

CHARGING INFRASTRUCTURE

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Lecture 1

Lec 01: Introduction to the EV Charging System

Hello everyone, welcome to Lecture Number One of the NPTEL lecture series on charging infrastructure, where we discuss different aspects of EV charging systems. In this lecture, we will introduce you to the EV charging systems in this ecosystem. Now if we talk about the course introduction, so the course briefly covers topics like introduction to EV charging systems like what are the building blocks in those EV charging systems are, what the EV charging system actually is, and then we will discuss in more detail the building blocks of an AC and DC charger. After understanding the different building blocks of an AC and DC charger, we will discuss in detail individual building blocks, such as the types, operating principles, design, and control of the power conversion unit, which primarily includes AC-to-DC and isolated DC-to-DC power converters. After that, there will also be

a discussion on communication. Whenever the charger plug is connected to the EV, there is a lot of communication taking place—a lot of handshaking between the charger and the EV to ensure the safe charging of the EV battery. This communication also depends on the type of charging system. If it is an AC charging system, the requirement for data to be transferred from the EV to the charger is not as critical as in the case of a DC charger. We will discuss this in detail as we progress in this course, explaining why DC chargers require more data to be shared from the EV to the charger, primarily because the power conversion unit in the DC charger is kept outside the vehicle, and you are directly plugging DC into the electric vehicle. We will also discuss different charging procedures, the protocols they follow during AC charging as well as DC charging, and in this, we will discuss in detail the different communication protocols being used in this process. However, while there are several charging procedures and protocols, we

will limit our discussion to AC charging systems, AC Type 2 chargers, and different communication aspects related to AC Type 2 charging systems. For DC chargers, we will discuss CCS2, another type of DC charging system, so we will cover topics related to CCS2 and also some aspects of DC001, or Bharat EVC DC001, charging systems.

Later, we will conclude by discussing the components of a charging station and how these components interact with each other. We will also discuss different aspects of power conversion. Now, let us start with the subsystems of an EV. An EV itself is a system comprised of several subsystems. These subsystems interact with each other to ensure that the purpose for which the EV was designed is fulfilled, or you could say the requirements for which the EV was designed are met. So, in this context, we have the mechanical subsystem.

If we talk about mechanical subsystem, we have the gearbox unit, we have the differential unit and we have the several mechanical linkages which will be connecting at the output of electric motor going towards the wheel of the vehicle. then from the mechanical subsystem we have the electrical subsystem or you can say the proportional subsystem in proportional subsystem we have the electric motor which is the machine which converts the electrical power into the mechanical power and then in order to ensure that ev motor or you can say the electric motor performs and listen to the command given by the driver or given by the user we require a powertronic converter which converts the battery voltage or you can say the battery output voltage and current into the form which is been which has to be fed in into the which is been used by the electric motor. after the electric motor we have to supply the electric motor we have a powertronic converter now this powertronic converter is used to actually convert the battery output voltage and current into the form which is being required by the electric motor mostly there are ac motors which are being used could be PMSM and induction motor which are being very frequently used in the evs around the world so that's why we have to convert the output of a battery to convert the output of the battery which is a dc into the AC which is actually been fed into the AC motor and then required torque is generated which is being given to the wheels.

If we talk about in order to control the powertronic converter we have the vehicle controller which is also sometimes called as the electronic controller unit which gives signals to the local controller of this powertronic converter to actually provide the required gating signal to different powertronic switches in the powertronic converter. which actually helps in generating the

required voltage and at required frequency to be fed into the electric motor in order to achieve required or you can say the speed demanded from the user. Then we have the accumulator management system or you can say the BMS or battery management system. If the accumulator is a battery, if it is a battery powered electric vehicle then accumulator will be a battery. If it is a fuel cell based electric vehicle then the accumulator will be the fuel cell or combination of battery and fuel cell.

So, that is why we have used the very common terminologies which is the accumulator. So, accumulator could be a battery pack or could be the combination of battery pack or fuel cell or could be the combination of battery pack and ultracapacitor. But for now, we assume that it is just the battery pack. So, in order to ensure the safe operation of the battery pack, we also have the battery management system which ensures the cell balancing of individual cells in the battery pack because battery pack comprises of series parallel combinations of battery cells so that the charge distribution among those cells will be ensured by this BMS also along with this it will also ensure the temperature of the battery and the voltage level of the battery and current level is within the safe operating region or not now whenever the vehicle runs

The battery gets discharged, and in order to replenish the energy which gets discharged while propelling the vehicle in either forward or backward direction, we require a charging system or a charger. That charger could be an AC charger or a DC charger, and that is what we will discuss entirely in this course—what this charging unit is. Or what is this unit which is being used to actually replenish the energy that is being taken out from the battery while the vehicle is in operation? This comes under the energy storage subsystem. This charger node can sometimes also be kept outside the energy storage subsystems as well. After that, what we have is another important thing, which is vehicle communication. That vehicle communication could be inter-vehicle communication or intra-vehicle communication—that means communication within the vehicle or between different vehicles as well. This is what the subsystems of an EV are all about, and we are talking about them in this course. Things related to the charger unit, and that charger unit is nothing but either an AC charger or a DC charger, which gets plugged into your EV to charge your battery pack. To support that charging, we require certain equipment and other infrastructure that we will discuss in this particular course.

Now, if we talk about some EV battery information, because that will define some of the important criteria related to the charging system. So, if we talk about EV battery information, particularly from the Indian perspective, most of the things will also be relevant for the rest of the world as well. In this, we have electric two-wheelers which have a battery capacity ranging from 1.2 to 8 kilowatt-hours. and have a battery voltage ranging from 48 to 72 volts. Now, these 48 to 72 volts are the nominal voltages I am talking about. However, when the battery is fully charged, it has a voltage nearly 15% higher than the nominal voltage. And whenever it is discharged, it goes down to a maximum of 75% of this nominal voltage. That means the charger unit must support 75% to 115% of the battery charging as well.

Then comes the EV 3-wheeler, or you can say EE 3-wheeler, which has a battery capacity again ranging from 3.6 to 8 kilowatt-hours. Again, the battery voltage will be somewhere between 48 to 72 volts. These are actually the nominal battery voltage levels, and the maximum voltage may go up to 15% higher than the nominal voltage. Then, when we talk about EV cars, or you can say electric cars, there could be electric cars with low-voltage powertrains. There could be electric cars with high-voltage powertrains. In low-voltage powertrains,

We have a battery voltage somewhere around 72 volts. However, over the time, it has been understood that the efficiency of the powertrain can be improved if we go for high voltage. Efficiency and performance of the powertrain can be improved if we go for high voltage and that is why it goes up to, you know, the high voltage powertrain will have a battery pack having the nominal voltage somewhere between 350 to 500 volts. and that is something which is you know which is important to understand for us because you know this this is this result in two kinds of charging system you know when whenever we are doing the let's say when we are whenever we are doing the DC charging whenever directly the DC gets plugged into the vehicle so entire power conversion is taking place outside the vehicle in that case we require two sets of charging system One is you can say you know charging system which supports somewhere between 40 to 120 volt DC and we have and second one will be the charging system which supports the high voltage which is somewhere between you know 350 to 500 volt generally.

Generally as I mentioned that this particular you know this voltages are the nominal voltage and generally the maximum voltage of the battery will be kept nearly 15% than that of this nominal voltage and we assume that whenever the battery voltage goes up to 75% of the nominal

voltage that's when we can say the battery is fully you know in a discharge stage. So the voltage level may go from 75% of this nominal voltage to 115% of this nominal voltage. And this when we talk about e-car with low voltage powertrain, this was the first generation cars where in early 2000s when the cars were there. Now over the period of time, the high voltage power train has been adopted with a battery pack somewhere around 30 to 80 kilowatt hour and having the, I mean, high voltage battery pack somewhere, having a nominal voltage somewhere between 350 to 500 volt range.

Now, so that's why we have charging system to support two voltages one is that low voltage which is going from 40 to 120 volt and then another one is the high voltage which is going from 350 to 500 volt and this is the important understanding which we get from this table because this will help us in understanding let's say when we have a car so we require a charging system which supports this high dc voltage at the output primarily talking about the dc charges because in ac charger the we are directly plugging in ac into the vehicle and inside the vehicle we have a power conversion unit to convert it that ac voltage into the required dc and which will be going which will be fed to the battery The data which are presented over here are as per the report given in the link below and some of the recent launches from different manufacturers. However, considering the rapid evolution of EV technologies, these numbers may change in future.

Now comes the another important topic which is the EVA battery charging Now the EVA battery charging obviously can be done in various ways The first way is you know conductive charging Where we have the AC and DC charger Where you are actually plugging in the charger plug into the vehicle And through the copper wires or through the wires the charges Or you can say the battery gets charged from the electric vehicle supply equipment Or you can say from the charger Now there are another kind of charging which is possible which is the contactless charging. In contactless charging primarily there are two kinds of technology which are available which is inductive I mean contactless charging using magnetic field and the second one is capacitive which is the contactless charging using the electric field. so these are the contactless charging this we are talking about static contactless charging where the vehicle comes in and gets parked and then automatically the charging of the ev battery will be taking place without actually plugging in any plug or any connector into the vehicle so that will give the full autonomy to the user that they do not have to bother about plugging in the charger into the

you know into the ev just like you have the wireless charger for your phones Now, if we talk about this one, both the conductive and contactless charging requires a dedicated infrastructure to charge the vehicle.

That means in case of conductive charging, you require AC or DC charger to be placed in the parking lot and then the user goes in and plug the charger into the EV then contactless charging you have to park your vehicle in the desired location or in a desired place where the power is transferred either through magnetic media or the electric media so in both the cases you have to go and park your vehicle into the designated place and that will lead to the charge anxiety or you can say the range anxiety range anxiety among the user. So for example, if let's say you are taking your EV and going into a long drive or going into a highway, then you have to always bother about where the charging stations are located, where I can go and park my vehicle and get it charged. So that's the range anxiety which actually has among the user when they are having the conductive charging and contactless charging.

which could also be there for people who are using or for the user who are using the gasoline vehicle, I mean where they have to fill in the gas or petrol. But the thing is the petrol pumps and the gas filling stations are very much nearby, are very much well stabilized and the infrastructure are very well laid down. So the you know you can find this the petrol pumps or charging station or gas filling station in every kilometer of a distance travel you will find those stations. So that's when the charge anxiety in the user is less as compared to the charge anxiety in the EV user because you have limited charging stations and that's when the range anxiety is one of the important botheration for the user. then you have a dynamic contactless charging where you can charge your vehicle while you are moving or you can say it is also called as the on-road vehicle charging where your transmitter coils are placed on the roads and your receiver coil is on the vehicle and when you are that and on the move itself you are able to transfer the power from the from the transmitter to the receiver and that's when can which can be used to charge the battery pack

So, that will actually increased the range So here you can get the range extension, but still, you know, it helps you to reach to certain points, but beyond which you require a dedicated charging stations or where you can go and park and charge your vehicle. However, in dynamic contactless charging as well, you require a dedicated infrastructure where you have, you can

place the transmitters onto the roads and then while running, you can charge your vehicle. Then comes another technology which is a battery swapping technology where the user can take the vehicle, swap the battery, only the battery pack with the battery pack having the same kind of health and having the larger SOC or you can say having the, I mean you can replace the discharge battery with the charge battery having the same kind of health. However, understanding the health of the battery or monitoring the health of the battery will be a challenge in this battery swapping technology.

technique however in this battery swapping method what you can do is you can range you can increase the range range is increased to infinity that means you just have to go to battery swapping stations just replace the battery pack with the charge battery pack and then move on so here you do not have to so you can actually practically increase the range to the infinity how obviously you require a dedicated battery swapping station but the stop time or the stoppage time is minimal as compared to as compared to conductive charging you do not have to wait and charge your vehicle I mean you do not have to wait too much to charge your vehicle as compared to the conductive charging or you can say conductive charging of in case of conductive charging so this is what is the battery swapping technology you know one can also use so range can be increased to infinity if the battery swapping stations are placed in nearby distances again here also one has to make sure that battery swapping stations are there and again you know the you know you but only one advantage you have you have is you don't have to stop for longer period of time However, here also there is complexity in identifying the health of the battery and that is why this technology is also quite complicated.

So, that is why most of the systems are conductive charging systems. So, we will discuss, we will focus our discussions on this conductive charging system because if we understood the conductive charging system, all those communication, all those charging procedures can be applied to contactless charging system as well. Then comes the battery charging modes. Now again we have seen what are the different battery voltages which are available in the ecosystem. We have also understood the different charging methods which are available in the ecosystem.

Now, while the battery is getting charged, there are several modes by which the batteries are charged. The first mode is the CC mode, which is a constant current mode. Now, in the constant current mode, what you have to do is continuously ensure that the batteries are

charged with a constant current. That means the charging is done with a constant current. Now, it leads to two things that can happen.

One is obviously overheating of the battery pack because of the internal resistance of the battery pack. I^2R losses will occur in that internal resistance. Second, one has to continuously monitor the voltage level of the battery pack because the voltage level of the battery pack cannot exceed the maximum voltage level of the battery cell or the battery pack. For example, if we take a standard lithium-ion cell, it has a nominal voltage of 3.6, which goes up to a maximum of 4.2, which is nearly 115% of 3.6. And whenever it is fully discharged, we generally allow it to go down to 2.7 volts, which is nearly 75% of 3.6.

Now, these battery cells will be connected in series to obtain batteries with several voltages. For example, if we take a 48-volt battery pack, it goes up to a maximum of 55 volts, which is 15 volts above the nominal voltage, and on the lower side, it goes down to 35 volts. Which is 75% of the 48 volts. So, we must ensure that the battery pack does not exceed 55 volts, or you can say each cell must not exceed 4.2 volts. So, continuous monitoring of the battery voltage is required. These are the two disadvantages of this charging method. Now comes the constant voltage mode. In the constant voltage mode, the charging is done with a constant voltage. In this case, the voltage is kept at a fixed level at the output of the charger.

Now, because of this constant voltage, two things may arise. One is obviously overheating, and this overheating may arise due to the overcurrent during the initial charging process. That means whenever there is a huge difference between the charger output and the battery voltage. Now, during that time, a huge inrush current will flow from the charger to the battery, and that's when the constant voltage has a problem of enormously high current during the initial stages of charging, or you can say the high inrush current. Now, to limit that, to avoid that, there is another charging method which is being used, or you can say charging mode, which is called CCCV, which is the constant current followed by constant voltage. And here, both things can be addressed. First, the constant current is applied, and that's when you can limit the value of inrush current because, since you are applying a constant current, you cannot have a very high inrush current which is drawn by the battery pack. Then, the constant current is applied, but we have to monitor the voltage of the battery. So that is why we can then ensure the moment the battery voltage reaches its maximum voltage, we can then change the constant current mode to the

constant voltage mode. Now, if we see the curve, which looks like so in CC and CV mode, generally what we have is something called a pre-charge stage, where what we will do is—

where a small charging current is being applied, such that you know, a small constant charging current, you can say the I pre-charge, is applied such that no inrush current will be drawn or no huge amount of current will be drawn at the start of the charging. Then, after that, the battery current is kept constant, and this we can name as ICC. Constant current we can apply, and during this portion, during this time, if we see, since our current is kept at a small value, our voltage will go with this slope, with some small slope, it is going. Then, after that, since you have applied a good amount of current, the slope of the voltage will suddenly rise up. And then, near to this maximum voltage, you can say V -rated of the battery, it goes and it clamps the voltage to that value. Now, during this time, since we have kept our voltage constant, the current will now— die down exponentially, or you can say with some RC constant. However, we cannot define an RC constant precisely because the internal resistance as well as the capacitance of the battery will change with the battery current. So, these are highly non-linear systems. However, there is some kind of exponential decay of the current, and then we can say whenever the current reaches, let us say— the I minimum value, we can then put the end of charging.

You know, whenever the current reduces to a value smaller than the I minimum value, we can then stop the charging. And this place is the CC, or you can say CC part, and this place is the CV part. Now, if we try to see our power, since the current is constant here, the power is also going linearly with the voltage. Then, from here to here, it will further go and reach its maximum power level. Then, from there, since the voltage is constant and the current is going down, the power will also have the same slope, same variation as that of current, and goes and then comes to this point and then goes to zero at the end of the charging phase. So this is the— charging power, or you can see power during the charging. That is how the power gets varied over the time when the charging is taking place. And over this, the time period during the CC part, we are having the fast charging of the battery, and during the CV charge, what you can say is, I mean, it is the time-taking— time-taking part of charging, or you can say it takes a huge amount of time for the current to go below the minimum value. And that's when we can ensure that the voltage of the battery pack reaches somewhere near to the rated value, and we can say that the

battery is fully charged once the current which is drawn during the constant current goes to nearly less than the I_{minimum} value.

Then we have another kind of charging which is constant power followed by constant voltage. This is another kind of charging mode where we first kept the constant power then followed by the constant voltage. So it will help in you know charging the battery with high currents at low SOC's and or at low charging level and the current goes down as charging progresses now there are another kinds of charging modes which are available you can also have multi-step CCCV where you can put the i mean here we have kept constant current we can put the some steps of current as well in case of multi-step CCCV this will help to optimize the you know the fast charging period or you can say this is the CC period to optimize the time for this fast charging period then you have the second one you want there is also pulse charging after that you also have you know

The variable current charging so where you know instead of keeping the constant current you can keep on varying the current kind of a multi-step constant current followed by constant voltage charging where instead of keeping the very large amount of current we can keep the variable current we can keep a very very high current at the low socs and then the socs are nearing towards the you know nearing towards the larger value we can reduce the current so many you know different charging modes are possible however is the CC followed by CV which are being commonly used in the as a charging modes for charging the EV battery so why we need a EV charger why we need a dedicated equipment called as a EV charger for charging our EV battery now it is primarily it is used because of the requirement of charging profile and that requirement of charging profile is defined by the battery management system of your EV so in the EV you have a battery pack and that to manage that battery pack you have a battery management system and it is a battery management system which will define what kind of charging profile it is needed to charge the battery which is being used so different manufacturer have different kinds of charging profile which is being you know communicated to the charger and accordingly charger will keep the output to charge the battery following that charging profile so we need the charger to actually support the specific charging profile along with required protection safety and communication and that communication is needed for monitoring and meeting purposes so the EV charge is needed to actually support the specific charging profile

demanding by the BMS of the vehicle also in more top level if you see the EV charges are being used because the charging is done from AC

is done from AC voltage source or grid AC grid we can say or you know uncontrolled DC DC source you know from renewable from the renewables like solar one example so charging is done from the AC grid or sometimes uncontrolled DC source as well so we are actually charging using an AC and we have the battery which is the which is the DC source so primary we require the charging we require the EV charger dedicated charger because we have a AC grid and we need to charge the DC batteries so we require some kind of power conversion unit and that power conversion unit must operate with the required inputs and that power converter must be operated at required operating conditions with required protections, safety in order to ensure the safe charging of the EV and in order to do the safe charging of the EV batteries because batteries are the one which are storing energy and they are prone to catastrophic failure in the vehicle since they are storing the energy. Now, if we talk in a briefly what is a building because we will discuss that in from the next class or not. But the building block of an EV charger is primarily comprises of a power convergent unit which is nothing but the AC to DC converter followed by isolated DC to DC converter.

Obviously, having some filters to ensure the required DC as well as the required AC current is been drawn with the specific power quality requirements. then we have the communication ports which comprises of proximity pilot control pilot and you know with the CAN channels like CAN high and CAN low channels and with sometimes it will also require the dedicated you know PLC modems as well so these are the some of the communication ports which are be needed Then comes the electric vehicle supply equipment. This is the unit which comprises of power. Sometimes, you know, when we talk about DCVAC, it comprises of power conversion unit.

In case of AC charger, it comprises of sensors, relays, protective devices in order to ensure that we have the input which is getting plugged into the EV is within the safe operation or within the safe range. limits so that is usage of the electrical supply equipment when we have ac charging we have ac evsc when we do the dc charging we have the dcvc and then you have the connectors and plug these are important because the charging plug is coming from evsc which gets plugged into the vehicle via vehicle inlet connector and those the compatibility of those

things or you can say form factors of the plug and the inlet connector must be same such that they both get plugged in a proper manner and further we need cables between the EVSE to the vehicle which can run from the EVSE to the vehicles and that is generally kept using the 5 meter standard cables. So, these are building blocks of EV charger. We will discuss in detail in the next class.

Till then, thank you and we will see you in the next class. This is just the introduction, introductory class. We will start our in detail discussion from the next class onwards. Thank you.