Fundamentals of Electric Vehicles
Technology and Economics
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Lecture 74
Analytics Part I

Hello everyone. So far in this course we have talked about EVs and EV sub-systems we learned about batteries, we learned about chargers, motors and what all things we need to learn as far as the parameters are concerned, performance of the sub-systems are concerned and also little bit around the designing part of all this sub-systems.

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Today, we are going to touch upon analytics around these sub-systems. Why do we require the analytics, what do we do in this analytics and how do we go about doing that.

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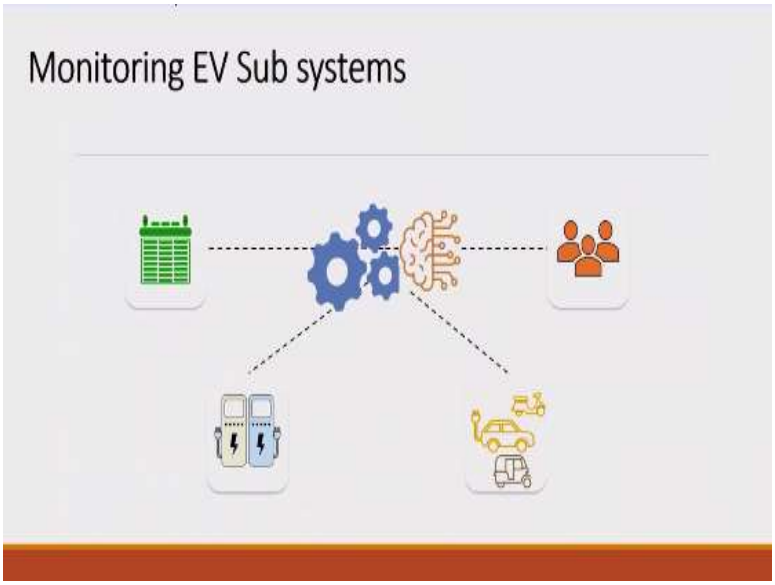

So if we go or talk about the analytics in electric vehicles and subsystems we talked about various actors in the whole ecosystem, we talked about batteries, chargers, vehicles and the users who are finally the consumers of all these sub-systems. And whenever we are talking about analytics it means the first step is that we are able to monitor all the sub-systems, capture the data and then only that analytics would be performed on capturing on the captured data.

So, once we have the captured data then there is a lot of things that we can do around that data and see that how the systems have been behaving and is there a scope that we can improve the designs or the performance of the sub-system. So, the basic purpose of analytics is three fold. One we can figure out if there is any safety issue, if there is any threat and can we take an action on that so that is the first part of it.

The second part is can we do something on the predictions of these sub-system. So, if we talk about like we have been talking and studying about that the battery is going to last for let us say 1000 cycles or 2000 cycles from the data, from the monitored statistics can I really tell and predict based upon the data that now 800 cycles are over and it is going to die in another 200 cycles.

And what is the range so if the initial battery was giving you 100 kilometers what is the range that it is giving you now? It is 20 kilometers or 50 kilometers so that there are no surprises. So, how do we go about doing the predictions on that data based on the capturing of that

information and what is the performance of that vehicle? So that is the second one and the third which may not be directly relevant to the users.

But it is more relevant to the designers of these sub-systems. So what is the feedback that you can give to your designer to the OEMs of that manufacturing component or that sub-system, can we do something about it is our data analytics good enough to figure out that there are faults in the design and how it can be improved designed. So, these are the three basic aims when we talk about analytics on that EV sub-system.

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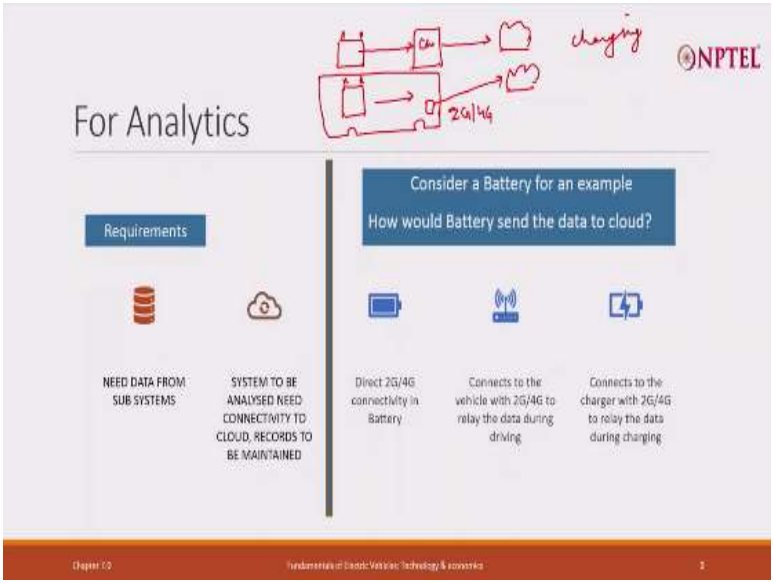

So, how do we go about doing it? The requirement that the first of us that we have is that we need to have the data from this sub-system. The second is that this system to be analyzed need connectivity to the cloud and here the biggest issue is that we are talking about the data to be captured from the mobile unit we are talking about vehicles after all. So, when we talk about the vehicles after all let us pick up one example let us say batteries.

So, if we have to consider for the batteries how do we capture that data. So, we are saying that analytics could be done only if you have the data yeah that is the basic requirement. Now how would we capture that data? The two ways of doing it one is a direct way, another is an indirect way. When we talk about a direct way this means that the batteries in itself should have a 2G or a 4G connectivity.

Such that while it is being used you can capture that data or it is being charged it can capture or send the data to the cloud so it is a direct connectivity that you need to have to the cloud.

So that is the first way of doing it that means the battery has inbuilt GPRS or a 4G module inside that and is sending or relaying that data directly. In a battery it can only do two functions.

It is either charging or it is discharging apart from lying idle if we do not want to consider that case. So, it is only two functions that a battery would perform either it would be charged or it would be discharged. So the second way that we talk about that is an indirect method of capturing. If the battery does not have a 2G or a 4G module to keep on relaying that data to the cloud the only way to capture that data is one; while it is getting charged.

The charger is connected to the cloud. So the architecture is something like we have the battery. This is connected to whatever our charger and charger is connected to the cloud. So this is the case while we are doing the charging of the battery. The second case is we have a battery. Now this battery is actually inside the vehicle.

In that case the vehicle has a unit somewhere which is actually 2G or a 4G module and this in turn is sending the data to the cloud. So these are the two ways that you can capture the data. If the battery is not having a directly inbuilt embedded chip of 2G or a 4G module inside. Now we keep on talking theoretically that this is the data you should capture from the battery, from the motors and sub systems.

Since we have been talking throughout this course that the batteries are the most important part of this whole EV system and the one of the reasons being that it is one that it is the costliest part in the vehicle. Second also being probably this is the newest form of the fuel that we are talking about and thirdly also because this is not very safe if it is left alone. So you need to continuously keep on monitoring that. So, for example for this class I am more focusing on the cell level data or the battery on the battery sub-system.

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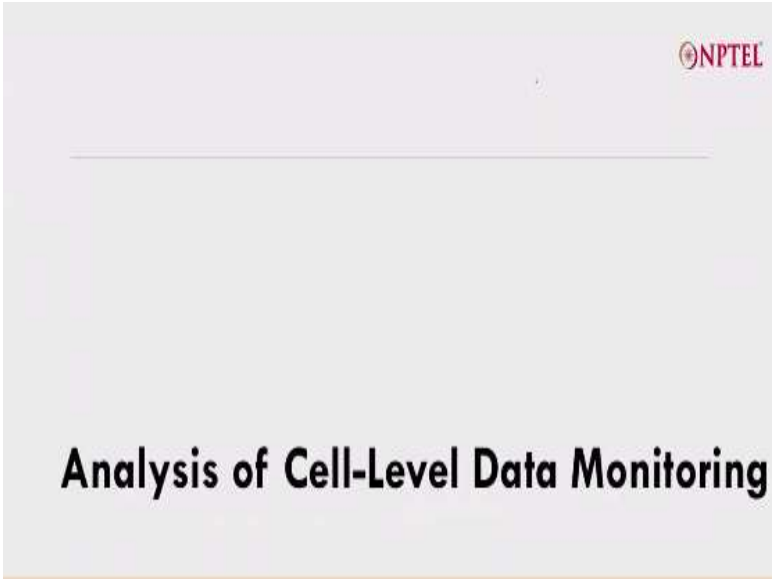

So, let us look at the cell level data what all things that we monitor and what are the things that help in analyzing the battery or the cells and different parameters that you have already studied.

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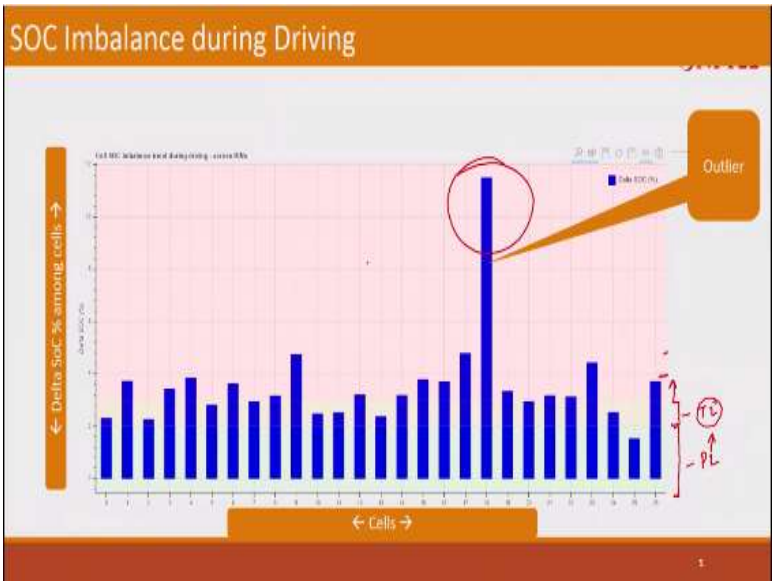

So, the first case that I am taking here is the SOC imbalance during driving. All of us know about the cell imbalance and how do we do the cell balancing in the battery management system. Now we know that cell imbalance is a very-very crucial can actually play a very crucial role in the damage of the battery and this is the most common cause of damage whenever we are talking about the battery.

So, what do we need to do is that while it is getting charged or it is getting discharged we keep on monitoring the cell information that what is the deviation that it is going through for any given cycle of charge discharge. So, here the case that we have taken is the SOC imbalance, the state of charge imbalance. So, while we are charging or driving the car or an EV what is the imbalance that is happening in the SOC.

While you are discharging all the cells may not be discharged by the same level that is the state of charge could be different. Now what is the tolerance limit that you can actually tolerate as far as this imbalance is concerned is important to keep on monitoring. If we do not monitor and left it alone any single cell or a pair of the cell that causes that goes through the cell imbalance would be really causing a big damage to the battery and that is where we have to see that how do we control that.

So analysis helps in figuring out where things are wrong and after that you need to have that control what do you do to control the monitored damage such that the damage could be avoided as far as possible. So here if you see there are 3 limits; this is the first limit which is defined in the battery pack or in the BMS we say this is the defined limit in which the cell imbalance can happen.

So your delta percentage of the SOC could be tolerated in this limit I mean this is the defined limit should be lying between this limit. All the values that fall in this range are the normal values. Certainly when we are driving we are not controlling any cell imbalance and most of the time the cell balancing happens during the charging or while it is ideal. We are not able to do much of the cell balancing while the battery is getting driven.

Because the driving charge rate or discharge rate is not in our control or the BMS control. So, that is where monitoring becomes very important. So we say that this is the prescribed limit and let us say this is the tolerable limit so this is the tolerable limit, prescribed limit. So, if we say that if it is going beyond the prescribed limit I define a tolerable limit that it can actually lie within this part and we need not take any action.

But what if it exceeds the tolerable limit as also. Further, we can define various levels it could be this, it could be this and what are the actions to be taken what if it is this, this means the cell is already damaged or it is going towards a damage and you need to control that immediately if you want to prevent a blast of the battery, a burst of the battery so on and so forth or any I mean connection has gone bad or MOSFET is not working etcetera, etcetera.

So whatever has gone bad in the battery the user does not know, all the technicalities are transparent to the user so he just understand that something has gone wrong, but how would you convey that in a simple term is that while we are monitoring all this only then it is possible that we convey to the user in time and the operator or the OEM also in time such that they can take a good action on it.

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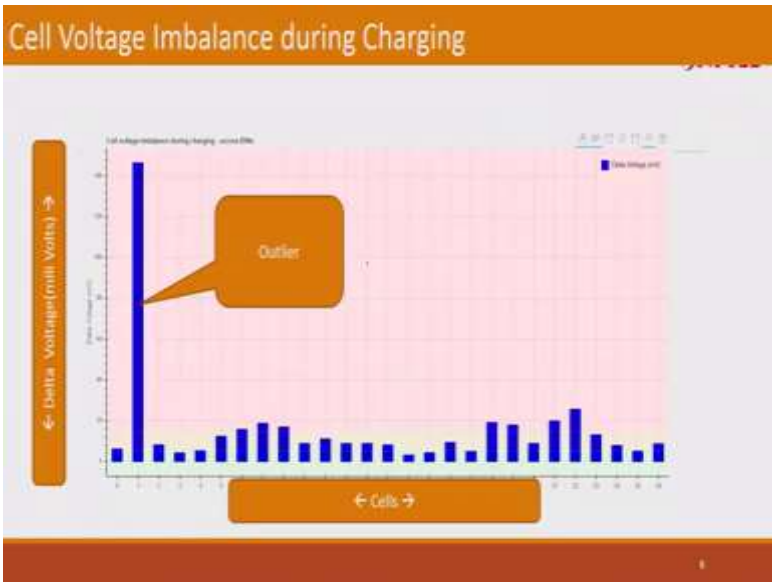

Similar stuff when we do for the imbalance during charging and this is for cell voltage. We just talked about the SOC percentage delta similar is the thing that we talk about delta voltage difference between one cell and the other cell and we keep on monitoring that the similar ranges that we have defined for SOC we define it for the voltage also. So now based upon the cell their chemistry, their characteristics these delta range could be different for every different cells and also based upon what is the cell balancing technique that you are using.

What is the BMS, what is the BMS chip that has been used accordingly these values are defined that means what would be the prescribe limit, what can be the tolerable limit and how and when to take a call. So for an NMC battery or an NCA or LMO or whatever different batteries and chemistries that we have been talking about it really depends upon that how much is the cell tolerable to this delta variation.

So, again we see one outlier so this again is from one of our readings live readings that we have been doing.

Student: What is the vertical axis and what is the horizontal axis?

Professor: So the vertical axis on the vertical axis it is a plot for delta voltage and on the x axis is the number of cells. So, we are monitoring number of cells in a pack and in that given pack what cell number or what is that cell pair number which is going into imbalance.

So keep on monitoring all the cells, so a battery we know is made up of series and parallel combination of cells or the modules that we make off 2P or 4P etcetera and that single module is getting monitored in that whole pack and we keep on monitoring that. Two things to do one to take a call what to do if it is an outlier, second how much of it we should keep on balancing and if we find something critical what is the action to be taken.

Is it that within that tolerable limit if we start charging it slowly and keep it for a longer time then probably the balancing would happen and it would be a good pack to be used again. So that is one part another could be that it has actually gone bad and you cannot use that, but unless we have such monitoring in place we cannot figure that out and for this kind of fuel when we say that the batteries are nothing, but like the high energy densities one that we start talking about. These are actually the bombs and you need to control and see that the bombs do not blast while you are driving.

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Similar readings for the graph again we are monitoring the delta voltages for every cell in the battery pack and seeing that what is the cell imbalance that is happening with respect to their voltage level that is their charge levels or discharge levels. Now this particular draft is for the driving just as a sample.

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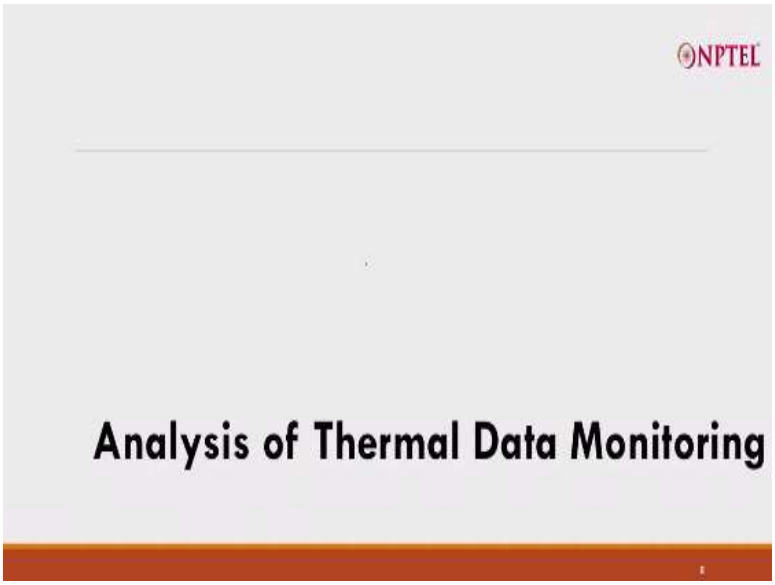

Now as we know that as we talk about how much is the voltage, what is the SOC that the cells are or the batteries are getting charged or discharged while driving charged while charging, the crucial one of the another crucial parameter is the temperature and in the previous classes professor had also talked about the impact of temperature on the battery performance. So we know that monitoring the temperature is very, very important.

We try to maintain the temperature of the battery and keep it under some limits. Dr. Kaushal had also taught about how do we do thermal management of batteries and why it is important. So we know that what is the importance of maintaining that temperature but what if the temperatures are not being maintained. So, either it is not being maintained in the lower limit or it is surpassing the upper limit.

What do we do that is one question that what do we do, but we come to that only when we know that this has happened that means again the analytics becomes important.

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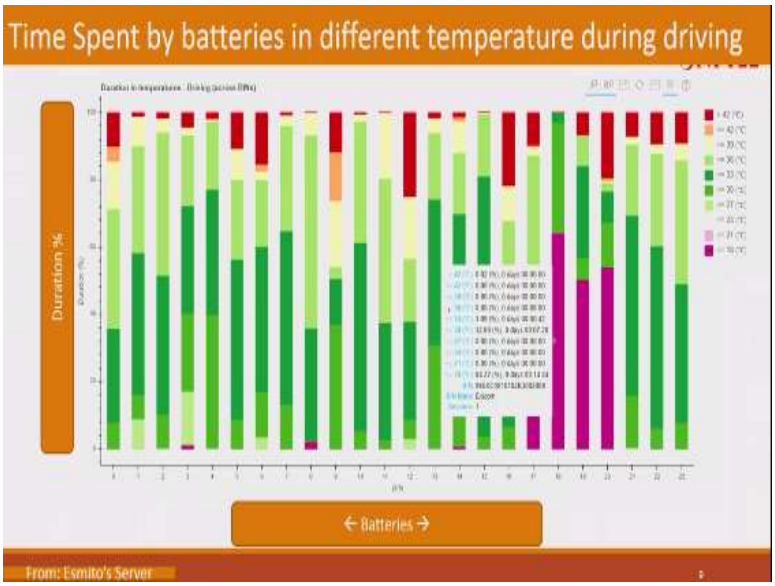

So, this graph is for showing the duration in which the battery is spending the time at that particular temperature while driving. Similarly, we will have graphs for charging so here if you see this is across the battery. So, for example if there is an operator who is using N number of batteries this plot you would see that it is for about 23 batteries. So, we are monitoring 23 batteries continuously and seeing that for how long each of the battery is spending time and what temperature.

Now for these colors I mean you can see it on your right side the red and the orange one are at a temperature 42 degrees in red actually shows greater than 42 degrees. So, what we are trying to maintain is this temperature around 40, 42 and should not be exceeding that, but we see that some of the batteries are exceeding that temperature.

And we have to see that what is the time that they are spending in that temperature and if these battery further are being used at the same place that is in same ambient, but some are continuously being used while their operating temperature has been 30, 35 while the others are showing that in that same ambient temperature and the same driving characteristics if it is matching they reach or surpass 42 degrees or may be sometimes 50 degrees, 60 degrees that means something wrong in that battery or it is thermal management is not working properly or something has gone bad in that battery.

So, from this whole graph we can do a lot of comparison between the batteries and see that how do we filter out good batteries from the bad batteries and if you see the pink one that indicates that the batteries have gone into a lower temperature range. So there is a range of

operation if we are specifying that it should be 20 degrees to let us say 40 degrees then again we have to find out the outliers and when we find out the outliers correlate that with the other battery performing data that we have captured and analyze the reasons around that.

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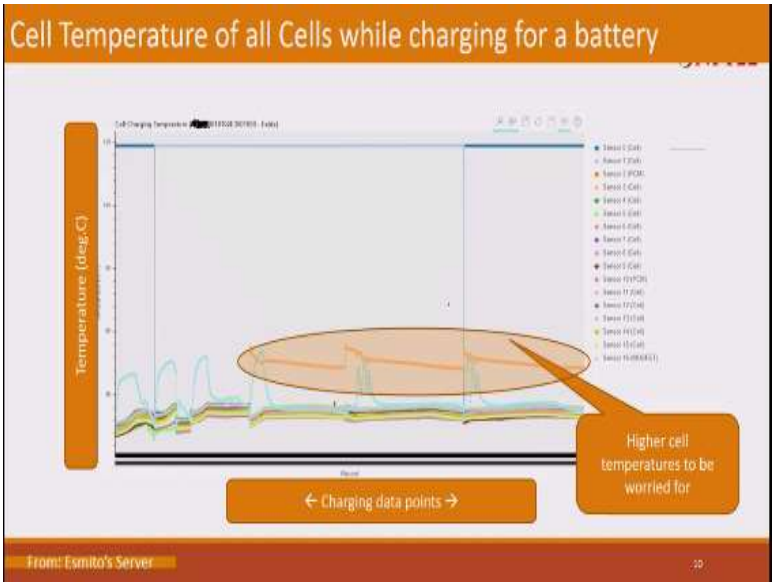

So again another kind of a graph where pictorially what we are showing is it the temperature versus the charging data points. So, while the battery is getting charged what is the temperature that it is going to. So in the charger again if we have specify that the temperature range should be between 20 degrees to 35 degrees or it can reach up to 40 degrees what is it that it is getting spending time at and for how much duration it is spending time.

And the way that we are capturing this data or monitoring this data is through the temperature sensors. So we have different sensors in the battery we keep on noting that value and the battery keeps on relaying it. Now relaying again like we talked about either directly or indirectly it is sending us the data. Now as soon as we see that temperature of the battery inside is going higher.

Again then we have to take a call based upon what is the region in which it is lying and region of criticality depends upon a number of parameters like not only in the battery temperature of course if it is reaching 70 degrees, 80 degrees, 90 degrees we just need to cut it off we cannot drive in that condition or we cannot keep on charging in that condition. Now this threshold again depends upon the chemistry of the battery.

Based upon the chemistry of the battery what is it tolerable limit that has been assigned in the BMS and if the BMS is not working. Now reasons why temperature is going high could be anything. One of the reasons could be that BMS is not working properly that is why it is not maintaining the temperature or anything else whatever has gone bad that means if BMS is not taking a call and if you have a server can you control it through the server and cut off the battery and say that the battery should not be used while you are driving or while you are charging the charger should stop that.

So, whenever we say that indirect methods while we talk about controlling or taking actions the very basic thing is you should not compromise with the safety of the battery that has been basically defined by the BMS. So, there are some parameters that have been defined by the BMS. So those are the basic prime safety features that have been defined in the BMS. Over and above that what you can do based upon this data is what we have to decide. So, BMS is there it should be cutting off the battery, but now we are seeing it is not cutting the battery.

It should be cutting off the battery. We see that there is a large risk that can happen and something can go wrong in the battery that is there this analytics helps in controlling those kinds of things. So two ways of doing it one like I said that direct if the batteries have the 2G, 4G feature inbuilt into this that becomes a live data monitoring. If it does not have then we have certain live parameters that you can define that the battery keeps on sending you while it is getting driven.

So whatever information you can retrieve and what we can do with that data is what we have to see here or else if we do not have anything like battery vehicle is also not capturing the data and it is not relaying to the cloud then if the battery also does not have a 2G, 4G module inside to keep on relaying the data life then what we can do is that it keeps on storing the data into its drive into its BMS and while we put that battery into a charger the charger gets the data and sends to the cloud.

So, if you do not get the data live we store the data and then the data is pushed to the cloud along with this charging data we also get the driving data log and then we perform the analytics. But in that case you cannot control the batteries while the batteries were getting driven. So, whatever technique we use we have to as far as possible maximize what we can do while the battery is in use or based upon what was the previous cycle and accordingly how to take a call for the next charging cycle.

So, if the battery was not monitored live during the charging what actions we can take and say that this battery should be operated in such and such way.

Student: Since there is going to be data pulled out from battery by the charger is the interface between the battery and the charger has to be standardized and what kind of standardization exists today or is possible?

Professor: Okay, when we say that data has to be extracted the standardization becomes important part of it because we want that wherever our vehicle is going we are able to fetch that data through the charger let us say. So we are talking here the charging side of it. Now if it is a public charger there are few standards that we have talked about so it could be CCS, GB by T and Chademo.

But further depends upon how much is the parameter, definition depth or the resolution that has been defined by the protocol. As far as this protocol is telling us that you can fetch the data we can keep the data in our cloud and store that. But if it is the battery the direct way of it usually they do not follow any protocol and these are largely proprietary protocols that are put into the battery by their OEMs and they keep on sending the data to the cloud and keep on doing their data analytics and send the reports to the users.

However, the third application that we can take here is the swapping application where the standardization become further very important for the sake of interoperability that you need to have within the battery and the subsystem even when we talk about single operator. Now there the operator defined protocol or whatever nation has defined that protocol needs to be followed to capture that data if we want uniformity in the data. You want something else on this?

Student: As far as I know the standard charging protocols do not have standards for data extraction, you were talking about data extraction protocol not charging protocol. They have charging protocol standardized data extraction protocols are not standardized.

Professor: There is no protocol as far as data extraction is concerned, so data extraction or data extraction techniques that we use for let us say in all our computer science background people would understand that, but when we talk about getting that data. So, when we are getting that data and we are saying that we are getting through the charger there are protocols or the standard defined between the charger and the battery.

So in what format the battery would be sending that data. There are some mandatory fields like voltage current and the temperature that it needs to keep on fetching the data while charging. So when we say that the battery is sending that data through the charger within a described or a prescribed set of rules or the protocol that we are talking about this is precisely the data that the battery keeps on sending during the charge.

So it is only the charge data we cannot send through that protocol the dump of the data. So, there is no driving dump that is stored on that data which could be send upon that unless we build another messaging structure I mean we can follow the same structure of that particular protocol, but define another message through which we can send that data and pass it on to the cloud.