An Analysis of Electric Vehicles Charging Technology and Optimal Size Estimation

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Abstract: *In this paper, there are many distinct types of electric vehicle (EV) charging methods that have been used in actual applications. In terms of converter topologies, power levels, power flow orientations, and charging control algorithms, this study provides an overview of existing and prospective EV charging systems. A review of the primary charging techniques is also provided, with the purpose of highlighting an effective and quick charging approach for lithium ions batteries in terms of extending cell cycle life and maintaining high charging efficiency. Following the presentation of the most significant features of charging technologies and tactics, the ideal size of charging systems is evaluated using a genetic algorithm, and prospective future developments in this sector are finally appraised based on a sensitive analysis.*

Keywords: *Electric vehicle, Plug-in electric vehicles, Battery charger, Charging infrastructure, Vehicle-to-grid, Grid-to vehicle, Charging methods.*

I. Introduction

Concerns about carbon dioxide emissions, greenhouse gas emissions, and the rapid depletion of fossil resources have heightened the need to develop and embrace new eco-friendly, long-term alternatives to internal combustion engine (ICE) cars.

As a result, electric vehicles (EVs) have grown more common in the previous decade, owing to their low flue gas emissions and reduced dependency on oil. By 2022, it is expected that there will be over 35 million electric vehicles on the road worldwide. However, one major difficulty with EVs is that their widespread usage produces severe problems on the power distribution grid, including power quality degradation, increased line corrosion, distribution transformer downturn, greater distortion, and higher fault current. [1, 2].

Integrating local power generation, such as renewable energy sources (RESs), into the EV charging infrastructure is one effective way to mitigate the damage. [3 – 5]

Batteries may be charged in two ways: conductive and inductive [6]. Wireless charging solutions are known as inductive chargers (WCS). WCS can be static, meaning they can only be used while the car is parked or in stationary modes, such as at car parks, garages, or at traffic signals, or dynamic, meaning they can be used when the car is moving. This technology allows the vehicle's battery to be charged while it is in motion. WCS may provide certain benefits in terms of aesthetic quality, dependability, durability, and user friendliness in general. Regardless, inductive chargers are not as widely used as conductive chargers due to difficulties such as electromagnetic compatibility (EMC), restricted power transmission, bulky and costly constructions, shorter range, and inferior efficiency [7, 8]. Only conductive charging techniques are examined in this research.

At all power levels, a battery charger can enable unidirectional or bidirectional power transfer. The bidirectional power flow adds a vehicle-to-grid (V2G) mode to the grid-to-vehicle interface (G2V). This latter technology can significantly improve the distribution grid's overall reliability, because in the event of a system failure, peak load demand, or other unexpected scenarios, EVs can be used as backup generation, supplying energy back to the grid when needed, thanks to a bidirectional power flow [9]. With V2G, like with any energy storage systems, EV batteries may be utilised not just as a backup resource, but also to enhance power quality, stability, and distribution network operating costs. Furthermore, V2G has the potential to decrease long-term investment in new power production infrastructure [10].

A component that must be examined throughout the charging operation is not only the charging technology, but also the charging technique. Constant-current/constant-voltage (CC/CV) and pulse current charging are the two most used charging methodologies for Li-ion batteries. These techniques, on the other hand, ignore the battery's internal processes, which impact its charging capabilities and ageing. As a result, various interesting charging procedures based on more full lithium-ion battery models are now being investigated.

II. Onboard Charger

Battery chargers can be installed within the vehicle (on-board) or outside the vehicle (off-board). Because onboard battery chargers (OBC) are limited in terms of size, weight, and capacity [11], they are often compatible with both level 1 and level 2 chargers. They normally only transfer power in one direction; however, depending on the arrangement, bidirectional power transmission can be performed. Figure 1 depicts the usual design of an electric car charging system, which includes both an on-board and an off-board charger.

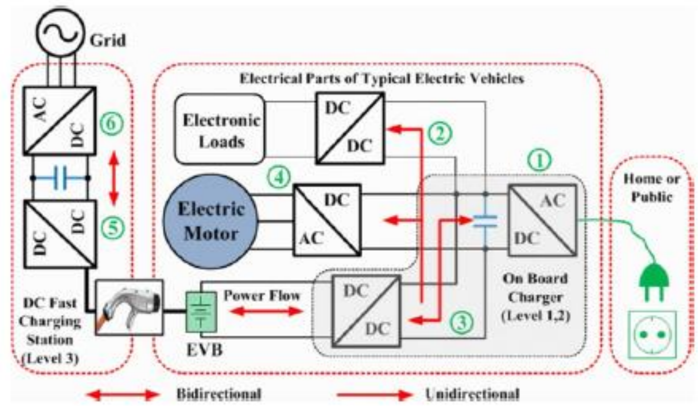

Figure 1: Charging system configuration for electric vehicle.

II-A Two Stage

A front-end AC–DC stage and a back-end DC–DC stage are frequently found in onboard chargers. For both converters, many topologies have been presented in the literature. To obtain a high power factor and minimal harmonic distortion, the front-end rectifier commonly includes a boost power factor correction (PFC) converter. A half-bridge, full-bridge, or multilayer diode bridge can perform the rectifier step. Because there are fewer diodes/switches in a half-bridge rectifier, it is less costly; a full-bridge rectifier is more complicated, but the components are subjected to lesser pressures. A multilayer architecture is a viable alternative for the ac–dc converter if larger power ratings are required. A full-bridge diode rectifier with a traditional PFC boost converter is shown in Figure 2 [12, 13]. A bidirectional power flow can be achieved by replacing all of the diodes with active switches.

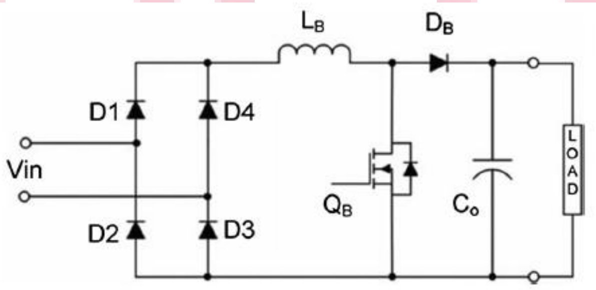

Figure 2: Full-bridge rectifier with conventional PFC boost converter.

II-B Single Stage

When the ac–dc rectifier and the dc–dc converter are coupled, a single stage battery charger is created. Single stage battery chargers allow the deletion of several bulky and costly components like as inductors and dc-link capacitors [14], which are necessary in two-stage chargers [16]. Single stage battery chargers with non-isolated converters, on the other hand, have a restricted conversion ratio, which limits their applicability for a wide range of output voltage. If, as in the OCB system presented in [14], a high frequency isolator is present, the low frequency component created by the rectification stage passes through the high frequency transformer, resulting in a substantial magnetising current.

II-C Integrated

Several integrated topologies have been developed and explored in the literature [11] to optimise the decrease of component number and therefore to further reduce the size, weight, and cost of the battery charger. The integration approach entails repurposing some drivetrain components (such as the inverter and motor windings) to implement the onboard charging system. However, certain issues may arise as a result of this combination: the configurations necessitated access to unreachable regions of the motor windings, and rearranging the motor windings is required when switching between operation modes. Finally, even if neither access to the neutral point of the motor windings nor their rearrangement is necessary, the management of the active switches becomes more complex when utilising the charger design provided in [15].

III. Off-Board Charger

Because of their rating powers, Level 3 chargers are frequently positioned outside the car (off-board). A wide number of potential solutions for level 3 off-board charger have also been examined in the literature [21 - 23]. Because the IEC EN 61,851–23 standard requires galvanic isolation between the AC supply circuit and the DC output circuit, only isolated off-board chargers have been discussed in this section. The most popular off-board charging method consists of two stages: a grid-facing AC/DC converter followed by a DC/DC converter that interfaces with the EV battery [16]. Both of these phases can enable unidirectional or bidirectional power flow depending on the converter architecture.

III-A Bidirectional AC/DC Converter

The three-phase LCL active rectifier, whose architecture is shown in Fig. 3, is one of the most extensively used bidirectional AC/DC converters.

Low harmonic input currents, bidirectional power flow, and power factor (PF) adjustment are all advantages of this type of converter. A neutral-point-clamped (NPC) three-phase three-level converter performs the front end ac–dc conversion. This converter was used to boost power density while also lowering current harmonic distortion [17].

Another benefit is that it enables the establishment of a bipolar dc bus that may be utilised to create partial-power converters. The NPC, on the other hand, generates a power imbalance and, as a result, a voltage balancing problem across the DC bus capacitors.

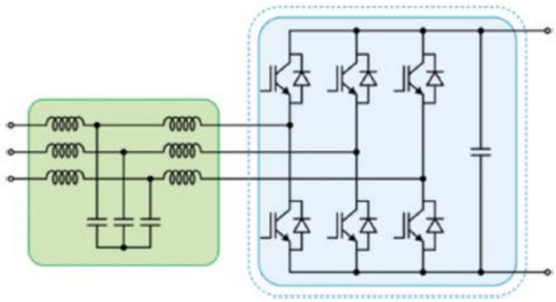

Figure 3: Three-phase LCL active rectifier

III-B Bidirectional AC/DC Converter

The Vienna rectifier [22] is the most popular unidirectional AC/DC converter used in off-board charging systems. It provides features such as minimal voltage stress and excellent efficiency on each switch. The primary drawbacks, however, are the limited reactive power management and the requirement for dc-link capacitor voltage balancing. The authors suggest a 25 kW off-board charger prototype in [22], which is made up of a single switch Vienna rectifier (shown in Fig. 4) and four three-level dc/dc modules linked in parallel.

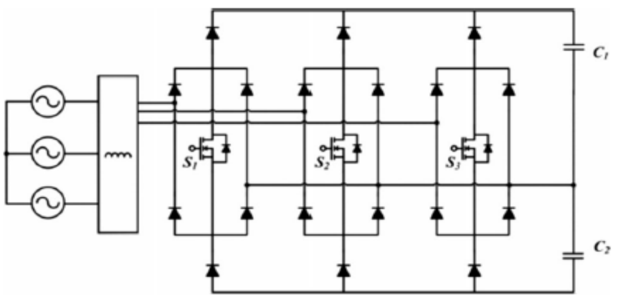

Figure 4: Vienna rectifier scheme proposed in [22]

III-C Bidirectional AC/DC Converter

The dual active bridge (DAB) and its derivatives (resonant DAB, multilayer DAB) are the most common isolated DC/DC converters used in bidirectional power flow. This architecture is gaining popularity because to the capabilities of modern wide-bandgap semiconductor (Gan/SiC) devices, which have improved converter efficiency and power density [20].

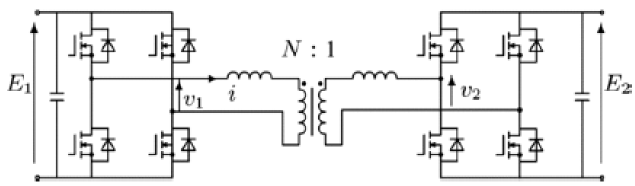

Figure 5: Dual active bridge scheme

III-D Unidirectional DC/DC Converter

Because of its advantages over other resonant topologies, such as the ability to operate at zero-voltage switching (ZVS) or zero-current switching (ZCS), it allows a wide output voltage regulation, and the output filter consists only of a capacitor rather than an inductor and capacitor (LC) filter, an LLC resonant converter is most often used as the power interface between the dc bus of the AC/DC converter and the EV battery if unidirectional power flow. The phase shifted full bridge converter, whose architecture is shown in Fig. 6, is another unidirectional DC/DC converter utilised in unidirectional off-board chargers. This sort of converter offers a number of benefits, including a high power density, minimal magnetic interference, and high efficiency, all of which make it ideal for use in battery chargers [17].

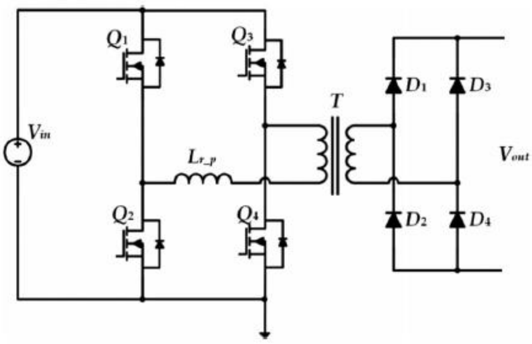

Figure 6: Phase shift full bridge converter

IV. Fast Charging Stations

There is a need for a charging system that can replace the present existing oil station in order to alleviate driving range anxiety and hence enable a stronger growth in the adoption of EVs worldwide. A fast charging station (FCS) can charge an EV to 80% within half an hour of depletion, but in order to reduce charging time from 7–8 hours to 30 minutes, FCS require a lot of power from the grid, which is why they are usually connected to the MV network, even though some FCS connected to the LV grid are also proposed. The installation of such charging stations would need a substantial financial investment, and the distribution network would quickly become overburdened. Another important factor to consider is the voltage drop that FCS connections might generate along distribution network lines, which must be less than 10% according to EN50160.

Energy storage systems (ESSs) can reduce peak power consumption and provide extra network services, reducing the impact of rapid charging stations on the distribution MV grid. Furthermore, ESS can boost the voltage level in the event of a too high voltage drop along the lines; however, this function necessitates the use of a voltage control.

Renewable energy resources can be included into the FCS to reduce the FCS' effect on the grid even further. In reality, during normal operation, throughout the day, the EV batteries may be charged by solar PV, avoiding the risk of the MV network becoming overloaded. When solar energy is not available at night, the EV batteries may be charged from the grid. If needed, 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.

IV-A Architecture

Figure 7 depicts the ultra-fast charging station's preferred configuration. The line-frequency transformer is responsible for providing isolation between the AC and DC sides. All EVs share the ac–dc stage; in fact, the output of the Cascade H Bridge (CHB) multilevel converter provides a unipolar common DC voltage bus to which all dc–dc converters are linked. A LLC resonant converter provides the power interface between the dc bus and integrated storage or the EV battery [18]. Figure 8 depicts the charging station that was used in this case. The three-level dc–dc converter requires a bipolar dc bus to feed it. On the one hand, this architecture improves the FC station's capabilities and lowers THD; on the other hand, this system necessitates a DC power balance control method.

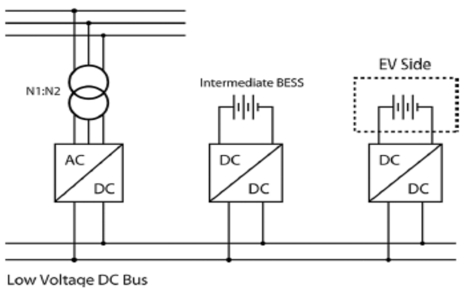

Figure 7: Fast charging station with unipolar dc voltage bus

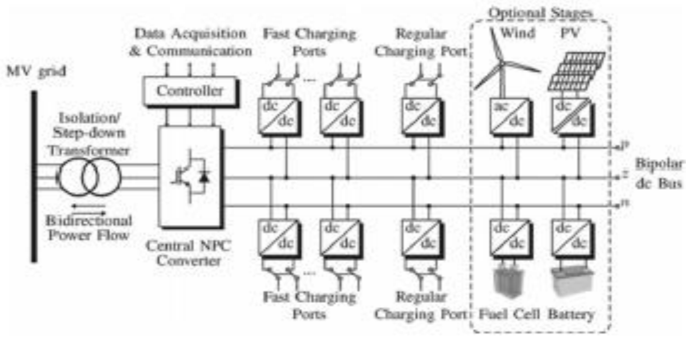

Figure 8: Fast charging station with bipolar dc voltage bus

V. Charging Methods

The benefits of lithium-ion batteries over other types of energy storage devices, such as high energy and power density, minimal memory effect, and resultant capacity loss, make them the ideal contender for use in electric cars. Li-ion battery charging, on the other hand, must be done with extreme caution, as the charging technique has a significant impact on how actively electrochemical side reactions occur inside the battery, and hence on the battery's cycle life. As a result, finding the best method for charging a battery in the shortest amount of time while maintaining high efficiency and avoiding damage to the cells has become a new issue for many academics.

V-A Constant Current-Constant Voltage (CC–CV)

Both an initial constant current and a final constant voltage are employed in this approach, as shown in Fig. 9. The charging procedure begins with a steady current and continues until the cut-off voltage is achieved. The cut-off voltage for Li-ion using standard cathode materials of cobalt, nickel, manganese, and aluminium is normally approximately 4.20 V/cell. The tolerance is ± 50 millivolts per cell. The battery is charged at a steady voltage that is just over the cut-off point. When the current drops to between 3 and 5% of the rated current, the battery is fully charged. The use of a trickle or float charge at full charge is not recommended for Liion batteries since it can create metallic lithium plating and risk safety. When the voltage falls below a certain level, a topping charge can be provided instead of a trickle charge [19].

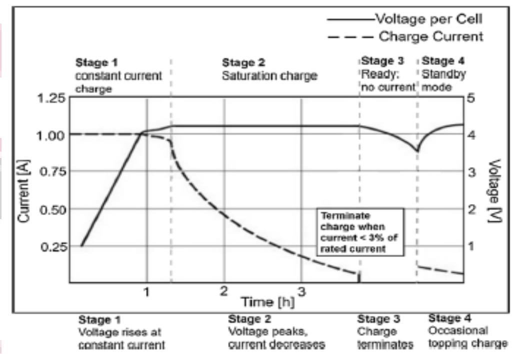

Figure 9: CC–CV charge stages for a Li-ion battery

V-B Five-Step Charging Pattern

A different strategy is discussed here in order to provide faster and safer charging as well as a longer battery cycle life. The five-step charging pattern is a constant-current multistage (five stages) charging method in which the charging period is divided into five sections. The charging current is set to a consistent threshold value at each step. The battery's voltage rises while charging, and when it exceeds the pre-determined limit voltage, the stage number rises, and a new charging current set value is applied appropriately. This procedure will be repeated till the number of stages reaches 5. The five-step constant current charging process is depicted in Figure 10.

Different methods may be used to discover the charging current in each step, however finding the ideal charging pattern can be complicated and time consuming.

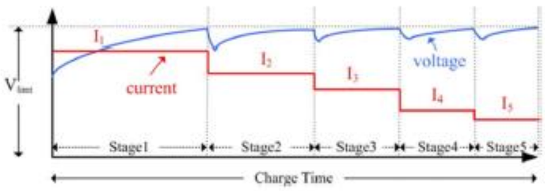

Figure 10: CC–CV charge stages for a Li-ion battery

V-C Pulse Charging Method

The charging current is delivered into the battery in pulses using this charging approach, allowing the ions to spread and neutralise during the rest interval. The charging rate, which is determined by the average current, may be adjusted by changing the pulse width. This approach is believed to be able to speed up the charging process, reduce polarisation, and enhance life cycles. The following characteristics describe every pulse charge current provided to the battery, as illustrated in Fig. 11: peak amplitude I_{pk}, duty cycle $D = t_{on}/T_p$, and frequency f. There are two types of pulse charging strategies: duty-fixed and duty-variable pulse charging. In comparison to the traditional duty fixed technique, the duty-varied strategy can boost charging speed and efficiency.

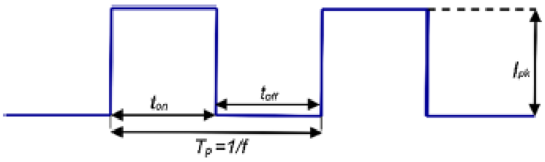

Figure 11: Pulse charge current parameters

V-D Charging Strategies Based on Battery Physical-Based Models

Only current and voltage restrictions are taken into account in all of the charging methods so far. Regardless, these limitations do not account for the ageing process and side reactions that occur inside the battery, and so they may be overly cautious for fresh batteries while being potentially harmful for older batteries owing to changing behaviour and features. As a result, unique charging algorithms are being developed and researched to address the issue of charging influence on battery state-of-health (SoH) and ageing. In fact, several recent studies have focused on developing innovative charging technologies that reduce charging time while also extending battery life.

The electrochemical lithium-ion battery models are used in this new category of charging techniques to compute quantitatively and nearly accurately the amount of battery ageing and to directly decrease the ageing in a given charge period. Because it is created from the internal microstructure of the lithium-ion battery, the electrochemical battery model assesses the internal states of a battery more accurately. However, exactly estimating the parameters is difficult due to the electrochemical model's sophisticated coupled partial differential equations (PDEs), which take a lot of computation due to the huge number of parameters and boundary conditions. As a result of their complexity, these models frequently need greater memory and computing effort, and hence they may be difficult to incorporate in the EV BMS's quick and real-time computations.

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