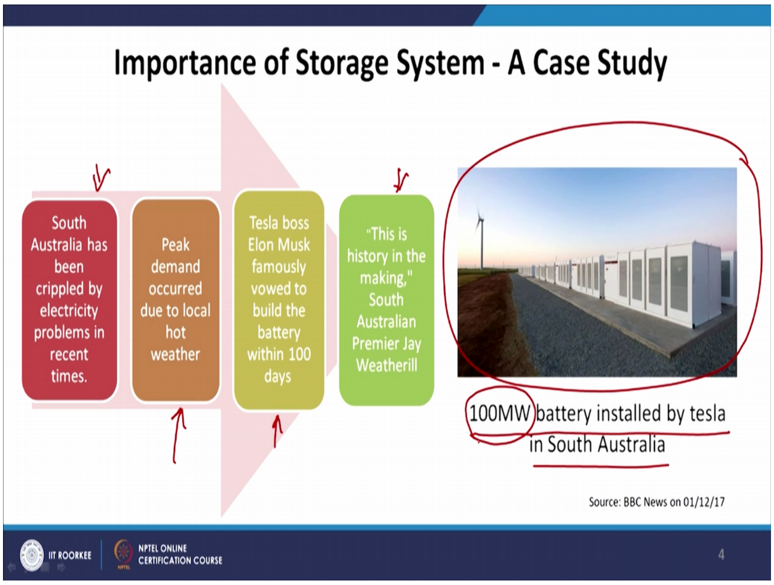

This is recently installed storage technology, and this is a 100 megawatt battery installed by Tesla in South Australia. You surprised to know South Australia has been crippled by electricity problem in recent times. Peak demand occurred due to local hot weather and Tesla boss Elon musk famously vowed to build the battery within 100 days to meet out the requirement during peak hours. This is the history in the making that is South Australian Premier Jay Weatherill says.

Now, what it happens that what it does basically 100 of 100 megawatt of energy megawatt hour of energy can be stored during peak renewable generation production and can be discharged during the peak demand of the consumers. Now there are a different type of non electric storage system that also we need to understand in a given power system.

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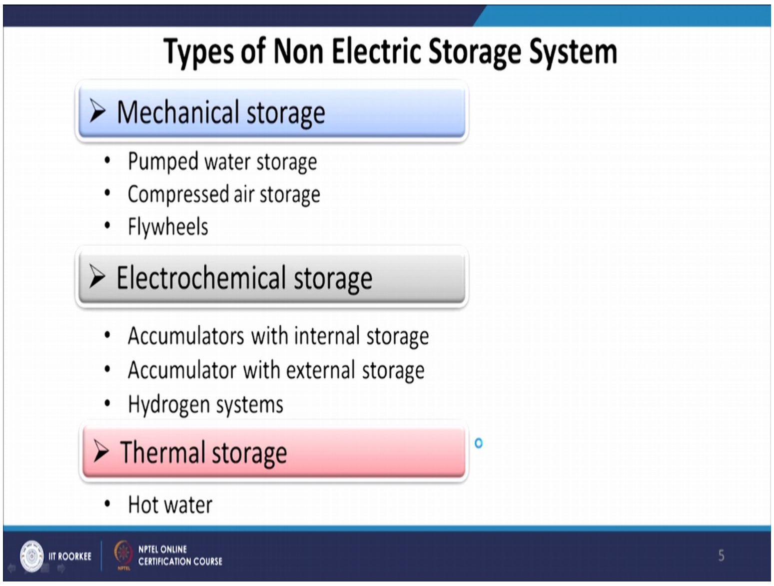

Now first one is a mechanical storage that is pumped water storage compressed a storage and flywheels.

One of the very common storage scheme today could be of pumped water storage, where the water can be pumped back to the dam during off peak hours, so that we can utilize those energy or the water during peak hours through proper discharge. Now in case of electromechanical storage we do have accumulators with internals of internal storage, accumulator with external storage and hydrogen systems. And we do have thermal storage which is hot water to storage.

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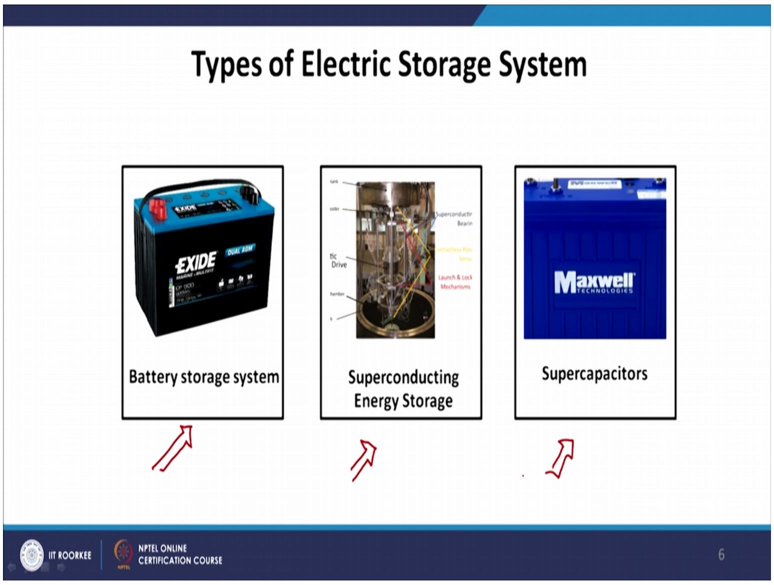

Look into the energy storage system, this is mainly my battery storage system and you can see the superconducting energy storage and finally, we do have super capacitor. Electric storage most of them are battery, but we can certainly move to superconducting as well as super capacitor, because they possess not simply store the energy, but also perform other technical challenges faced by any given grid.

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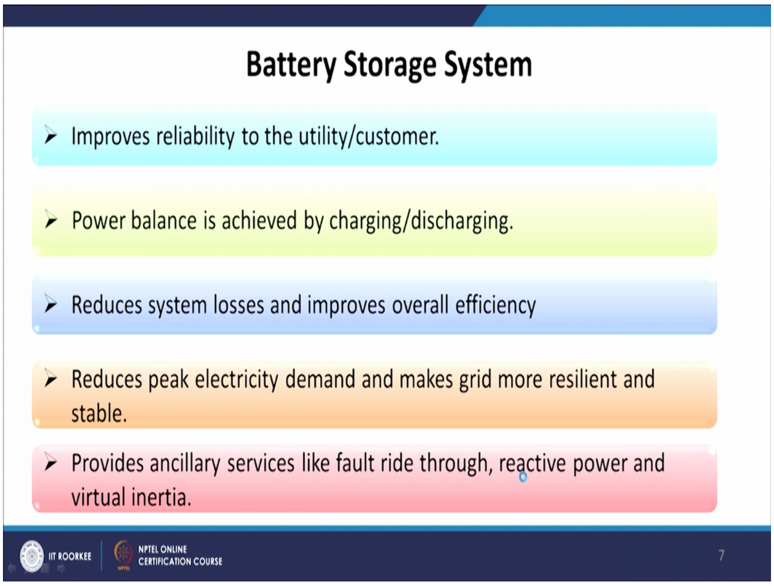

Now the battery storage system improves the reliability to the utility or customer, because it can provide you energy as and when required, power balance is achieved by both charging and discharging. Reduces system loss and improves overall efficiency because it is locally being supplied, reduces peak electricity demand and makes grid more resilient and stable. Provides ancillary services like fault ride through reactive power and virtual inertia.

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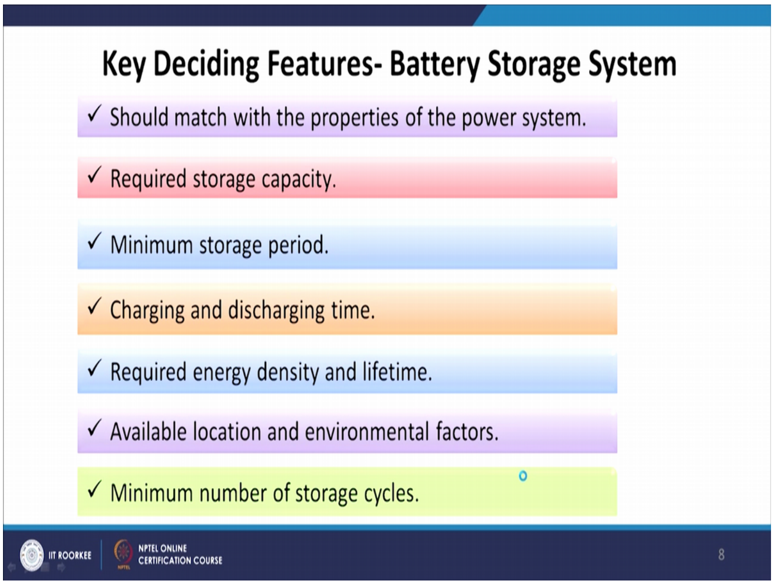

Now how do you decide where to place your battery, what would be its magnitude? Number of batteries everything need to be analysed before we manufacture and put them in place. It should match with the properties of the power system required storage capacity, minimum storage period charging and discharging time, required energy density and lifetime, available location and environmental factors and minimum number of storage cycle.

So, those factors one note one need to keep in mind during taking a decision.

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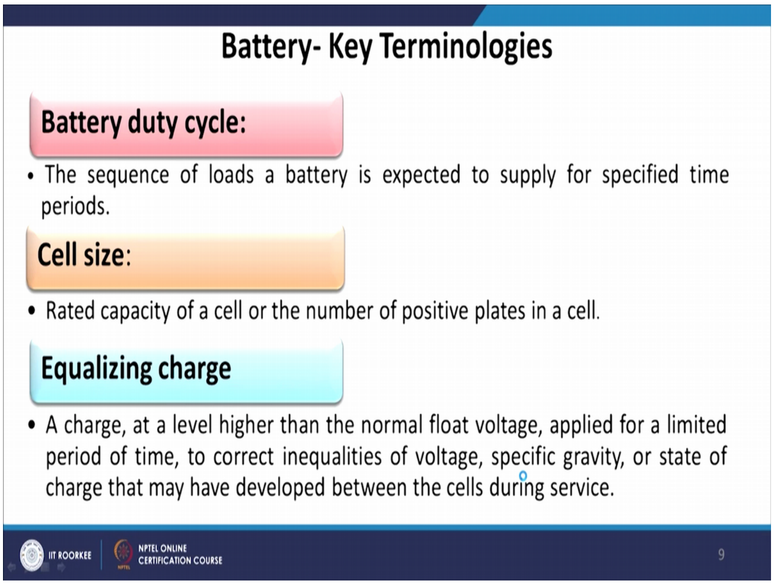

Now, these are the key important terminologies one has to understand before we start modelling the system especially the energy storage system; first one is battery duty cycle. The sequence of loads a battery is expected to supply for specified time period is known as battery duty cycle.

The next will be the cell size rated capacity of a cell or the number of positive plates in a cell, equalizing charge it charged at a level higher than the normal float voltage applied for a limited period of time to correct any qualities of voltage, specific gravity, or state of charge that may have developed between the cell during services.

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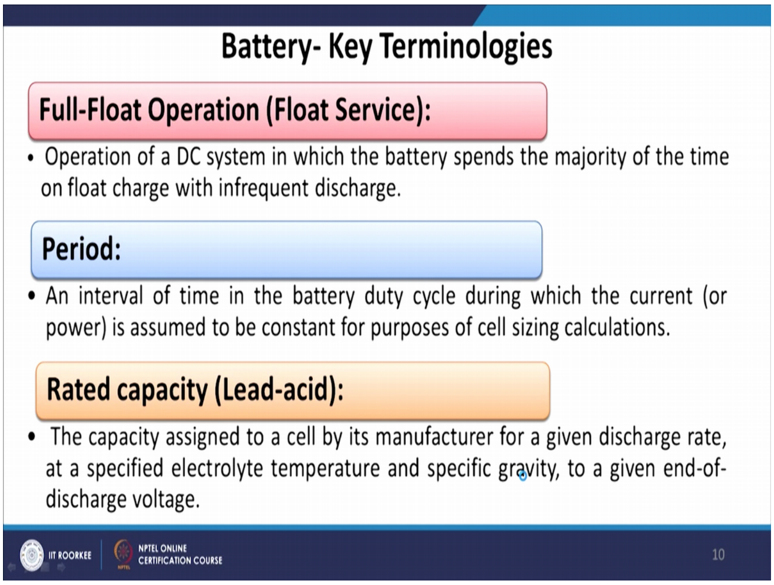

Full float operation, operation of a DC system in which the battery spends the majority of the time on float charge with infrequent discharge period. An interval of time in the battery duty cycle during which the current is assumed to be constant for purpose of cell sizing calculations, the rated capacity is specific to lead acid, the capacity assigned to a cell by its manufacturer for a given discharge rate it has specified electrolyte temperature, and specific gravity to a given end of discharge voltage.

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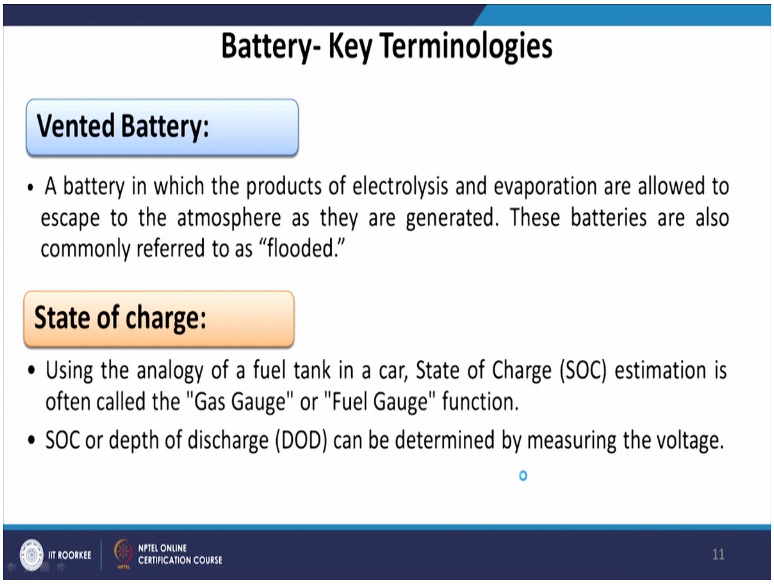

Vented battery; a battery in which the product of electrolysis and evaporation are allowed to escape to the atmosphere; as they are generated these batteries are also commonly referred to as flooded; state of charge very very important. Using the analogy of a fuel tank in a car, state of charge estimation is often called the gas, gas or fuel gas function. SOC state of charge or depth of discharge DOD can be determined by measuring the voltage of the battery terminals.

Now, let us go through different type of batteries currently available and their merits as well as demerits; first one lead acid battery.

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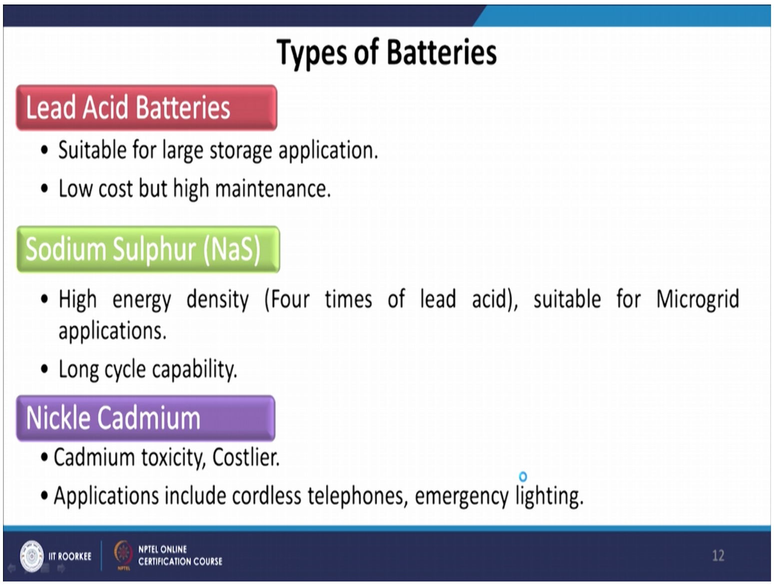

It is mainly suitable for large storage applications low cost, but requires high maintenance. Sodium sulfur high energy density four times of the lead acid, suitable for micro grid applications. It has long cycle capability and nickel cadmium. Cadmium is toxic and is also costlier. Applications include cordless telephone emergency lighting etcetera.

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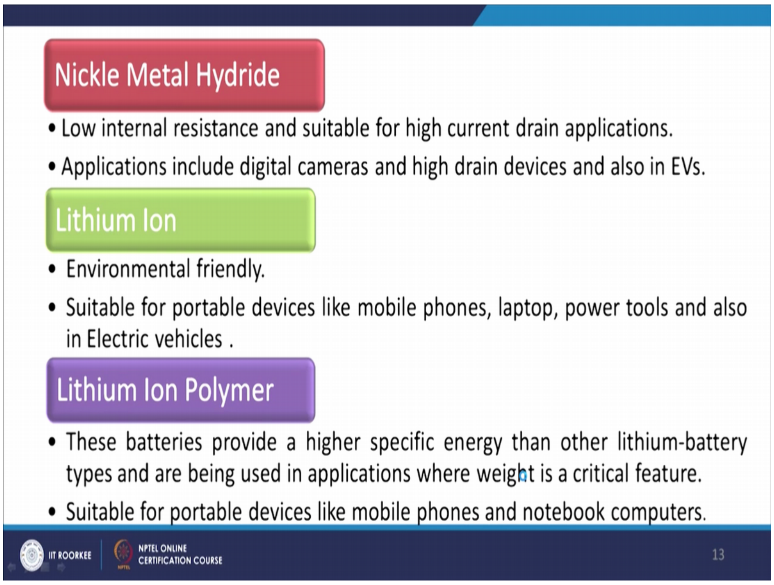

Nickel metal hydride; low internal resistance and suitable for high current drain applications include digital cameras and high drain devices and also in EVs electric vehicles. Lithium ion environmentally friendly: suitable for portable devices like mobile phones laptop power tools and also in electric vehicles lithium ion polymer.

These batteries provide a higher specific energy, then other lithium battery type and are being used in applications where weight is a critical feature suitable for portable devices like mobile phones and notebook computers.

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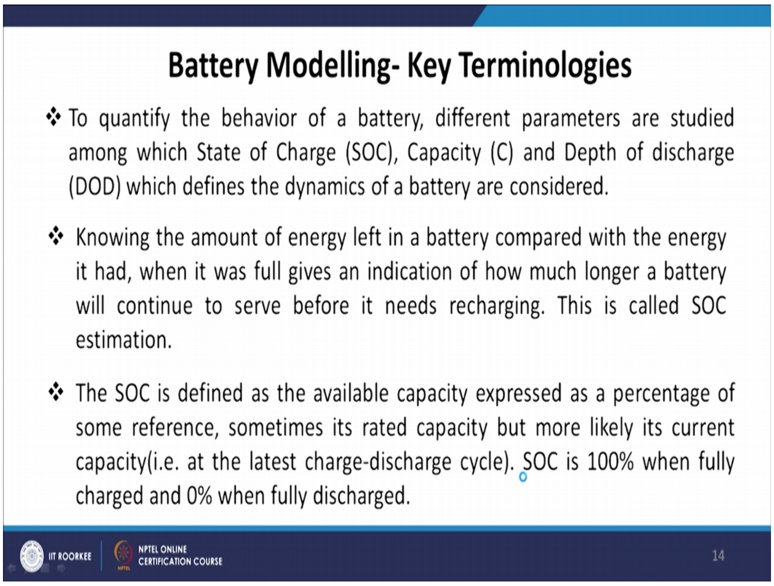

Now, when we wish to model storage devices? So, we have understood different type of batteries and their role in a power system. Now before we move to mathematically model them we need to understand the following key terminologies very quickly. To quantify the behaviour of a battery different parameters are studied among which state of charge of the battery, capacity of the battery; depth of discharge of the battery who defines the dynamics of the battery are considered during the modelling.

There are three important things your SOC DOD and C that is capacity knowing the amount of energy left in a battery compared with the energy it had. When it was full gives an indication of how much longer a battery will continue to serve before it needs recharging.

So, we need to understand the time period at which it started charging and also keep on discharging. So, knowing the current state we can plan oh after a couple of hours or minutes the battery can be now allowed for charging; this is called your SOC estimation. The SOC is defined as the available capacity expressed as a percentage of some reference sometimes its rated capacity, but more likely its current capacity. SOC is 100 percent when fully charged and 0 percent when fully discharged.

But in ideal condition we do not allow the battery to be discharged close to 0 percent and neither charge up to 100 percent. So, we perhaps allow it to be between 20 30 as a minimum SOC 20 30 percent and maximum could be I mean 70 to 90 percent.

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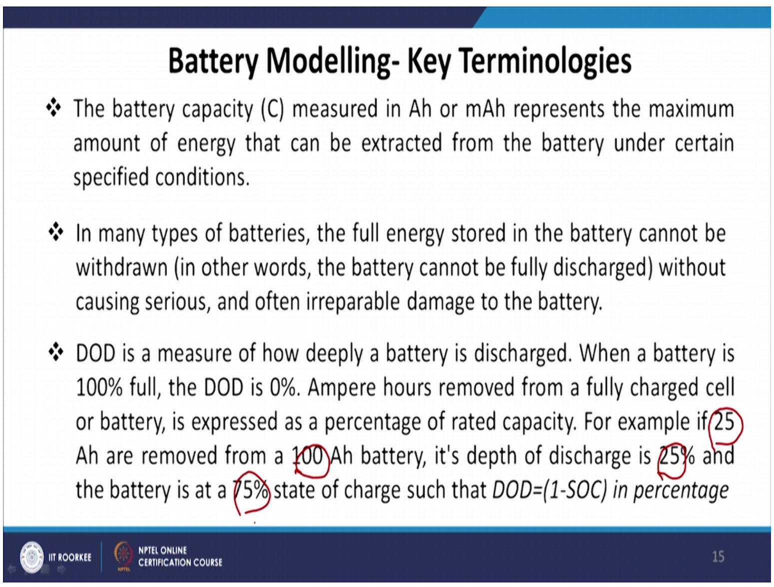

the battery capacity measured in ampere hour represents the maximum amount of energy that can be extracted from the battery under specific conditions.

In many type of batteries the full energy stored in the battery cannot be withdrawn without causing serious and often irreparable damage to the battery. DOD is a measure of how deeply a battery is discharged when a battery is 100 percent full the DOD is 0. Ampere hours removed from a fully charged cell or battery is expressed as a percentage of rated capacity for example, if 25 ampere hour are removed from 100 ampere hour battery its depth of discharge is 25 percent and the battery is at 75 percent state of charge such as DOD is 1 minus SOC in percentage.

So, we can clearly see this 25 out of 100 allows me the DOD to be 25 percent and rest 75 percent is my balanced SOC.

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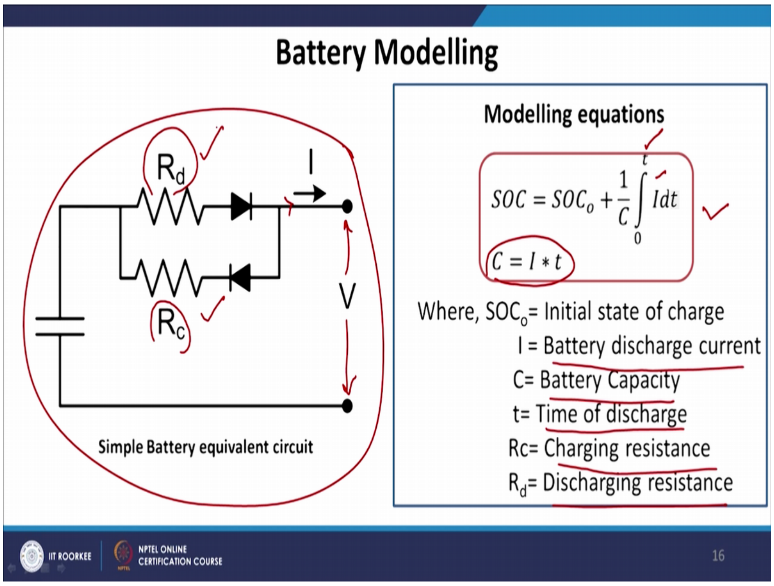

Now, battery modelling I think please have a look.

Now, this is the battery configuration is an equivalent circuit and the value of R c and R d depends on the design parameters and this is what the voltage which is available to me across the terminal and this is the current that we recently talked about in ampere or milliampere. The modelling equations for your SOC is now expressed as SOC plus the integration of the current. And I is given as battery discharge current which is same as this and C is the battery capacity and t is the time of discharge. R c is the charging resistance and Rd is the discharging resistance.

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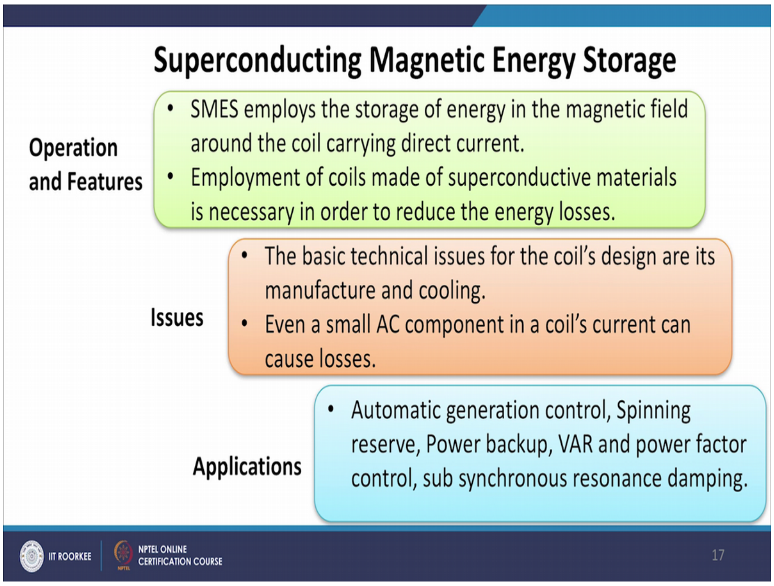

Moving into superconducting magnetic energy storage, SMES, SMES employs the storage of energy in the magnetic field around the coil carrying direct current. Employment of coils made of super conductive materials is necessary in order to reduce the energy losses.

Now, the main issue here the basic technical issue for the coils design or its manufacture and cooling. Even a small ac component in a coil current can cause losses. The main applications automatic generation control agc, spinning reserve, power backup VAR and power factor control sub synchronous resonance damping.

Now, the final the third type not necessarily the final one, but the third type that we are covering in this lecture today, a super capacitor ultra-capacitors.

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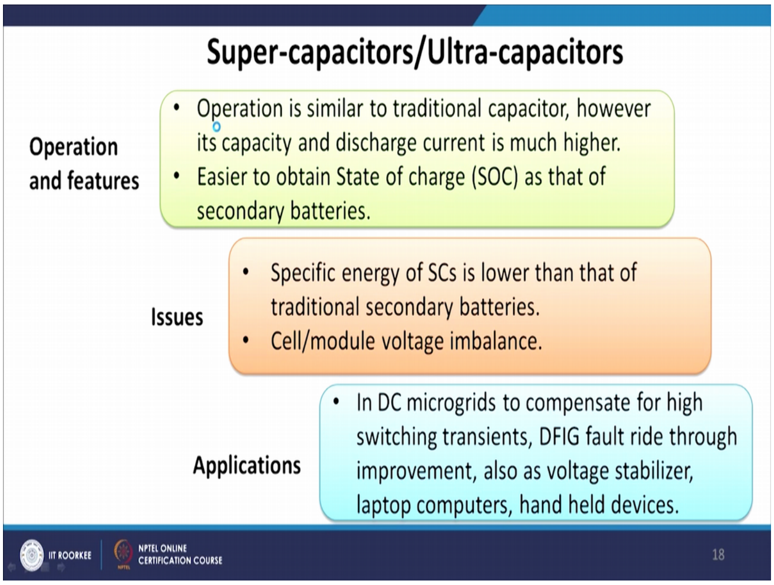

I need your attention at this stage because this is one of the very important component, the operational features is similar to traditional capacitor. However, its capacity and discharge current is much much higher.

So, that is why it is called super capacitor. Easier to obtain SOC S that of a secondary batteries, but there are issues specific energy of super capacitors is lower than that of traditional secondary batteries. Cell module voltage imbalance which is common and the major application is in DC micro grid to compensate for high switching transient DFIG fault ride through improvements also as voltage stabilizer laptop computers and hand held devices.

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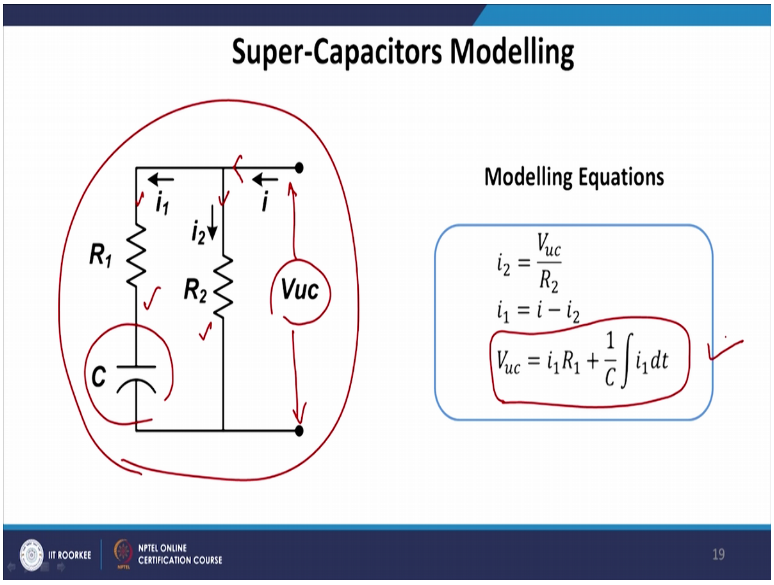

Now super capacitor modelling you can see that this is what actually the general layout, the voltage and you could see the current i 1 i 2 there are two resistances insand and the capacitor and the voltage is given by this expression to represent the V cu V uc can be obtained by this equation which is your terminal voltage available to you.

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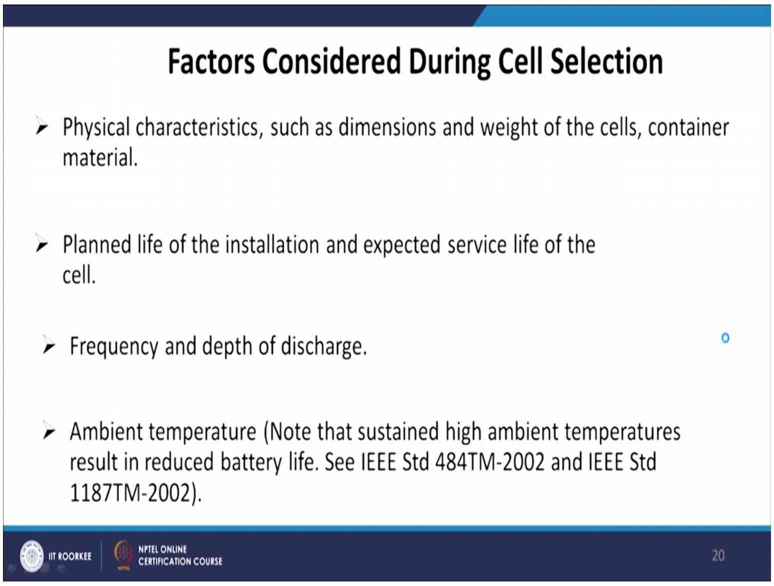

Now when you consider cell the physical characteristics such as dimensions and weight of the cell which is important; planned life of the installation and expected service life of the cell, frequency and depth of discharge, ambient temperature, charging characteristics.

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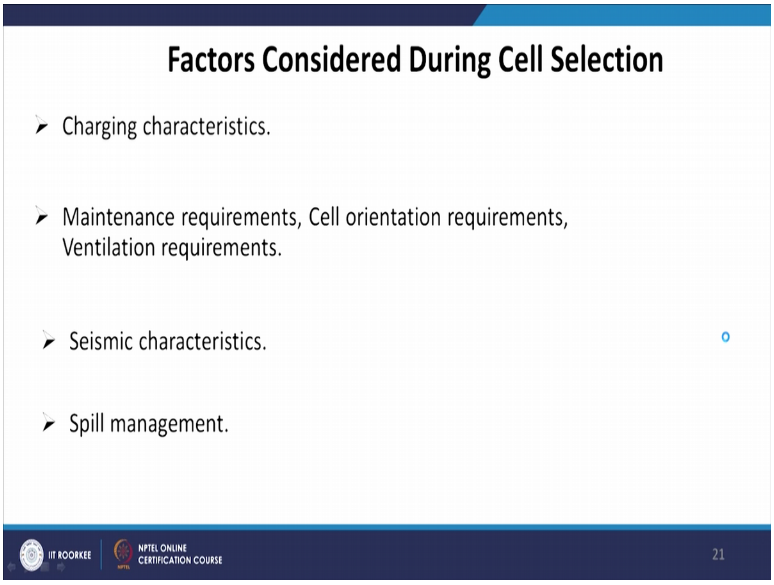

Maintenance requirement, cell orientation requirements, ventilation requirements, seismic characteristics spill management. And finally, because the cells are quite expensive and they are used in any power system to improve the reliability of the power system providing a sort of preserve or backup or storage.

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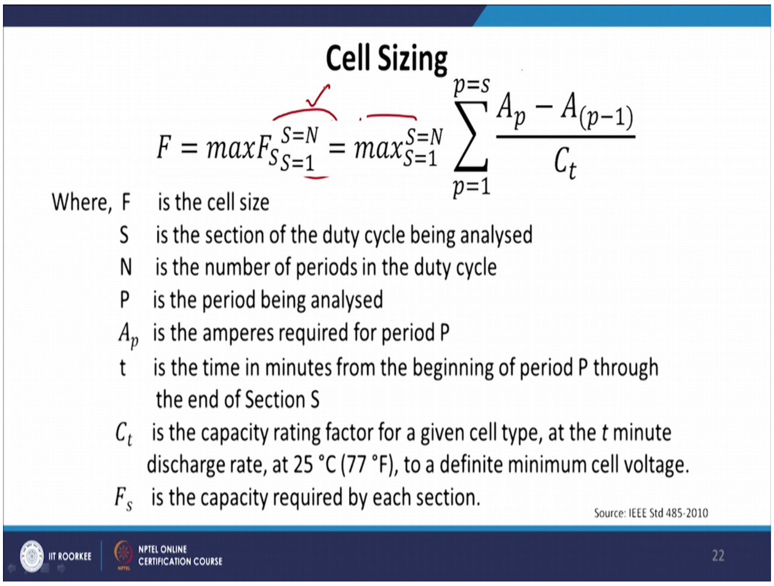

Now, hence to make the system cost effective we need to plan its size, what would be the best size of a cell or a storage need to be placed at a given location or a node of a power system so, that you can utilize that storage device efficiently.

Now you can see that we need to maximize the function F of S where F is my cell size that need to be optimized where S is the section of duty cycle being analysed, N is the number of periods in the duty cycle, P is the period being analysed Ap is the ampere required for the period p.

T is the time in minutes from beginning of the period P through the end of the section S Ct is the capacity rated factor for a given cell type at the t minutes discharge rate in specific at 25 degree Celsius, to a definite minimum cell voltage Fs is the capacity required by each section.

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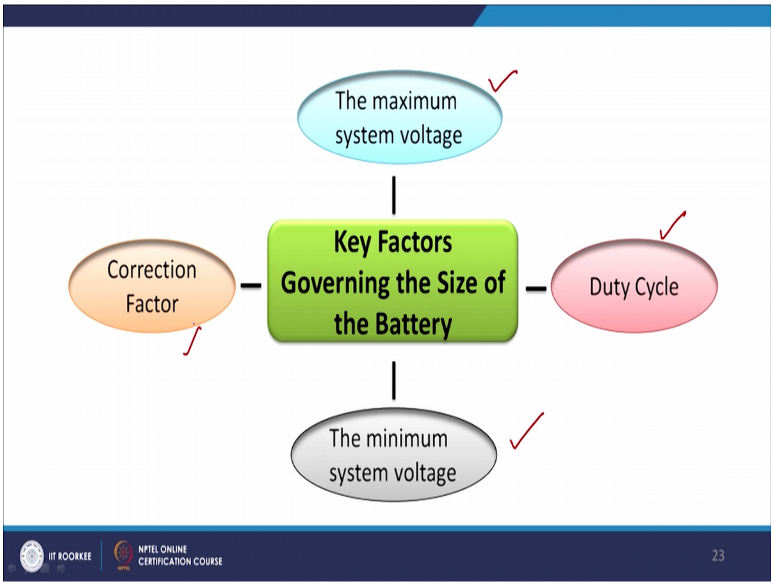

Now what are the factors governing my size? The maximum system voltage, a duty cycle, the minimum system voltage and finally, the correction factor; so these are the four important factors decides the size of the battery.

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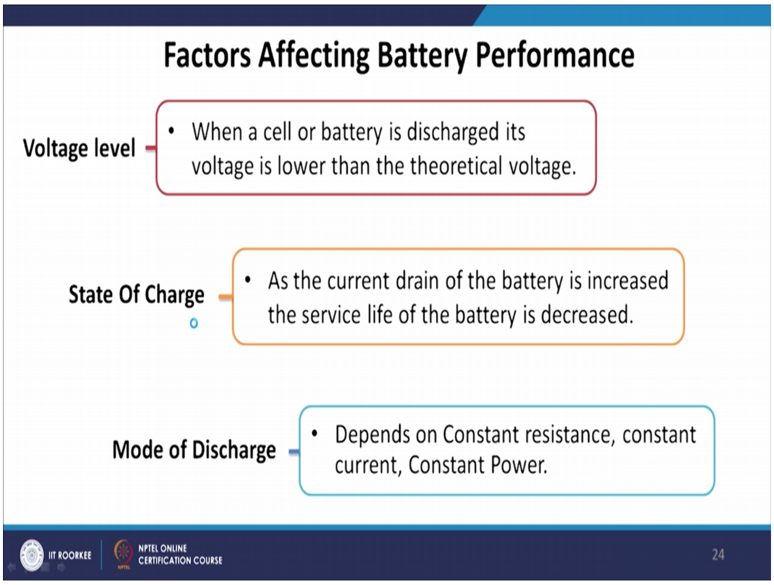

And there are a few factors that is deciding your performance first one is voltage level; when a cell or battery is discharged its voltage is lower than the theoretical voltage. State of charge is the current drain of the batteries increased. The service life of the battery is also decreased.

Mode of discharge depends on constant resistance constant current as well as constant power.

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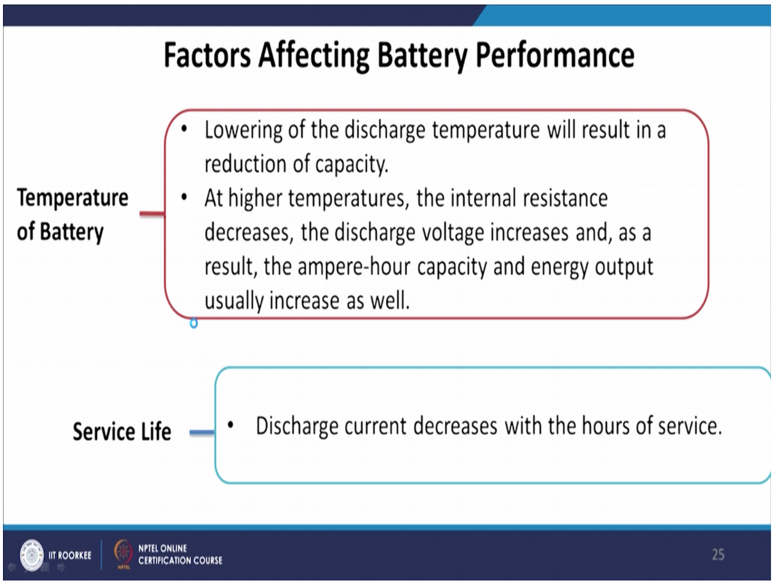

Temperature of battery, lowering of the discharge temperature will result in a reduction of capacity, at higher temperatures the internal resistance decreases the discharge voltage increases and as a result the ampere hour capacity and energy output usually increases as well. Service life discharge current decreases with the hour of services.

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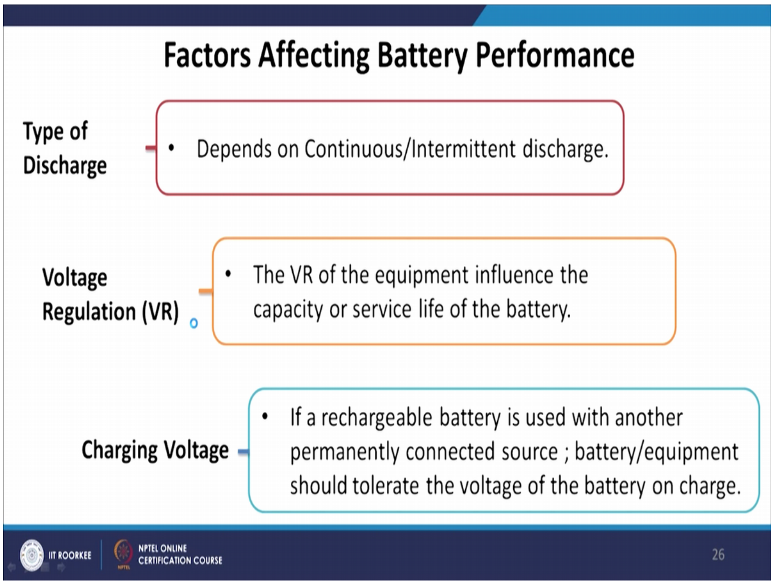

Type of discharge depends on continuous or intermittent discharge. Voltage regulation: the voltage regulation of the equipment influence, the capacity or service life of the battery. Charging voltage: if a rechargeable battery is used with another permanently connected source battery or equipment. So, tolerate the voltage of the battery on charge.

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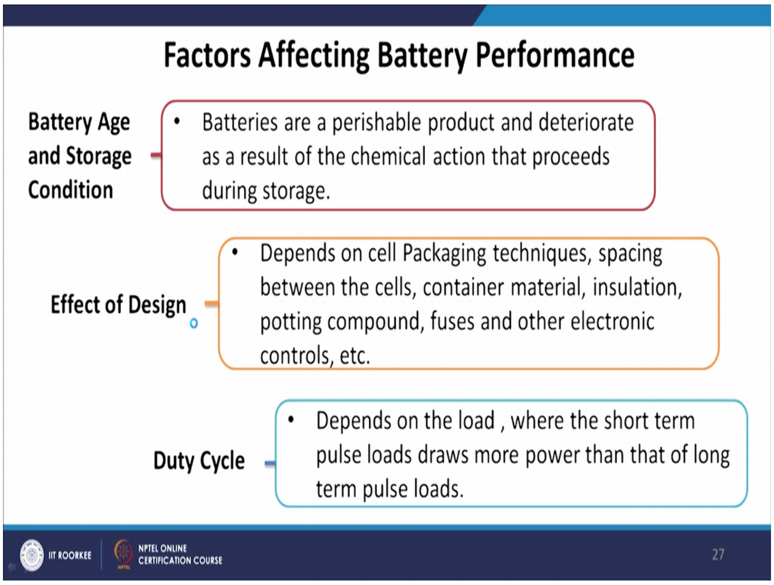

Battery age and storage condition batteries are very simple product and deteriorate as a result of chemical action, that proceeds during storage because the life is not permanent; and hence we need to plan your battery. So, that the age you to plan your charging and discharging character in such a manner the life of the battery is also taken care.

Effect of design; depends on cell packing technique spacing between the cells continued material, insulation, potting compound, fuses and other electronic control. Duty cycle as we already discussed depends on the load where the short term pulse loads draws more power than that of long term pulse.

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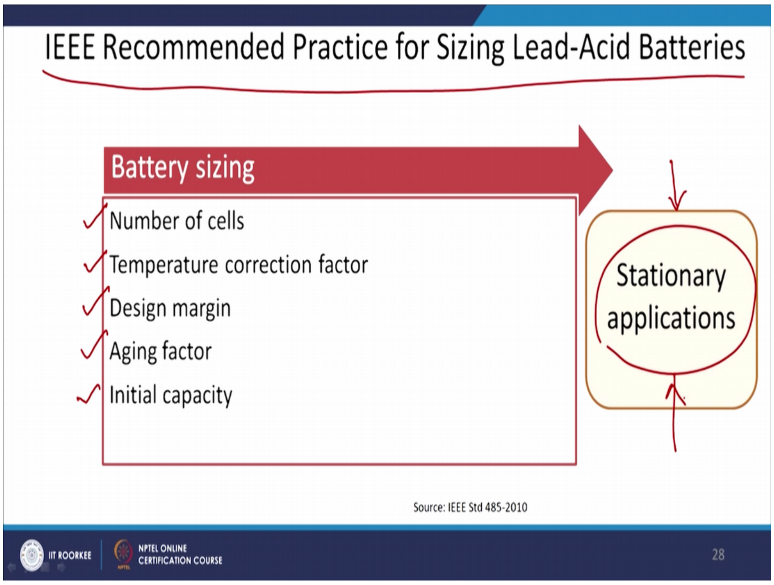

Now, few recommendations given by IEEE for sizing lead acid batteries, now for stationary application which is very common. The factors that is number of cells, temperature correction factor, design margin, aging factor and initial capacity are looked into or taken care for any stationery application of lead acid batteries.

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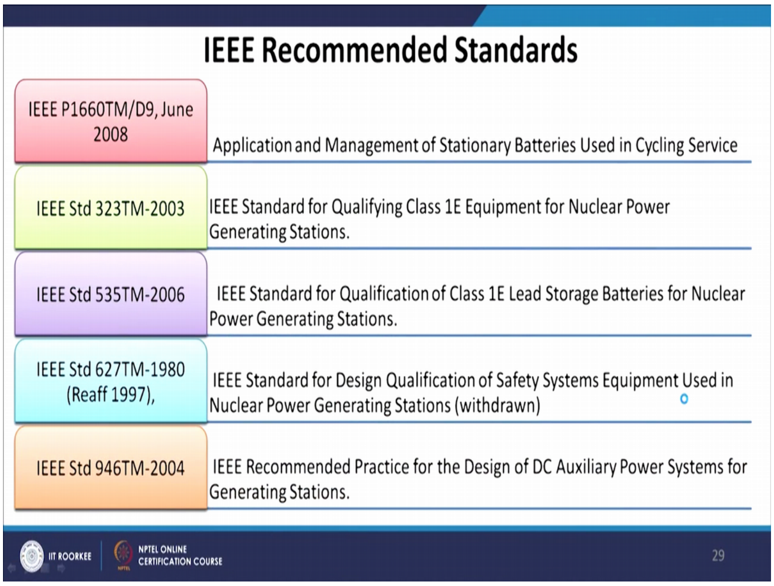

Now, what does IEEE recommends today, how do we go ahead with storage technology before we ambered or put it them in the grid.

Now, the first IEEE P 1660 TM in 2008 it says application and management of stationary batteries used in cycling services. I took E standard 323TM 2003 talks about qualifying class 1E equipment for nuclear power generation stations 323 IEEE standard 3 535 TM in 2006 talks about lead storage battery for nuclear power generating stations as well.

I triple E standard 627 TM in 1997 talk about IEEE standard for design qualification of safety system equipment, used in nuclear power generation stations. So, most of them do focus for nuclear power station applications. IEEE standard 946 TM recommends practice for design of DC auxiliary power system for generating system stations at all.

So, today we mostly discussed the importance of storage technology, types of storage devices their modelling, optimal sizing and applications recommendations by IEEE

Thank you.