Economic Operation and Control of Power System

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Week - 12

Lecture – 59

Hello and good morning one and all. Welcome you all for the NPTEL online course on Economic Operation and Control of Power Systems. Today we will be covering a very important topic, EV opportunities, challenges and impact in power sector. This is the last topic that we are going to cover in this course. Electric vehicles are getting lot of importance in recent days as there is a serious interest to reduce the carbon footprint from the transportation sector as well. So let us look into this important dynamic as in I said dynamic it may be used for various purposes the electric vehicle not only for transportation especially let us try to discuss how electric vehicle can be utilized for enhancing the control and operation of the existing distribution system.

And also let us look into the challenges and possible impact due to the proliferation of electric vehicles in the power system that we are going to see in the future. So let us move forward. So first of all the motivation, what is the key motivation towards pitching in electric vehicle into the system? So as you can see the prime focus is to reduce the carbon footprint that I have already told and there is a significant increase in the carbon footprint in recent days because lot of conventional vehicles are the number have been increased. So there is a serious interest to reduce the carbon footprint.

So there is a head to head comparison between EV based transportation and gasoline based or petroleum based transportation. You can see there is no tailpipe emission that means you know because oil leakage that what happens when you transport from one part of the world to another part of the world and it will also have a side effect on aquatics living in ocean. So that can be reduced here and there is once important thing is the hour to recharge. This is a serious concern. So electric vehicle may take more time as compared to the refueling that you do with the conventional petrol based or diesel based vehicles and the mileage range is significantly good in electric vehicle as well.

So there is lot of advancement being happening, technical advancement and innovations being brought in electric vehicle to ensure that the limitations of electric vehicle will be as minimal as possible and the advantage would be more. So benefits of electric vehicle.

So these are the different benefits that I have listed out here. Low running cost. So the maintenance cost would be less as compared to the conventional petrol or diesel based vehicles, low maintenance cost because you see you know petrol price is so high say 80, 90 I think 95 rupees plus in Indian system

So but the energy that you require to recharge the batteries is very minimal and especially if you have a solar based charging stations. So you have your green energy and utilize it for your charging purpose and the maintenance and running cost would be very less. Zero tailpipe emissions. There is tax and financial benefits, lot of support from the government, encouraging electric vehicle purchase. So and mainly you can reduce the carbon footprint so that you can save this planet for the next generation.

Electric vehicles are easy to drive and less noisy also. I mean you don't hear any noise because of electric vehicles and convenience of charging at home and no noise pollution. So that's what is we have listed as the key benefits of electric vehicle. So need for electric vehicle. Post to the Paris Climate Agreement where more than 190 countries they had participated in 2015.

They have pledged to reduce the carbon footprint by 2 degrees Celsius. Earlier it is 3.5 degrees Celsius estimated rise of temperature. So you can reduce, it's been planned to reduce the global carbon footprint by so that you know you can reduce the temperature by 2 degrees Celsius. So electric vehicle is expected to reduce overall carbon footprint.

The dependency on fossil fuels would decline. The peak loading on the grid can be reduced. So you have electric vehicle. It's a variable storage. You can use it either for charging purpose or discharging purpose.

So you can reduce the demand as seen by the grid at a given point of time. So and the answering services can also be rendered. You have electric vehicle. Why don't you use it for rendering some reactive power or loss minimization can also be a good objective and we can also make it used to reduce the harmonic effect on the system. And not only that electric vehicle can also help the consumer to earn some money.

If we call it for a demand response program, electric vehicle will surely have a role to play there. So types of electric vehicles. So one is the hybrid electric vehicle. Here the motor is small and it's IC engine based. Though battery is there, you can see there is a battery but battery is used to supply for whatever the load requirement is there within the vehicle.

It is meant for that purpose. The only means of input is the fuel input that is either petrol or diesel and then we have plug-in hybrid electric vehicle PHEV. So this is a dual fuel and dual traction based vehicle where you have fuel input, conventional fuel input and

also you can charge your vehicle. The battery can be charged plug-in to a charging station. You can also charge the battery and run the vehicle.

And there is something called as battery electric vehicle. So this is completely battery driven vehicle. There is no scope for you to give a fuel input, the conventional fuel input. The fuels are electric vehicle. So this is a vehicle with electric engine and power is generated on board from hydrogen.

So because lot of discussion is happening with respect to hydrogen. So it's a fuel cell that is hydrogen driven electric vehicle. So there are multiple varieties but as of now maybe people are interested to go for plug-in hybrid electric vehicle because you have an option provided there is shortage of charging stations. You can either get a fuel input or wherever you find a charging station you can plug-in your vehicle and get it charged also. But in future it is expected to move forward for a battery electric vehicle or fuel cell electric vehicle so that we can avoid the conventional fuels.

So even in the Indian grid context, Indian context you can see at 2026, 16 percentage and 2040 it is expected to replace all the conventional vehicles with the electric vehicles. But what are the main factors which are hindering the growth of electric vehicle? It's the lack of charging stations. As of now the infrastructure development is not so up to the mark so that you know the customers would feel confidence to move out from their house and there is high battery cost. 40% of, nearly 40% of the entire electric vehicle cost is because of this battery. So that is another important limitation because if cost is high then people will not get motivated to purchase electric vehicle and high charging time.

So you plug-in and it takes lot of time to charge whereas if you go for a specific you know petrol pump where the conventional vehicles get fuel very quickly as compared to this waiting time that you have to spend in charging stations and the typical users concern over a long range of travel that's what you know the sufficient infrastructure development is yet to be achieved and some regulatory government norms to encourage both the manufacturers as well as the customers to increase the electric vehicle market within this country. But still you can see you know there is a growing interest within this country to with respect to the purchase of electric vehicle. It's a 2021 data you can see there is a significant rise in the vehicle purchase as compared to the conventional vehicles. I have given an overview of the picture of how electric the vehicle purchase is there. You see here at 22 cars per 1000 vehicle car ownership is low while two wheeler ownership is among the highest in the world.

That means the transportation sector is mainly dominated by two wheelers here. So in terms of numbers as such. So while electric vehicles currently account for less than 1% of total vehicle sales in India the market is growing rapidly and is expected to worth around at least 475 billion Indian rupees by 2025. So a very significant number. So total two

wheelers account for the largest share of this market up to 62% whereas the three wheelers accounts to 37%.

So you can see there is significant because India is a very thickly populated country so lot of vehicle purchase would be there. So this gives a overall picture about the weightage of two wheeler as compared to the three wheeler purchase. The point is the market is quite huge. I have given a case study about Bangalore some estimation. You can see here currently the growth rate is around 5.88% with respect to two wheeler and by 2030 EV penetration rate would go up to 30% from currently it is 10%. Whereas three wheeler it's currently 40% it may move up to 70%. So it is estimated as per the deadlines or timelines this government has set up. So there is a strategy to increase the EV penetration into the system. So what a typical EV charging infrastructure would look like? You can look up to this schematic.

It's a very simple schematic that I have displayed for your easy understanding. You can see here there is a charging station, this is a charger. There is a vehicle which comes to a charging station plug in there to get it charged. So there are five things very fundamental components which have to be there. One is socket outlet which is part of the charger where it's a outlet of a charger where you plug in your vehicle cable and there is a plug which is also part of this charging station.

There is a cable which is connecting a charger with respect to the car. There is a connector which is part of the car and there is a vehicle inlet. So these are the five important aspects and where the vehicle would come and get connected. So most of the EV models can accept both AC as well as DC. Most of the electric vehicles have the AC to DC converters which allow the vehicles to be charged directly from the AC available at the house.

So there should be a provision for both AC as well as DC connectivity. So anything, any new mechanism that you bring in there should be some standards preset, standards should be developed actually. So EV charging also have certain standards being developed. You can see here there are level 1, 2, 3 charging types. So level 1 constitutes to a small vehicle where you can plug into 230 volt household supply and the power level is around 1.8 or less than that kilowatt. Level 2 is slightly a bigger vehicle, could be your car, four wheeler. So you can plug into a three phase supply and the power level is quite significant and level 3 is a really big vehicle, you know maybe electric bus, very huge vehicle, you know transportation, heavy vehicle. So it is expected to you know get it charged through a ultrafast DC charging stations with 380 volt, 480 volt DC supply. Power level is 50 kilowatt to 150 kilowatt. Moving ahead with the charging standards, the famous charging standard is combined charging system CCS.

It is a open internationally recognized standard. This is standard for charging electric vehicles. Combo 1 and combo 2 connectors are used to provide up to 350 kilowatt. The CCS allows AC charging using type 1 and type 2 connectors. So this charging infrastructure compasses charging couplers, communication, charging stations, the electric vehicle and various functions for the charging process such as load balancing and charge authorization.

So I have just displayed here the typical outlet of a charging point. You can see here there are, it is a single phase and this is a three phase charging port and you have, these are very conventional points. This is a phase, again this is a phase and this is neutral, this is a neutral point and this is your earthing, this is your earthing and this is AC aspect. This and there is also a DC, DC positive and DC negative. So there is a provision for AC as well as DC charging.

Apart from these power points, there is two important communication aspect. One is control pilot and there is a proximity pilot. So control pilot, it is a communication line which is used for signal charging level between electric vehicle and the charging station. Whenever the electric vehicle would come to a charging station, park there for the charging. So there should be communication that should be passed on.

There should be information exchange with respect to what is the expectation from the electric vehicle and what the charging station can offer to meet out the expectation of a vehicle. The signal can be adjusted by electric vehicle to initiate charging as well as for other information. The signal is usually 1 kilohertz square wave at plus or minus 12 volt which is generated by the charging station to detect the presence of electric vehicle to send information regarding the maximum allowable charging current and starting and end point of the charging. So at any given point of time, electric vehicle charging station would have limited capacity to meet out multiple electric vehicles which may be present at that point of time. So then it would communicate to different vehicles and then give an information or idea like how much, what, when can, when, what is the charging point, starting point of the charging, what is the ending point of the charging, what is the charging rate and how much time it would take to complete the charging.

So all these communication would be exchanged between the electric vehicle as well as the charging station. Then there is another important communication port what we call it as proximity pilot. This is safety communication, it is like a locking point, locking communication point where when the electric vehicle is present and is being connected to the charger. So due to any reasons there should not be a movement of electric vehicle from its position. Otherwise it may you know disturb the entire charger itself.

So this would ensure that during the time when the electric vehicle is being plugged in

and charging, the vehicle is not allowed to move from its position. So you see the charging time, it depends upon the capacity of the battery which is present within the electric vehicle and also the capacity of the charger. So you see if there is a battery of capacity 18 kilowatt hour which is present in a small vehicle. If you plug into 3 kilowatt capacity charger, naturally it would take 6 hours provided that the 3 kilowatt charger is operating at its rated capacity. It takes 6 hours but the same vehicle if it is plugged into a 50 kilowatt charger provided the battery within this vehicle is capable of receiving such a high charging current and the charger is also capable of operating at its rated capacity then and the cable is also good enough to carry the current then it would just take 22 minutes.

Its charging is just a matching between vehicle capability and the capability of the charger and the connectivity. Similarly you know you can do the mathematics for other combinations as well. And then I would like to discuss little bit about one of the important component of the electric vehicle which is batteries. Though I will not go the chemistry aspect of the battery but I would like to give you an overview of what are the different combination of battery technology that are present in the market today and what is the expectation from Indian grid perspective or Indian market perspective. Where do we stand, what is the expectation and what are the limitation and challenges to scale it at a larger number.

So the first battery type is a lead acid battery. Very conventional, age old, the advantages as well as disadvantages. The disadvantage is high weight. Weight of a battery is quite high. Power density is very low and heavy maintenance you know you keep on changing the acids, the distilled water and all these things. But the advantage is low cost, suitable for different applications.

It is seen for vehicle ignition, backup power supplies, UPS at home and all these things. Though the existing three wheelers, the auto rickshaws and all if you go and talk to a auto rickshaw and ask him what is the battery that he is using, possibly the likely answer is he may be saying I am using lead acid battery. The only reason that it comes to his mind is it is cheap because they can gain more profit but in the long run the maintenance cost and so many things issues are there which they may not be able to foresee. So this is about lead acid battery. Then if you discuss about the second type which is nickel cadmium, the good, the advantage is good performance over low temperature, good life cycle at low temperature.

The main problem with this nickel cadmium battery is its dreaded memory effect. So what is this? If you have a nickel cadmium battery and let us say you consistently operate this nickel cadmium battery based some application, anything it could be and you discharge it up to 50% of its rated capacity consistently. From 100 to 50% you discharge and then you go for charging, you charge up to 80 or 90%, then you discharge up to 50%.

You keep on repeating this for a good amount of time. Then let us say if you decide to discharge it due to some reasons, you want to discharge it more beyond 50%.

Let us say you want to discharge at a specific time up to 20%, then the nickel cadmium battery may not be able to meet out your expectation. The reason being it has forgotten its capability to me to, so that it can discharge up to the capacity up to 20% or even low. So this is a dreaded memory effect. It is used for toys and aircraft and electric vehicles, multiple applications are there. And then there is a third type which is nickel metal hydride which is high capacity and energy density, battery type and used for consumers, electronics, electric vehicles, so on and so forth.

So and there is a big player which is lithium ion. So multiple technical benefits, high energy density, no dreaded memory effect, low self discharge, used for multiple applications like defense, aerospace, space applications, electric vehicles, consumer electronics, multiple applications. Only problem with lithium ion battery is the cost is quite high, significantly high compared to any other battery type. This makes the lithium ion battery a sort of limited choice for the electric vehicle application because in the large scale if you want to manufacture electric vehicles, the cost is very important aspect that we need to look into it apart from the technical benefits. So let us see the requirement of lithium ion battery in India. You can see here lithium ion raw material required for 1 watt, you know around 1 watt hour of battery manufacturing may require around 2 gram cathode NMC is required.

Whereas the overall cumulative battery requirement of Indian system is for the first phase 120 Giga watt hour, second phase 970 Giga watt hour, third phase is 2410 Giga watt hour. Quite a significant battery expectation on 3500 Giga watt hour of battery requirement is there. So to have such a vast battery requirement, so what is the cathode resources? You see here 5 into 10 to the power of 9 kilograms. This accounts to 150,000 million US dollars, very huge amount of money. So this is quite a challenging thing and not only that you know you see the raw material to have such an amount, such a huge capacity of battery manufacturing you need to have raw materials within this country.

From the Indian perspective if you see in the entire list of the countries where you can find the lithium ion resources, the countries like USA, Namibia, Brazil, China, Chile, Australia and all these African Australia and US countries but where is India? India is nowhere in the scene. So yet it will become like another issue similar to that of the uranium resources and base nuclear power plants. So one side we have a lot of battery requirement to make sure that EV is a successful solution to meet out the expectation of this country and on the other side we do not have sufficient raw materials. We have to be dependent on other countries and apart from this the other challenges, factors another important factor affecting detail man battery market in India is the cell manufacturing

unit.

You need to manufacture it. It is not just a raw material. You need to have some good amount of technology and infrastructure to make it, make the battery manufacturing. So US you have the battery manufacturing units. In China you have Japan and so many other countries whereas India is not there again in the same. So this is another important challenge. So what are the alternate options that we have? One is redox flow battery, sodium sulphur batteries, lithium sulphur batteries and sodium ion batteries.

Redox flow the advantage is long life safer for operation, fast response, the demerit is low energy density. Sodium sulphur batteries, this is sodium sulphur, sodium sulphur batteries. The merits are high energy density, high operating temperatures.

The demerit is less safety. Then we have lithium sulphur batteries. The merits are high energy density and low cost whereas demerit is limited life cycle and we have sodium ion batteries which is good for high energy density, low cost, suitable for Indian market and demerit is technology need to be well established. May be a good option would be to have some combination of sodium because the raw material problem is solved. India being a subcontinent, three side covered by saline water you have, you need not have to depend on others who are solved. So sodium based batteries with sulphur batteries or sodium ion or any other future upcoming batteries may be a good viable option from this country perspective. May be I am not expert in battery technology but this is one such thought that it can be a good option in future.

So what are the factors affecting charging? Battery size, if battery size is higher than longer it will take to charge naturally. Battery state of charge, it takes more time to charge if the battery is drained out compared to battery charges let's say 50% or 40%. Maximum charging rate of vehicle, if the vehicle charge rate is 7 kilowatt then it is not possible to charge using 22 kilowatt charge point. That means there is a capacity limitation with respect to vehicle charge in inflow and maximum charging rate point of charger, the charge point is capable of charging at lower capacity than the maximum charging rate and the vehicle is restricted to charge at the lower rate. Suppose the vehicle is capable of receiving a high charge rate but the charger is of limited capacity and then still we have to be limited with whatever the charger can offer to the battery.

And environmental factors like a colder temperature can take it slightly longer time to charge. The extreme temperature let's say the battery, same battery which is been deployed in southern state may perform in a different manner when compared to a battery which may be present in northern states where the temperature fluctuations is quite heavy. So the temperature surely will have an impact on the performance of the battery as well. And hour of the day, during the peak hour charging the electric vehicle takes more time as more energy is consumed from the grid. In the peak time the grid is congested

and there is limited resources to meet out the expectation naturally the charging capacity of the battery will have to be limited.

And the more electric vehicles, let's say a particular charging station where multiple electric vehicles are crowded then still there will be limitation with respect to how many vehicles the charging station can cater and for how long and what is the capacity limitation and all these things need to be decided. Type of charge cable, the cable is also a limiting factor whether it is capable of holding a high charge rate or not that need to be understood and then battery drain out allowing battery to deep discharge affects the longevity and the time duration of the battery to charge completely. So basically it is not recommended to drain out the battery even you might have observed in the mobile phones, it is not recommended to completely discharge a battery or completely charge the battery. So maybe 20 to 80 percent or 20 to 90 percentage whatever the battery technology is there it is always better to hold some charge before you think of draining out. And then battery idling, so if you keep a battery for a long time without usage so that may also result in the overall operation of the battery, the life cycle of the battery may get affected.

And then we will discuss about the type of EV charging. So one is onboard charging and there is solar power based EV station, wireless charging and road constructed for dynamic charging. You can see here this is the onboard charging, you just park the electric vehicle and connect to a charging station and get it charged. It is very simple and very simple to understand. There is a solar power based EV station. Let us say you take electric vehicle as you can see here, so most of the IT parks and you know so many companies they may be having their own parking stations.

If in the parking station the solar panels have been placed which can also give shadow and also help the vehicle to charge because the car is idle, use these solar panels to charge the electric vehicle. By the time the owner is ready to depart to his home, so the vehicle is ready with the full charge. And then the wireless charging, so this is another technology where you need not have to provide a cable between a charger and a charging point in the vehicle. So there will be two different coils being situated physically at a different location, different spots.

So there will be exchange of power through the wireless charging approach. And there is a road constructed for dynamic charging. This is another interesting research being carried out and some pilot studies being done. You can see here there is a lane, specific lane dedicated to electric vehicle itself. So the main advantage with this kind of EV charging is the vehicle need not have to be a stationary. The vehicle is moving in a specific lane through the wireless charging mode, the vehicle is continuously charging while the vehicle is moving from one point to another point.

So this is another important innovation being done. So EV charging station including off-board and on-board charger, you can see here. This is a typical electric vehicle. So there is a DC to DC converters which is meant for meeting of the electronic loads which are present in the vehicle and there is a battery which is present. There is a DC bus.

You can see here this is small DC microgrid sort of thing and there is a motor. Motor is a main driving force by the way vehicle is moving. So there is a DC to AC converter to help the motor to drive the vehicle and there is a battery which operates in DC to DC mode. So there is a DC to DC converter.

So and there is a on-board charger. There is also a super capacitor. We have discussed about this. The battery and super capacitor based hybrid combination would help to improve the life cycle of the battery because super capacitor is a high power density device. Battery is a high energy density device. So super capacitor would certainly help the battery life cycle to be better.

So there is also super capacitor being placed. So if there is a on-board charger, so you connect to a EV station and then there is a AC power supply and there is a direct charging and whereas if there is a off-board charger connection then what happens is there is a AC to DC conversion and DC to AC, DC to DC converter is being placed and the way the battery is again charged. So either you go for off-board charging or on-board charging based on whether you have a charging station present or not, you can connect to any of these modes. So with this we will conclude for today and we will continue our next discussion with respect to electric vehicle. Thank you so much.