A Review on Electric Vehicle Charging Systems

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Abstract - *Electric vehicles powered by batteries are becoming increasingly popular around the world. Several causes are driving this trend, including the need to reduce air and noise pollution and reliance on fossil fuels. To have a better understanding of how batteries behave in various situations. It is vital to be aware of certain battery performance factors in certain circumstances. A battery management system includes a battery fuel gauge, an optimal charging algorithm, and circuitry for cell and thermal balance. It estimates essential states and parameters of the battery system, such as battery impedance, battery capacity, state of charge, state of health, power decline, and remaining useful life, using three non-invasive measures from the battery: voltage, current, and temperature. This paper reviews several papers published regarding EV charging types, methods, BMS, state of charge.*

Key Words: Electric Vehicles, Li-ion Battery, Battery Management System, CAN Protocol, Open Charge Point Protocol, State of Charge, Billing System, Battery Capacity.

1. INTRODUCTION

Electric mobility is becoming increasingly important in recent years as a strategy to reduce the dependence on fossil fuels for transportation.[1] Energy efficiency is now a core concern, propelled by rising concern about climate change and rising oil prices in countries that rely heavily on foreign fossil fuels. According to research published by the International Energy Outlook, the transportation sector would raise its oil consumption share in the world market to 55 percent by 2030.[2] Cleaner and more environmentally friendly mobility will also contribute to decreasing CO2 emissions in the atmosphere and hence global warming. [1] Electric Vehicles (EVs) and the usage of Renewable Energy Sources (RES) are the solutions for decarbonizing the transportation sector, and their use is unquestionably increasing.[5] The global market for electric vehicles (EVs) is now a small percentage of the entire auto sector, but this is likely to change quickly. EVs' worldwide market share increased from 8% in 2019 to 12% in 2020, according to Boston Consulting Group, which predicts that by 2026, EVs would account for more than half of all light vehicles sold.[7] Now it is obvious that to support electric vehicles, the development of charging stations is very essential. One of the very first tasks in the process is to design charging stations that offer optimal power and the components that go into them.[1] One of the most crucial objectives for accelerating the growth of e-mobility is to enhance electricity production and management. [1]

Whenever there is an electric power outlet available, the onboard battery chargers enable EV owners to charge their vehicles. As a result, when compared to stand-alone (off-board) chargers, the cost of the infrastructure network is reduced, resulting in a better spread of charge spots and better coverage. Onboard topologies are classified into two types based on their connection to the drivetrain: independent and combined (integrated) circuit topologies. This paper is concerned with all types of onboard integrated chargers. These chargers are divided into two major categories (isolated and non-isolated) [17]

The implementation of 'Charging Structure Infrastructure' is one of the three primary aspects responsible for boosting EV adoption.[1]

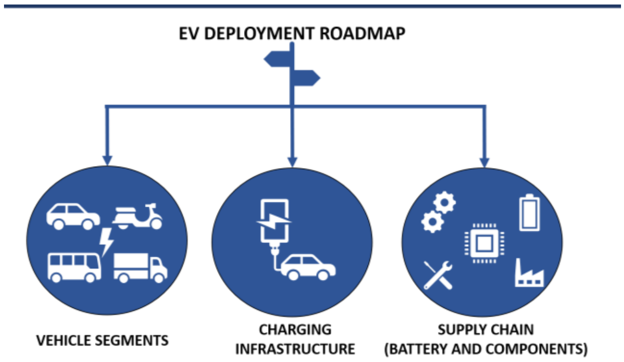

Fig. EV Deployment Roadmap

The main focus will be on measuring the electrical features of the battery in an electric car, which is a very important factor in determining the driving distance available. If the remaining battery capacity level is not displayed by the driver, the decision on when to recharge the battery can be made. It is important to understand certain battery performance data in order to fully understand battery behaviour under a variety of conditions. [2] EVs have been in vogue for the past few years, but little effort has been made to make the car battery more efficient. Therefore an in-depth knowledge of Lithium-ion batteries (Li-ion) is essential during charging and discharging, as is the case with most electric vehicles. [5]

As electric vehicles (EVs) become more powerful in the transportation sector, it is important for manufacturers to have a complete understanding of the best charging strategy. Depending on it, it may increase battery life and reduce the risk of environmental damage. [5]

While safety, efficiency, and comfort are all important factors to consider when buying a car, there is another important factor to consider when purchasing a Plug-in Hybrid Electric Vehicle (PHEV) or Battery Electric Vehicle (BEV): charging time. While recharging the Internal Burning Engine (ICE) takes only a few minutes, recharging the main battery in PHEVs and BEVs takes longer. [3]

Basically, charging can be AC or DC. The battery requires DC charging, so, for AC charging, a switch is required between the charging socket and the battery, while the DC charging motor is connected directly to a DC that can be plugged into the battery. Various 'levels' are related to the amount of energy that can be delivered, and this, too, is related to the source of energy. Higher quality, more power available and charging time shorter. Another big difference is where the charger is. In DC charging, the charger is outside the car and all repair power (integration and repair) is performed outside the car. DC charging usually has very high power ratings and is used for most commercial/public charging stations, such as those located on the premises of gas stations or near a highway. [3]

The operators of most of the charging stations now operate on the basis of selling the transferred power, without the slightest incentive for the driver to remove the vehicle after it has been fully charged. Users of charging stations are looking for ways to improve their efficiency without interfering with customer information. The introduction of time-based costs, based on parking lessons, may help to increase the efficiency of the charging station capacity. Even though payments are known to influence the choice of billing, little is known about how the fees affect the decision to move the car once it is fully charged. [6] Price strategies appear to have an impact on charging, depending on the number of indicators. If the cost varies widely enough, the choice of charging station may be affected. However, estimates of the effect of price strategies, especially time-based strategies, are lacking. [6]

Our main goal here is to understand the operating cycle and charge of Li-ion batteries, to design an effective way to determine the State of Charge (SoC) of Li-ion batteries accurately, and to design a Level-1 onboard intelligent charging system and ultimately provide an automatic payment system to calculate prices.

Level 1 charging is relatively inexpensive as it uses a standard 230-volt outlet, which allows EV owners to charge their electric vehicles almost anywhere. This charging method is very time-consuming and is often used as a backup or other emergency charging method. In multi-unit dwellings (MUDs), such as apartment buildings or townhouses, and in other businesses. Price level 1 may be a possible option. Most Level 1 charging in MUD areas is done using the existing 230-V outlets in the parking lot or private homeowners' garages. The Level 1 charging power output varies greatly but is usually between 12 and 16 amps of unchanged power amps. [8]

1.1 Literature Review

Kadlag Sunildatta Somnatha, Mukesh Kumar Gupata [2] discuss different types of chargers and charging methods with different topologies along with their advantages and disadvantages. It also gives us insight into the construction of battery charging systems and efficiency of EVs. It explains different categories of ac-dc and dc-dc converters topologies such as unidirectional, bidirectional along with non-isolated and isolated topologies which can be used for constructing an onboard charger circuit for EVs. The role of battery management system in EVs and the functions of BMS is discussed such as Data acquisition, State estimation, Charge/Discharge control, cell balancing, thermal management and safety protection.

Xu Xiao, He Molin, Paraskevi Kourtza, Adam Collin, Gareth Harrison, Sasa Djokic, Jan Meyer, Sascha Müller and Friedemann Möller[9] discuss typical circuit topologies and control algorithms for an onboard unidirectional single-phase electric vehicle charger and provide a simple yet detailed component-based model. The presented methodology can be used for modeling an onboard level 1 charger for EV. The full circuit of the EVBC (Electric Vehicle Battery Charger) model consists of a supply system, EMI filter, DBR, Boost converter, DC-DC full-bridge F converter, a-PFC (Power Factor Control) control, PWM (Pulse Width Modulation) control, and battery which together form front end and backend of the circuit. Boost converter with inductor current kept in a continuous conduction mode forms the a-PFC of the circuit presented. A high-frequency transformer is used for galvanic isolation. The battery is charged is two modes which is controlled by the back-end DC-DC circuit: Constant current and constant voltage mode. The battery is charged up to 80%-90% in constant current mode by keeping the current in constant at the reference value. Then it is switched to constant voltage mode. The functionality of each block is explained in detail with its characteristics, advantages and disadvantages. The importance of active-PFC control, the control circuit is discussed along with comprehensive circuit diagrams with appropriate equations. The accuracy of the results is validated against actual EVBCs for ideal voltage supply and distorted voltage supply waveforms and are presented with relevant graphs.

Morris Brenna, Federica Foiadelli, Carola Leone1, Michela Longo [10] discusses an overview of different EV battery chargers based on power levels, direction of power flow and charging control strategy. It includes inductive and conductive charging methods along with their advantages and disadvantages. The characteristics of level 1, level 2 and level 3 chargers are tabled. The need of vehicle-to-grid power flow (bidirectional) is explained with its contribution to the power grid. A two-stage onboard charging system consists of AD-DC stage and DC-DC stage. AC-to-DC stage can be constructed using half-bridge, full-bridge or multilevel diode bridge and an PFC converter. Resonant power converters with LLC configuration are used in the second stage. A suitable charging method for Li-ion batteries used in EVs is discussed which includes the constant current-constant voltage method. The battery is charged initially in constant current mode until a certain value of voltage know cut-off voltage is reached and then it continues charging in constant voltage mode until the current decreases to 3-5% of rated current. A graph representing current vs time is plotted which represents current and voltage throughout the charging process. An alternative method for faster, better battery charging life and safety is also explained known as the Five-Step charging pattern.

Mingyue Zhang and Xiaobin Fan [11], describe in their review paper that one of the electric car's hurdles has been battery technology. Whether in theory or in reality, battery management research is critical, particularly for estimating the battery state of charge. The battery, in fact, has a wide range of time-varying and non-linear features that are exceedingly sophisticated. As a result, precisely determining the level of charge is difficult. We chose this paper as it examines a number of typical patents and papers relating to methods for estimating the state of charge of an electric vehicle battery.

In this paper, the estimating techniques were divided into three groups based on their theoretical and experimental characteristics: Conventional methods based on battery tests, Current methods based on control theory, and Alternative approaches based on novel concepts, with a specific focus on control theory algorithms.

Electric vehicle battery management is critical for vehicle safety, prolonging battery life, lowering costs, and increasing driving range. In a real car, a typical Battery Management System (BMS) is made up of a number of sensors, actuators, controllers, and communication lines. A battery management system's level of charge is analogous to a traditional petrol car's fuel metre

Hariprasad with his students [12] explains that, in Electric Vehicles, battery management systems (BMS) are used to monitor and control the charging and discharging of rechargeable batteries, making the operation more efficient. The battery management system keeps the battery safe and dependable while increasing senility without causing damage. This paper discusses the basic structure of a Battery Management system and its functionalities like analysis of the condition of charge, health, and longevity, as well as the maximum capacity of a battery. Different monitoring techniques are employed to maintain the status of the battery, including voltage, current, and ambient temperature. Different analog/digital sensors with microcontrollers are utilized for monitoring purposes. As the batteries used in electric vehicles should not be overcharged or excessively drained, the battery management system (BMS) is a critical system in electric vehicles. If this happens, the battery will be damaged, the temperature will rise, the battery's life span will be reduced, and the people who are using it will be affected. It's also utilized to extend the range of a vehicle by efficiently utilizing the energy stored in it.

Why BMS particularly for Li-ion Batteries?

This paper also helps us understand that Lithium-ion batteries are very reactive, light, and have the high energy. Lithium-ion batteries charge and discharge much more quickly than traditional batteries.

To avoid a cascade of chemical reactions, a rise in temperature, cell venting, and fire, lithium-ion cells should not be driven beyond their safe operating voltage range. As a result, a battery management system (BMS) is employed, which allows the battery to run within its safe operating range.

For the following reasons, a battery management system is required.

1. Maintain battery safety and reliability.
2. Charging Status and Battery Life.
3. Controlling billing status
4. Control the operating temperature and balance the cells
5. Managing renewable energy

Balakumar Balasingam, Mostafa Ahmed and Krishna Pattipati [13] have studied and mentioned the challenges faced in the various SoC measurement techniques and the solutions to the problems faced in their paper.

Based on voltage data, the OCV-SOC model may be used to predict the SOC. However, since the battery must rest for several hours before OCV can be measured, it is not possible to monitor OCV in real-time during battery operation. A measure of OCV may be derived when the battery is functioning by estimating the voltage across the battery ECM (electrical equivalent circuit model).

This needs the calculation of the ECM characteristics as well. After estimating the OCV, the SOC may be calculated using the OCV-SOC characterization parameters.

Davide Andrea [14], one of the leading experts in Li-ion Battery Management technology in his paper mentions why a suitable Battery Management System is absolutely necessary for the CCCV mode of Battery charging in High Voltage Batteries.

Why BMS is absolutely necessary for CCCV mode of Battery charging in High Voltage Batteries

For small batteries, a CCCV (Constant Current, Constant Voltage) mode of charging is optimal. The battery is charged at Constant Current at first. When the battery is nearly full, the charger's Constant Voltage setting kicks in, and the current begins to decrease exponentially as the battery receives a last charge. In a tiny battery, the charger voltage is distributed quite evenly across the cells.

When charging a vehicle battery, for example, a Constant Voltage of 13.5 V is given to the 12 V battery, giving each of the 6 cells around 2.25 V.

If one cell is more charged than the others, its voltage will be somewhat greater, detracting from the voltage of the others. Therefore, with a high-voltage battery with several cells connected in series, the overall pack voltage is more likely to be unevenly distributed across the cells. A battery made up of ten LiFePO4 cells connected in series (with a maximum voltage of 3.6 V) may have a total voltage of 36 V. However, it's impossible to say whether some cells are at 5 V and others are at 3.2 V. Li-Ion cells do not deal well with the overcharging problem; once charged, they can't take any more current until the remaining cells in the series have received their required charge. Because their voltage rises quickly after being charged, it's quite easy to overcharge them.

When charging high voltage Li-Ion packs, a BMS (Battery Management System) is required. The BMS will not just inform you if a cell's voltage is too high. When correctly connected to the charger, the BMS will cut off the charger as soon as any cell reaches its maximum charged voltage. A good BMS will also withdraw charge from the highest charged cell until its voltage falls low enough for the charger to turn back on and charge the remaining cells. After many cycles, all of the cells will be at the same voltage and fully charged, indicating that the pack is balanced.

Battery Chargers:

The battery charger is crucial in the development of the EV. The charger for the battery should be efficient and reliable, with a high-power density and low cost of low power consumption, as well as low volume and weight. EV chargers are required to ensure that utility currents are drawn with as little distortion as possible to minimize power quality effects while maintaining a high-power factor to provide the most real power available from the utility outlet. [19]

Topologies Of Integrated Charger

1) Traditional DC/DC converter

As shown in Figure 1, this section only integrates a conventional DC/DC converter as part of the onboard charger. By adding a few components, a DC/DC converter can be used as a new converter. In some integrated chargers, converters also act as rectifiers.

The reference proposes a single-stage integrated charger capable of achieving V2G while minimizing the second harmonic current ripple. However, gird-side filter inductors are still needed. When the charging power increases, the inductance increases. The size and weight of the inductor increase, requiring more space. As a result, the concept of incorporating motor windings into chargers was raised.

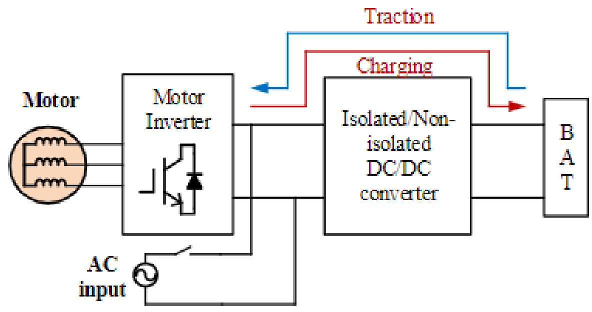

Fig. 1. Using the traditional DC/DC converter.

2) Z-source network

F.Z.Peng proposes a Z-source network. The Z-source network, which is a bi-directional converter, can also be used as a boost function in EVs. Benefits are mentioned. The reference suggests a modified Z-source integrated EV charger. A voltage boost is possible in only one phase. In addition, the Z-source includes a split charger for battery charging. A method of controlling the Z-source integrated charger is proposed. As shown in Figure 2, no additional components are needed to charge the battery. [18]

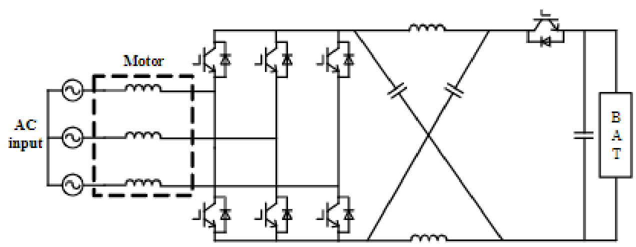

Fig. 2. Z-source integrated charger.

Charging Strategies:

It is generally accepted that widespread EV adoption can have serious consequences for the distribution grid, including distribution transformer overheating, voltage fluctuations, and harmonic distortion. To cope with the above difficulties, in the long run, the grid will need further upgrades. It will be necessary to build infrastructure. It is recommended to use pricing methods. There are two of them. There are two types of charging strategies: integrated and integrated strategies. When EVs are high, it is natural to adopt a coherent strategy. Owners will charge the EV battery as soon as they arrive at home or charge the car randomly from the home's power outlet. Charges that are not integrated increase the local load. When demand increases, prices rise rapidly. As a result, there is more power consumption. Damage is caused by overload distribution transformers and wires. The charging tactics that are integrated are the answer to eliminating the consequences of high EV penetration grids by optimizing the charging schedule and the length of time it takes to charge.[20]

Communication Protocols:

Nayan and Chandrasekhar [15] aim to create a CAN protocol for communication between a battery charger and a BMS (battery management system). This enables the battery charger to interact with the battery management system and make choices without the need for human intervention, protecting the battery from damage. The Controller Area Network, or CAN, is a multi-master half-duplex protocol that allows for real-time control of up to 1 Mbps. The battery management system uses the CAN network to communicate with the battery charger and instruct it to take appropriate action if the current, voltage, or temperature data exceeds the threshold limit. The charger also gives information about the battery management system such as current supply, the temperature of the charger, etc. The architecture of the CAN module consists of a message controller, a protocol kernel, and a CAN transceiver.

The CAN protocol used for communication makes the whole system more reliable and accurate as no data loss was observed during the study.

Studies have shown that in some severe situations, such as a sudden surge in voltage and current or over-temperature, the charger shuts off immediately, which helps prevent any damage to the lithium-ion battery. This can only be achieved if the protocol is more reliable and supports faster communication speeds.

Pruthvi, Niladri, Phaneendra and Sai [16], in their paper, describe that the goal of OCPP (Open Charge Point Protocol) is to provide a truly interoperable EV charging base, one that is flexible and easy to use for both EV drivers and system administrators. Clients can use the OCPP to integrate charging stations from a variety of merchants into a single IT back-end architecture.

There are 16 Functional Blocks in total, each with one or more use cases. Only a few of these are required to set up a simple Charging Station. Some of these use cases are –

1) Booting, Configuration, and Resetting a Charging Station
2) Authorization options
3) Transaction mechanism
4) Availability
5) Sending transaction-related Meter values

3. FUTURE TRENDS

Although it is estimated that electric vehicles will become the main means of transportation in the future due to their environmental benefits, the proportion of EVs is now low in Australia and around the world. The main reason for this is the long charging period and the waiting time (7-8 hours) for the automobile to fully charge. Although home and public chargers are becoming increasingly common, charging time cannot be easily reduced due to the power rating limitations of the connection.

The only viable answer is to build fast-charging stations (FCS), which can function just like a gas station and allow the EV to charge within half an hour after its reduction. However, widespread adoption of FCS is challenging as it also requires distribution grid updates. In addition, FCS technology, codes, and standards are in their infancy, requiring significant investment to build the system. Renewable Energy Resources and Energy Buffer Units (EBUs) are commonly associated with FCS to reduce the effects of FCS on the grid.

Fig.3 shows the future of FCS for public charges. Solar PV energy and EBU are used to reduce grid problems due to the fast-charging pulse power.

The grid, EV battery, and energy buffer unit can all exchange energy. During regular operation, if necessary, EV batteries can be charged by solar PV during the day with the help of EBU or other parked EV. EV batteries can be charged from the grid at night using an EBU or other parked EV. If necessary, EVs can also assist the grid during peak load demand. The grid will never become unstable as a result of high EV charging pulse power.

Recently, rooftop residential PV systems have become more popular in Australia, as having an EV charged at home using PV solar energy is considered environmentally friendly. From this point of view, the concept of combining two power conditioning systems in one system is established. This reduces investment costs and reduces the need for high-power equipment while improving the stability of the system. [20]

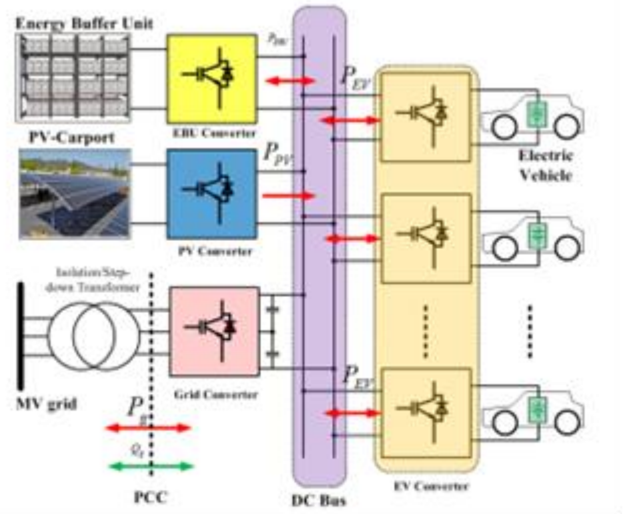

Fig.3. The infrastructure of a future EV fast-charging station.

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