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Charging Perspectives and Implementation Strategies for Dual Active Bridge Converter in Electric Vehicles

Sandesh Patel*, Shekhar Yadav*, and Nitesh Tiwari*

Abstract *– Electric vehicles (EVs) have gained popularity as a sustainable transportation solution. The development of efficient and reliable battery charging systems becomes crucial. This paper provides a thorough evaluation of EV battery charging systems. EV adoption continues to increase, effective, and efficient charging systems are crucial for widespread acceptance. This study encompasses various aspects of systems and technology for charging EVs, infrastructure, modes, and standards. It explores charging technologies such as AC charging at levels: L1 and L2, and DC fast charging at level: L3. This discussion extends to charging infrastructure, covering residential, public, and workplace charging stations, as well as considerations for placement and accessibility. The challenges associated with EV charging systems are discussed, encompassing grid integration, power demand, charging time, range anxiety, safety, and security considerations. The future trends are including wireless charging technologies, Vehicle-to-Grid (V2G) integration, Vehicle-to-Home (V2H), renewable energy integration, and smart charging with demand response. This paper serves as a valuable resource for understanding and advancing battery charging systems for EVs.*

Keywords –AC and DC charging, electric vehicles, energy management system, smart charging, V2G and V2H charging systems, wireless charging

1. INTRODUCTION

EVs are progressively being used in the transportation industry, but the majority of vehicles continue to be powered by conventional gasoline or diesel engines. To promote the adoption of EVs to provide environmentally friendly transportation, the constraints that mostly consist of pricey EVs, range anxiety, the shortage of infrastructure for electric vehicle charging, and grid pollution from EV chargers must be removed. The usage of EV chargers with inductive power transfer technology helps in solving the range anxiety problem. The electric vehicle has built-in onboard chargers and converts the AC electricity, which they are in charge of doing from an outside source (charging port or wall socket) into DC power to charge the vehicle's battery. Off-board chargers, also known as DC fast chargers or rapid chargers are separate charging units installed outside the electric vehicle [1]. The integration in favor of EVs and industrial machines into the Smart Grid (SG) is expected to grow significantly in the coming years. The employment of information technology with electricity to transfer electricity in both directions is the main definition of SG. This refers to the operation known as V2G, which involves importing and exporting energy to the grid using EVs. V2G technology offers a bidirectional power flow that makes it easier to charge devices during times of low demand and discharge them when the power is needed [2]. Fast charging involves high-rate batteries, high-power infrastructure, and grid effects. Power quality issues are on the rise as a result of fast charging stations [3]. Long-term plans and policies in both developed and developing nations call for the use of EVs rather than gasoline or diesel engines and the production of power from renewable energy sources, increasing the number of charging ports [4]. The desire for more powerful and effective systems with electric traction that improve fuel efficiency for a certain battery charge is being driven by increased electrification and changing mobility [5]. The battery autonomy is the biggest issue because the maximum range is only 250 km, which puts a limitation on the distance that can be traveled. The storage capacity and battery management system are primarily the topics of the current research gaps. To handle the technical, environmental, and economic issues and oversee the crucial role of monitoring battery status change, efforts must be made to build charging controllers [6]. The majority of commercial EVs now charge their batteries conductively. An alternative charging technique known as inductive charging has lately received a lot of attention because of its improved user safety and convenience [7]. We explore the effects based on three charge pricing assumptions - residential time-of-use rates for EVs, tier 2 flat-rate housing, and real-timing cost-on energy, cost, and climate change using a comprehensive optimization platform for managing and designing the infrastructure for EV charging [8]. Fast charging stations, the charging procedure, autonomy, and the cost of EVs on the road are all critical factors in the effective introduction of electric vehicles into the transportation sector [9]. Since a power electronics converter acts being the main connection between the electric vehicle battery system and the electricity grid, there exists a sizable demand to purchase new power

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converters that are affordable and highly reliable as the improved EV charging technology [10]. The electrification of the transport industry is one potential strategy to lessen unfavorable climate change. A secure and effective fast charger must be created to improve anxiety's range and minimize EV charging times [11].

The accessibility to massive data, and high-performance computing platforms with large data storage capacities has significantly accelerated the investigation and development of intelligence algorithms, and control strategies for BMS in Electric Vehicles (EVs). These advancements have revolutionized how BMS operates, making them more efficient, safer, and capable of optimizing battery performance [12]. The selection of candidate locations and their sizes in the first stage is based on two main criteria: The first criterion takes into account the overall benefits that can be achieved from the proper use of charging stations for vehicle charging and discharging [13]. Drivers of EVs have the option of charging at charging stations, in parking lots, or at home, to recharge their batteries. The EVs may be charged using both DC and AC chargers. Due to the large currents required for charging and the high capital cost, DC chargers are most frequently encountered in fast-charging stations [14]. Recently, the deployment of charging stations and EVs has attracted the attention of both the industrial and academic communities [15]. Dynamic charging, also known as wireless or inductive charging, is a potentially useful technological advancement to address the issue of extended charging times for EVs. When an EV equipped with the necessary receiving technology drives over these charging pads, it can efficiently receive electrical power, charging the vehicle's battery while in motion [16]. The safety feature of charging techniques in electric vehicles is of paramount importance to avoid charging-related mishaps and ensure the security of passengers, and other road users [17]. The demand for charging infrastructure rises as there are more EVs on the road. To accommodate the shifting demands of EV owners, a widely dispersed and effective network of charging stations is essential [18]. Charging an EV to 100% SoC occasionally is acceptable but should be avoided daily unless necessary, as it puts more stress on the battery and can slightly reduce its long-term capacity [19].To ensure smooth traffic flow during EV charging, wireless power transfer technology is now recognized as a potential alternative. Without a physical connection, electrical energy may be sent from a power source to an EV via wireless power transfer technology [20].

The first contribution of the author in this paper is to examine conventional and advanced battery charging systems. The second contribution is a proper explanation of unidirectional and bidirectional chargers. The third contribution is explaining future perspectives with the integration of renewable energy resources, smart charging, and energy management systems. The charging strategies are shown in Figure 1.

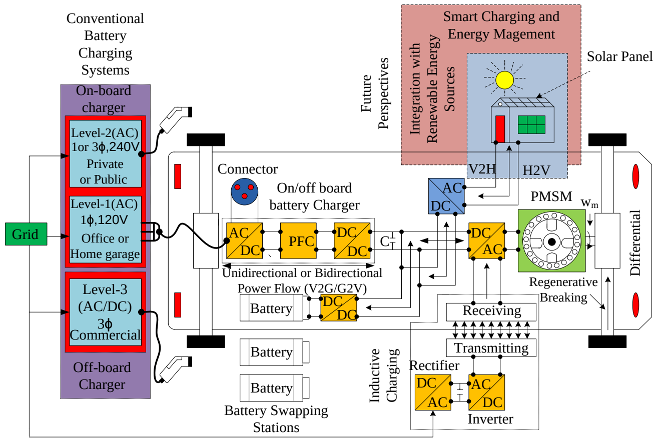

Fig.1 Overview of the charging strategies

2. CONVENTIONAL BATTERY CHARGING SYSTEMS

Three levels, such as AC charging at levels: L1 and L2, and DC fast charging at level: L3 make up the conventional battery charging systems for electric vehicles.

2.1 Level 1 (L1) Charging

This type is the slowest charging method and typically uses a standard household outlet with 120 volts AC. It is commonly achieved using a portable EVSE (electric vehicle supply equipment) that comes with the vehicle. L1 provides a charge rate of about 1-5 miles of range per hour. For example, if an EV has a range of 200 miles and is completely discharged, the time frame would be about 8-20 hours to fully charge using Level 1 charging.

2.2 Level 2 (L2) Charging

It operates at higher power levels than L1 charging. It uses a 240-volt AC power source, similar to the power supply for household appliances like electric dryers or ovens. L2 charging requires the installation of a dedicated charging station or wall-mounted EVSE. The charging rate for L2 charging can range from 10-60 miles of range per hour, based on the vehicle and the recharging apparatus. Using the same example as above, an L2 charger would fully charge the EV in 2-8 hours.

2.3 Level 3 (L3) Charging

L3 charging, also referred to as DC fast charging or rapid charging, provides significantly higher power levels and allows for faster charging times. DC fast charging stations supply direct current (DC) power to the vehicle, bypassing the onboard charger, resulting in faster charging rates. DC fast chargers are typically available at a location with public charging and highway rest areas. The charging rate can vary concerning specific charging stations and the capabilities of the vehicles. DC fast charging can provide an 80% charge in as little as 20-60 minutes, depending on the vehicle and battery capacity. The compression between L1, L2, and L3 (DC fast charging) in Table 1.

Table 1. Outlining the differences between L1 charging, L2 charging, and L3 (DC Fast) charging for EVs.

Charging Level	Voltage	Power Output	Typical Charging Time	Connector Types
L1	120V AC	Up to 1.9 kW	8 - 20 hours	Standard household outlet (NEMA 5-15)
L 2	240V AC	Up to 19.2 kW	2 - 8 hours	J1772, Type 2 (IEC 62196)
L 3 (DC Fast)	200-600V DC	25 - 350 kW	30 minutes - 1 hour	CHAdeMO, CCS, Tesla Supercharger

3. ADVANCED BATTERY CHARGING SYSTEMS

This section includes three types of charging systems. A detailed explanation of these charging systems is given below:

3.1 Inductive Charging

A transmitter pad that receives an AC with a high frequency (HF), a compensating network, and a (10-100) kHz HF inverter that regulates HF AC make up the transmitting side of an IPT system is illustrated in Figure 2. The operating range of IPT systems is 79 to 90 kHz, with 85 kHz being the most common frequency. The inverter is powered either directly by a DC source, such as a solar source or by a DC bus that has been improved from a single and three-phase AC supply. The receiver coil attached to the vehicle is operated by electromagnetic fields provided by the HF AC. The HF AC-DC converter (rectifier) and compensating circuit are constantly linked to the coil attached to the EV to charge the onboard battery. The relative location and alignment of the transmitting (charging pad) and receiving (vehicle) coils in an inductive charging system have a crucial impact on the transmission power and overall system efficiency [21]. Here, L1 and L2 are transmitting and receiving side inductance.

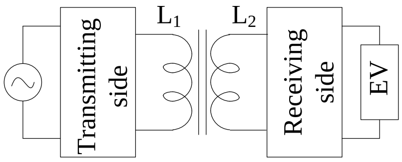

Fig. 2. Inductive Charging for EV

3.2 Capacitive Charging

The capacitive coupling of a capacitive power transfer (CPT) system is represented by two capacitors connected in series as shown in Figure 3. This model isn't necessarily appropriate for simulation. An equivalent coupling capacitor connects the primary and secondary sides.

There are cross-couplings and unwanted leaks that occur in CPT.

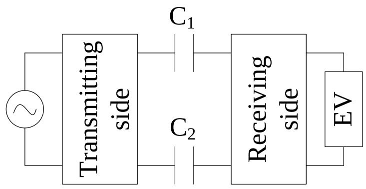

Fig. 3. Capacitive Charging for EV

3.2 Battery Swapping Stations (BSS)

An EV battery is often charged rather than swapped out, according to the concept of battery swapping. An entirely new battery is installed in its place, together with the entire battery pack, at a remote battery changing station. This strategy provides a substitute for conventional charging techniques. Exchanging a discharged battery pack for a fully charged one allows EV owners immediately to extend their electric vehicle range. The reason for this can reduce range anxiety and make it possible to do longer journeys without needing to stop frequently for recharge. For the battery swapping station structure see Figure 4.

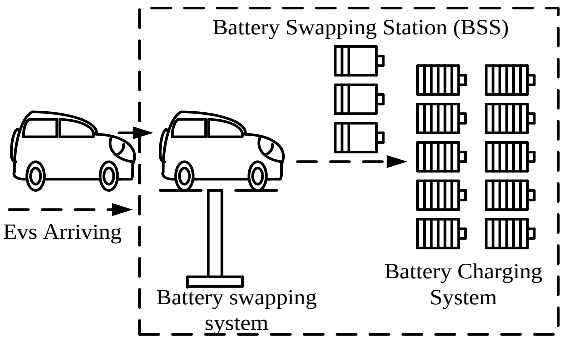

Fig. 4. Battery swapping station structure

4. UNIDIRECTIONAL AND BIDIRECTIONAL CHARGERS

Battery chargers are used in a variety of EV models, including PHEVs, to charge battery packs externally from a power source. The charger will use controlled and processed electric current to transfer energy into the battery and charge the EV's battery. Because of the power grid's availability of AC, although the EV battery requires DC, the charger uses AC during the charging process. The rectifier is included in the EV charger's architecture to provide the proper level of DC power to charge the EV battery. Typically, an AC/DC converter is used to construct the EV charger. To improve energy conversion for quick charging, a DC/DC converter has been added to the EV charger.

4.1 Unidirectional Chargers

EVs can only be charged using unidirectional chargers; they cannot, when necessary, supply electricity to the power grid. This charger is made with the diode Bridge, filtering components, and DC/DC converters. A configuration of a unidirectional level 1 onboard series resonant charger is presented in Figure 5. The utilities' decision to use unidirectional chargers is motivated by the simplicity with which the highly loaded feeders brought on by the high penetration of EVs can be managed. Unidirectional chargers with active front-end converters may control the phase angle of a current to provide reactive power assistance, and this can be done even without the battery being discharged. To provide the best charging methods for vehicle owners, and distributors, and effect analyses on power infrastructure, several research projects on unidirectional charging are now underway. L_{PFC} is inductance for power factor correction. N_P, N_S is the primary and secondary side number of turns, and L_0 is the load inductor. Input power and DC supply are denoted by C_{in} and C_{DC}. The rectifier diode of the grid side is represented by D_1, D_2, D_3, and D_4 and the battery side diode of the rectifier is denoted by D_5, D_6, D_7, D_8. The inverter switch is denoted by S_1, S_2, S_3, S_4 [23]. The 3D plot in Fig.6 shows the relationship between resonant frequency (in kHz), inductance (in mH), and capacitance (in µF) for an on-board series resonant charger. The resonant frequency values range from 10 kHz to 100 kHz.

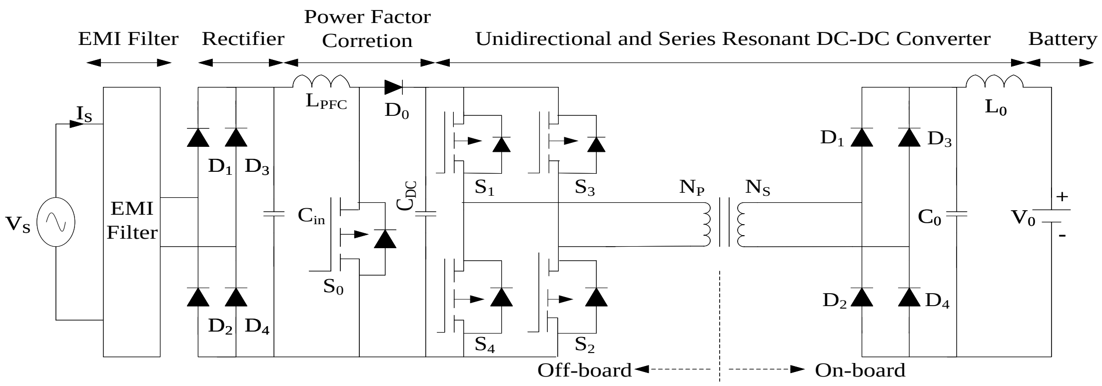

Fig.5. Unidirectional Level 1 On-Board Series Resonant Charger

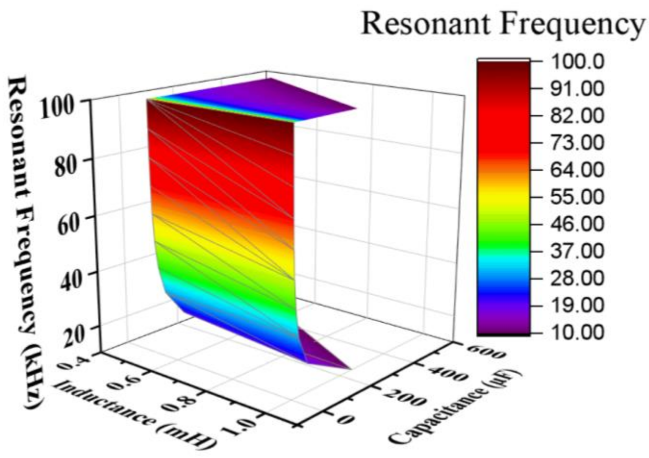

Fig.6. Resonant Frequency of On-Board Series Resonant Charger

4.2 Bidirectional Chargers

EVs with bidirectional chargers and power flow can accomplish a variety of functions. An important advantage of the V2G technology is provided by electric vehicles with bidirectional chargers. EVs' batteries can still be linked to a network even when they are not in use, they may fuel a power grid when it is under the most loads and so increase grid efficiency; known as V2G technology. This technology is built on managing and controlling EV loads through communication links between the vehicle and utilities or aggregators. With the aid of V2G technology, bidirectional power flow increases the ability to adapt a power network to govern the conserved energy batteries of EVs to preserve the sustainability, dependability, and efficiency of a power network. The grid powers electric vehicles, have their batteries discharged, and then executes buck and boost operations. For the setup for an isolated bidirectional charger, see Figure 8. Where L_r and L_t are indicated receiver and transmitter inductance, respectively. L_m is mutual inductance. The K_p, K_i, and K_d parameters of an Adaptive PID controller are adjusted online based on the state of the system. The parameter of the APID controller is updated using the gradient descent method. Figure 7 represents a block diagram of the APID controller.

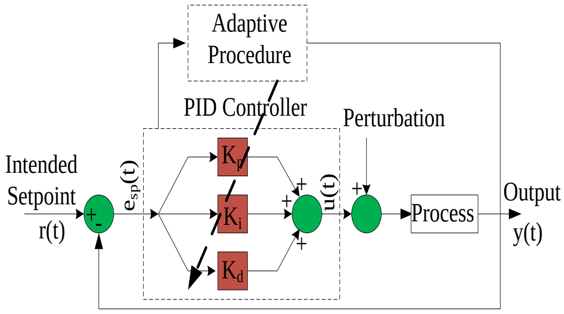

Fig 7. Block diagram of APID controller

The controller is resistant to fluctuations in the system due to online tuning. This updates the system parameters based on deviations in output control. Ordinary controllers such as PID, move the system's poles to the suitable position in a finite amount of time to produce the intended response. The only reason for using an APID controller, all control parameters are adjusted adaptively to prepare for differences in the system. The APID is better than ordinary PID controllers because of its adaptive flexibility. The following should be taken into consideration to obtain the governing equations (1) to (3) associated with our implied APID.

$$\hat{K}_p(t+b)=K_p(t)-\eta\frac{\partial\Omega}{\partial K_p} \tag{1}$$

$$\hat{K}_d(t+b)=K_d(t)-\eta\frac{\partial\Omega}{\partial K_d} \tag{2}$$

$$\hat{K}_i(t+b)=K_i(t)-\eta\frac{\partial\Omega}{\partial K_i} \tag{3}$$

Where, Ω is the diligent function, $\widehat{K}_p(t+b)$, $\widehat{K}_d(t+b)$, and $\widehat{K}_i(t+b)$ are the modified gains obtained from the PID gains that have been achieved before, η represents the learning factor.

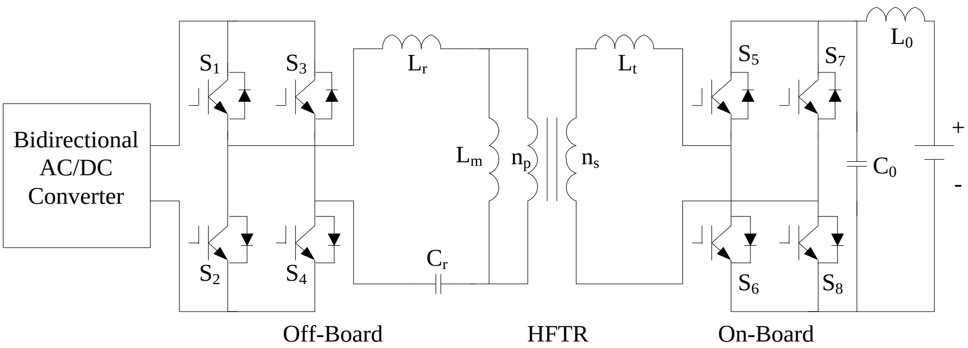

Fig. 8. Dual active bridges with an isolated bidirectional charger

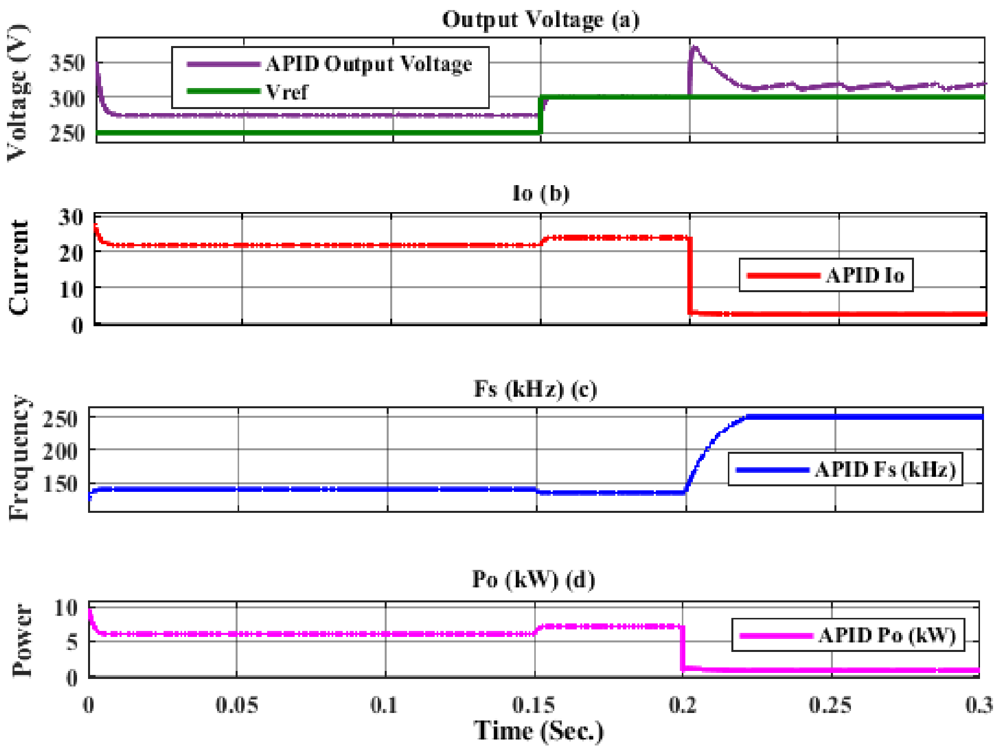

Fig. 9. Results of the isolated DAB Converter

The results of the isolated DAB converter are shown in Fig.9. The comparison between the APID controller's output voltage and the reference voltage (V_{ref}) is illustrated in Fig. 9(a). A notable voltage drop occurs at approximately 0.15 seconds**,** where the output voltage settles near the reference voltage of 250 V**.** After 0.2 seconds, the output voltage shows a transient response but stabilizes close to the reference value. The APID controller output current is shown in Fig. 9(b). Initially, the current remains steady at 20 A**.** At around 0.15 seconds**,** the current drops sharply to approximately 5 A**.** This behavior indicates a load change or a system response to a change in the operating conditions. The APID controller's switching frequency is illustrated in Fig. 9 (c). The switching frequency remains constant at approximately 100 kHz until 0.15 seconds. After 0.15 seconds, the frequency increases sharply to about 250 kHz. It stabilizes at this higher frequency for the remainder of the simulation period. This indicates that the controller adjusts the switching frequency to respond to changes in the load or system conditions. The power output of the APID controller is in Fig. 9(d). Initially, the output power remains steady at around 10 kW. At approximately 0.15 seconds, there is a sudden drop in the output power to around 2 kW. This power reduction aligns with the observed drop in current in plot (b), indicating reduced load conditions. The power remains constant at this reduced level for the rest of the intervals.

5. FUTURE PERSPECTIVES

Integrating renewable energy sources, smart charging, and energy management is crucial for creating a sustainable and efficient energy system.

5.1 Integration with Renewable Energy Sources

Switching to a low-carbon, sustainable energy system is highly correlated with the grid integration of renewable and EVs. Solar, wind, hydro, and geothermal energy are all renewable energy sources that fluctuate in quality. As grid demand continues to increase, a big barrier is the cost of living is really expensive updating infrastructure including things like transformers and distribution lines. Distributed generation systems (DGs) near the load have been introduced as a type of generation as a result of these restrictions; this generation type lowers the load on the power cables and transformers used for distribution. Appropriately sized and installed DGs tend to exceed power and voltage with limitations while also reducing losses. Additionally, renewable power generation methods like solar as well as wind-based DGs play a role in lowering greenhouse gas emissions. The DG and EV integration for renewable energy within the PCC, see Figure 10 [24].

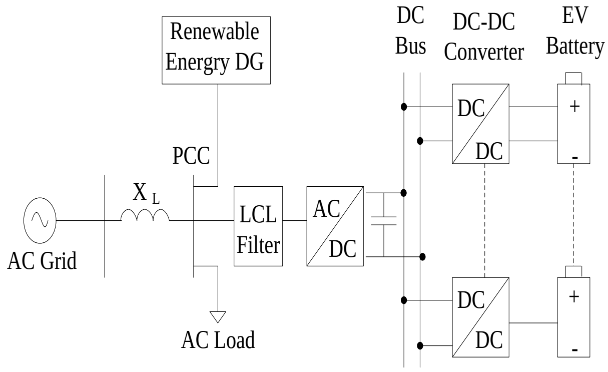

Fig.10. DG and EV integration for renewable energy within the PCC

5.2 Smart Charging and Energy Management

EMS, in the context of a smart charger for EVs, typically refers to an Energy Management System, as seen in Figure 11 [22]. An EMS's main objective is to improve the charging process, manage energy flows, and enable intelligent control and monitoring of the charging infrastructure. The EMS helps distribute and manage the electrical load of charging multiple EVs simultaneously. It ensures efficient utilization of available power resources while avoiding overloading the electrical grid or causing power imbalances. It can optimize the charging time and rate to balance the charging requirements with available power capacity. It is desirable to use EV battery capacity for changing short-term renewable sources. They can also be utilized for solar energy in rainy scenarios [25].

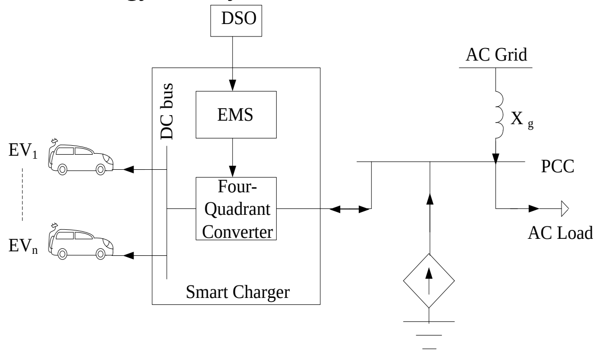

Fig. 11. Smart charging system is controlled by an energy management scheme

6. CONCLUSION

This paper concludes a thorough examination of battery charging systems for EVs. The study highlighted various aspects, including charging technologies, infrastructure, modes, and future trends. The analysis of charging technologies revealed the existence of both AC and DC charging options, such as L1, L2, and L3 (DC Fast Charging). Each technology offers distinct advantages and considerations, contributing to the overall charging ecosystem. The challenges in EV charging systems were identified, including grid integration, power demand, charging time, range anxiety, standardization, and interoperability, safety, and security considerations.

Addressing these challenges is crucial for maintaining the reliable and effective functioning of the infrastructure charging. Wireless charging technologies such as vehicle-to-grid integration, high-power charging, renewable energy integration, and smart charging with demand response emerged as promising avenues for further development and innovation.

NOMENCLATURE

Symbol	Description	Unit
APID	Adaptive PID	-
BMS	Battery Management System	-
CPT	Capacitive Power Transfer	-
DGs	Distributed Generation Systems	-
EVs	Electric Vehicles	-
HF	High Frequency	-
SG	Smart Grid	-
η	Learning Factor	-
V_{ref}	Reference Voltage	-

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