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A Brief Review of Charging Station Topologies for Electric Vehicles

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Abstract: Over the next few years, electric vehicles are expected to play a major role in the transportation industry. Therefore, it is important to design the charging infrastructure concurrently. This paper presents the many methods and tactics for electric vehicle charging systems. This page covers fast charging stations with solar PV integration, charging stations based on predictive controllers, PV-assisted EV fast charging stations, MPPT Algorithms for Solar PV based Charging Stations, and EV charging stations based on multiport converters. Future researchers and students who are interested in developing solar-powered quick charging stations for electric vehicle design will find this study useful.

Keywords – Electric Vehicle, Charging Station, Fast Charging, MPPT.

1. Introduction

Electric vehicles (EVs) have grown in popularity over the last ten years. Demand is increasing due to the steadily declining supply of fossil fuels such as crude oil, coal, natural gas, and heavy oil, which are sought after by the growing populations of industrialized and developing countries [1]. Due to ongoing efforts and innovative research projects in the Battery Management System (BMS) for applications in EVs, electric cars have evolved into a class that is further separated into hybrid electric vehicles (HEVs)2 and plug-in hybrid electric vehicles (PHEVs)3. PHEVs are definitely more popular than HEVs, despite the fact that they make up the bulk of EVs presently on the market. This is due to the flexible fuel options offered by these vehicles, which can operate on both conventional fuels like gasoline and oil as well as electric power stored in a battery (energy storage device).

Depending on where and when an EV is charging, several charging techniques are used. The ability to charge at work or at public charging stations should be taken into account when buying an electric car, according to a study on electric cars by (Accenture 2011). The infrastructure for DC quick charging is presently being built by certain significant manufacturers, such as Nissan and Tesla. This rapid charging infrastructure eliminates "range anxiety" among EV users by enabling an EV to be charged more quickly than with a normal charger. The continual worry that the battery may run out of power while driving an electric vehicle and leave it stranded is known as range anxiety (Blanco 2010). Some business owners are placing charging stations with complimentary charging options close to their showrooms or retail establishments in an effort to draw in a larger customer base. One of the EV producers that is significantly progressing in this area is Tesla.

In this text, "electric vehicle" is a catch-all term for any kind of motorized transportation that utilizes rechargeable batteries, including automobiles, buses, motorcycles, and trucks. Increased grid power usage is a new issue brought on by the growth in the number of electric vehicles. One efficient strategy to reduce the consequences is to decentralize power production, for example, by integrating local renewable energy sources into charging infrastructure. In the context of smart grid technologies to solve this issue, Liu et al. [2] discuss the relationship between renewable energy and issues with EV charging.

2. Different Scenarios of Charging EVs

There can be four different scenarios for charging of EVs.

2.1 Uncontrolled Charging or the end-of-travel charging:

This is a typical charging setup for an electric car that is parked at home. To manage how and when charging occurs, no complicated control technology is needed. Additionally, it doesn't provide any data on user behavior or incentives, including time of use rates (ToU). A constant charging rate of 1.4 kilo Watt (kW) is considered for this application based on a typical household 110/120 volt 20 Ampere circuit with a continuous rating of 1.8-2.0 kW. A completely charged battery takes around six hours to charge, even at this sluggish rate.

2.2 Delayed Charging:

This is comparable to end-of-trip pricing, except it doesn't begin until after 10 p.m. To control power use in this case, a timer is necessary, either in the vehicle or in the charger. With just a little improvement in infrastructure, ToU may be utilized. Utility companies are more likely to choose this scenario because of the present incentives for off-peak energy usage. Xcel Energy is one of the utility providers that offers ToU tariffs to residential customers. The 1.4 kW charging rate is the same as the uncontrolled charging case previously mentioned.

2.3 Off-Peak Charging:

Since automobile charging may be controlled either directly or indirectly by a local utility provider, in this scenario all charging occurs at night in residential areas with the intention of offering the most effective, affordable charging possible. In the case of indirect control, the vehicle would react intelligently to a real-time price signal. The charge rate is increased to 3.2kW during off-peak charging for complete system optimization. This indicates that 20% of all charging is done using 240 V/40 Ampere level 2 chargers, which is greater than the continuous charge rate of a normal residential circuit. It is anticipated that the charging process would take around six hours.

2.4 Continuous Charging or publicly available electricity charging:

Similar to the end-of-trip charging scenario, this scenario makes the assumption that the electric vehicle is recharging at a public charging station. Even though charging during off-peak hours is advised, vehicles are charged if they are left idle for more than one hour. This also serves as an illustration of unregulated charging. This charging profile is most often used twice a day, typically in the morning and evening.

3. Electric Vehicle Charging Standards

The Society of Automotive Engineering (SAE), the CHAdeMO association, and the International Electro-technical Commission are three major organizations that seek to standardize electrical characteristics of EV charging stations across the world (IEC). Aside from these organizations, Tesla Motors, the world's leading electric vehicle manufacturer, establishes its own standards for its Model S, Model X, and Roadster electric vehicles.

Every organization listed above offers a variety of charger standards that function with both AC and DC power. The SAE, for example, has been working on standard J1772, which divides electric vehicle chargers into three levels [5]: Level 1, Level 2, and Level 3.

i) Level 1: The charger is built-in and delivers DC voltage with a maximum current of 80 A and a power output of 40 kW.

ii) Level 2: The charger gives a DC voltage of up to 200 A with a maximum output of 90 kW.

iii) Level 3: The charger is disconnected from the board. With a maximum capacity of 240 kW, the charging station delivers DC electricity straight to the battery through a DC connection.

Level 3 chargers are all considered fast chargers. CHAdeMO and the International Electro technical Commission (IEC) suggested various power and current requirements for DC rapid charging. A quick summary of power and current level evaluation for electric car DC charging standards is presented in table 1 for additional information.

Table 1: EV Charger categories

Standard	**Level**	**Max Current Rating (A)**	**Max Power Rating (kW)**
SAE	DC Level 1	80	40
	DC Level 2	200	90
	DC Level 3	400	240
CHAdeMO	DC Fast Charging	125	62.5

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IEC	DC Fast Charging	400	100-200
Tesla	DC Super Charger	340	136

4. Different Charging Station Technologies

4.1 Fast charging station:

A quick charging station with a solar (PV) system, an energy storage system (ESS), and a connection to the local grid was proposed by Pablo Garca-Trivio and his coworkers [3]. This configuration enables the FCS to mostly function as a stand-alone system, with sporadic grid assistance. They are governed by the voltage management of the common medium voltage DC (MVDC) bus, to which all the energy sources are connected. According to their voltage, the PV system, ESS, or grid are thus used to provide the energy needed by the EVs.

The EV FCS under research (Fig. 1) uses two 48kW fast charging units (FCU), which may be powered by a PV system, a Li-ion battery pack (ESS), or the grid. The IEC 61851-1 classifies this FCS as "Mode 4, DC level 2." All of the FCU's components are connected to a 1500V DC voltage (MVDC) using DC/DC converters in order to control the power balance between them and the MVDC bus voltage. The grid connection is made using a transformer and a DC/AC converter.

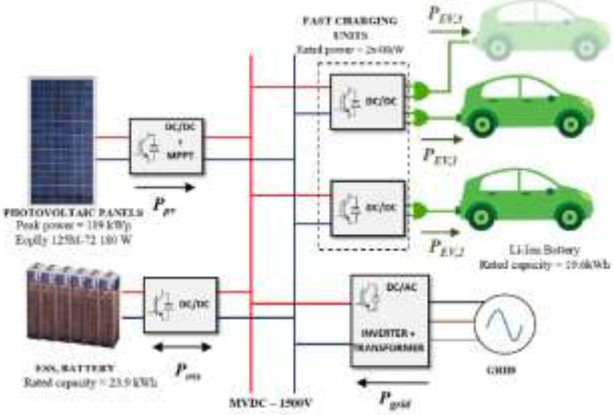

Figure 1: Configuration of the EV FCS

4.2 Cascaded High Frequency AC Link System

One way to shorten the time it takes for an EV to charge is to build high-power fast charging stations (EVFCSs) that are directly linked to the medium-voltage grid. In order to provide an isolated power electronic interface between the charging station's low voltage (LV) DC bus and the three-phase MV AC power network, the charging station uses cascaded-high-frequency-link (CHFL) technology. The CHFL system uses a high/medium frequency transformer to provide isolation and a high stepping-up ratio. The system's major flaw is the vast number of active switches.

A unique design for the CHFL system was proposed by Nour Elsayad et al. [4] based on cascaded half-bridge direct matrix converters. Their proposed topology decreases the number of active switches by more than 40% when compared to topologies that have already been published in the literature. A more straightforward multilayer hysteresis current controller (MLHCC) for the system is also discussed. The planned EVFCS design features a solar (PV) system to lessen dependency on the power grid. A bidirectional power flow controller is used

to inject excess PV power into the grid and withdraw energy from the grid when the amount of PV power produced is more than what the station needs.

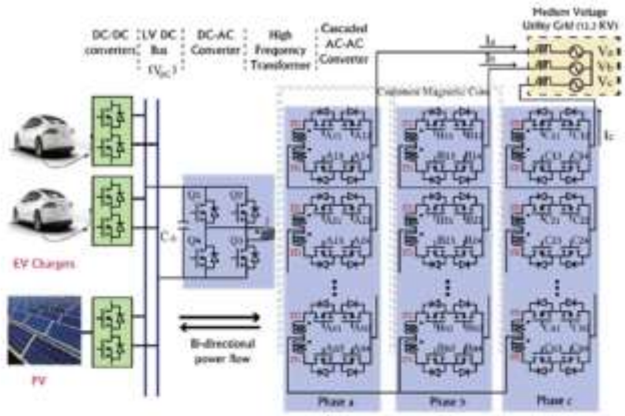

Figure 2: General Block diagram of CHFL system

Figure 2 shows a block schematic of the CHFL system. In the cell topology, a half-bridge matrix converter is used. The CHFL system with this cell layout lacks a dc connection. It meets the criteria to be a CHFACL system as a consequence. The transformer's secondary windings are 2n for n cells. Each cell is connected to two secondary windings, as seen in fig. 2. The transformer's main winding and one of its secondary windings have a turns ratio of 1: m. The PV modules are connected to a VDC LV DC bus (the maximum power point tracking (MPPT) method is used to establish this voltage reference; see [5]). When a single phase inverter has a duty cycle of 50%, the voltage at the primary side of the transformer is -VDC for 50% of the periodic time and VDC for the remaining periodic time. The voltage at one of the secondary windings of the transformer will be (-m.VDC) for half of the periodic duration and (m.VDC) for the other half. Each cell is bi-polar in operation, allowing it to output either (m.VDC) or (-m.VDC). By altering the time of these two voltage levels' realization, the cell may transform the high frequency voltage into a low frequency voltage component.

4.3 PV-Grid Charging System:

Figure 3 depicts a charging architecture with two conversion phases created by AC/DC and DC/DC converters. This charging architecture has been studied from a variety of angles in a large number of published papers[6], [7]. Additionally, the dc bus is essential since it will link the PV array, ESU, and EV battery pack in addition to other dc-powered devices. In this configuration, batteries or an energy storage unit (ESU) may not be required since the station is directly connected to the grid. Even yet, it would be really helpful if individuals were willing to reduce their dependency on the grid. According to the authors of [8], friendly topologies for integrated PV-grid chargers are preferred.

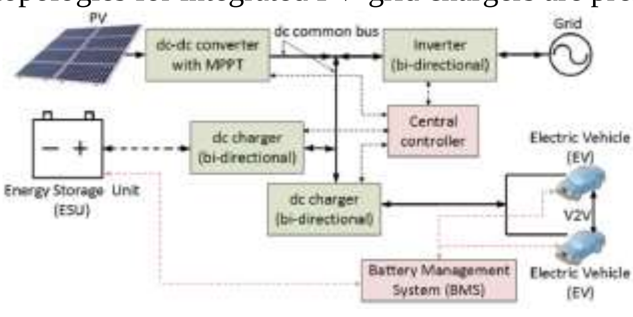

Figure 3: Block Diagram of a General PV-Grid CS

When an EV is initially plugged in, its SOC is typically below 100%. The following pricing priorities apply to the most basic PV-grid system (without ESU, V2G, and V2V activities) [6]:

• Case 1: The PV will be used to fully charge the EV if it produces more power than it needs. Charging does not make use of grid electricity. Any remaining excess power will be sent into the grid.

• Case 2: The charging will only be done by the grid if PV power is not available due to bad weather or at night. The same process will also be used if an issue with the PV system arises.

• Case 3: The EV will be charged using whatever power is available from the PV if the available PV power is inadequate to charge the EV because of low irradiance. The grid will handle the remainder (balance).

• Case 4: The PV energy will be instantly delivered into the utility grid, generally to the owner's financial benefit, if the charging station does not have a promise to charge (i.e., there is no EV to be charged).

The first mode (PV charging mode)-If there is enough PV energy to fully charge the EV, the PV will take care of it. The process is shown in Figure 4 [9] using a dc-dc converter and a dc charger. In this case, the PV will charge independently, and the system will be electrically decoupled from the grid. To fit the charging profile of a particular EV, the dc charger modifies the dc voltage.

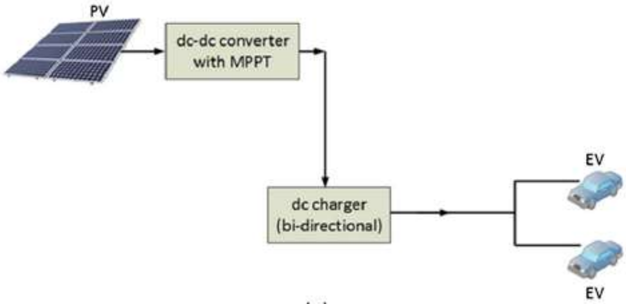

Figure 4: PV Charging Mode

2nd Mode (Grid-connected rectification mode)-On the other side, the EV will be charged directly from the grid if the PV system is absolutely unable to provide any power (due to zero or very low irradiation). Initially, a bidirectional inverter in rectification mode is used to convert grid ac power to dc. The dc charger then adjusts the dc voltage further. Figure 5 [9] shows how this situation is.

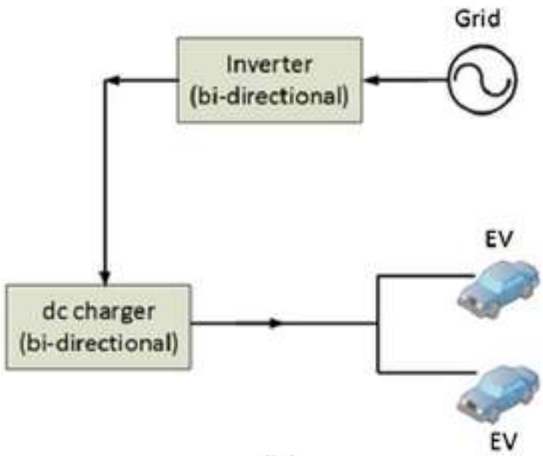

Figure 5: Grid Charging Mode

Mode 3 (grid-connected rectification and PV charging)-As shown in Figure 6 [9], the grid and the PV both contribute to charging the battery when the PV can only provide a small percentage of the energy (insufficient for fully independent charging). How much electricity the PV can offer often determines how much energy is drawn from the grid. The grid will cover the shortfall. The controller must continually monitor the electricity generated by the PV and adjust the grid intake in accordance with changing irradiance conditions to ensure that the EV continues to get the necessary power.

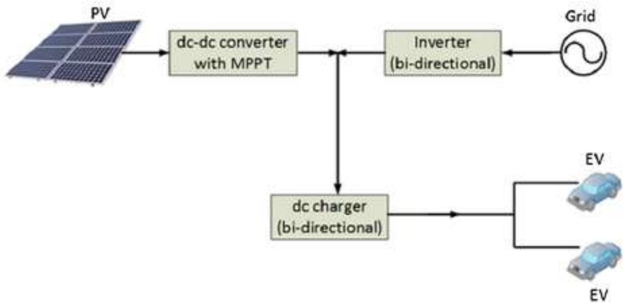

Figure 6: Hybrid Charging Mode

4th Mode (Grid inversion mode)-The dc-dc converter and the bidirectional inverter are two two-step conversion processes that are used to sell all of the energy to the grid when there are no EVs accessible for charging and the PV system is generating power. This procedure is seen in Figure 7 [9]. In certain situations, it could be more economical to operate in this mode even when the EV is charging. Such a notion becomes workable at much higher feed-in tariff rates.

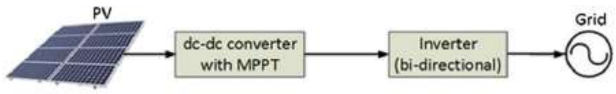

Figure 7: Grid Inversion Mode

4.4 Standalone PV Charging System

PV-standalone charging, as shown in Figure 8 [10], is the process of recharging an electric vehicle (EV) entirely from solar power, independent of the utility (grid). It is more effective since there are fewer processes involved in power conversion [11, 12]. On the other hand, the PV array must be sufficiently big to accommodate the number of automobiles that are need to be charged [13]. Figures 8(b) or 8(c) [15] demonstrate a charging goal attained using an intermediate ESU, whereas Figure 8(a) [14] depicts a straight PV to EV connection. In addition, there are several approaches that make use of hybrid solutions.

The PV power is inadequate and erratic to charge the EV continuously, which is the main issue with the direct charging method. On the other side, when PV power is not available, the ESU enables extra energy to be stored and utilized later [8]. This is better, but the ESU's initial investment cost could be too high [16]. In both cases, the charge controller is a crucial element. It functions fundamentally as a dc-dc converter with MPPT capabilities and the additional feature of controlling PV voltage to ensure the charging current is at its best.

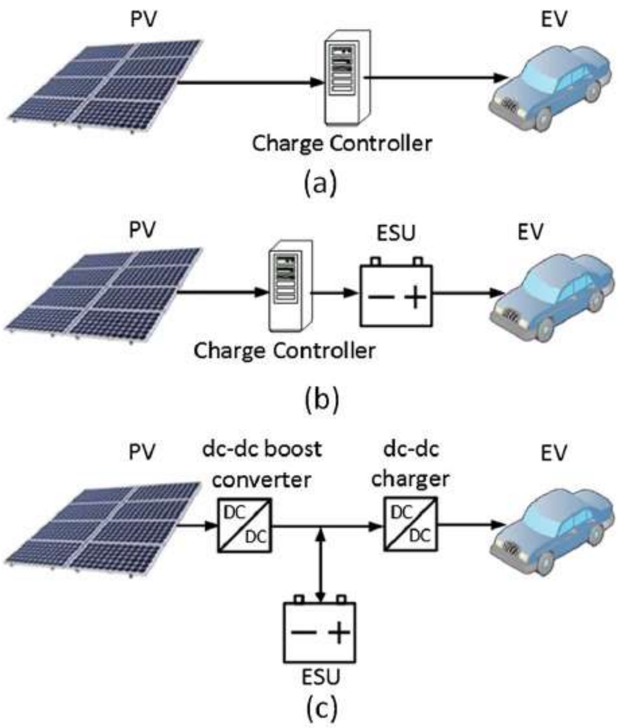

Figure 8: PV standalone CS

A hybrid PV standalone charger that combines an electric car battery with a hydrogen fuel cell system was described by the authors in [17]. It is shown in Figure 8 as a conceptual diagram. The PV is divided into two tracks, one to power a fuel cell car and the other to charge the lead acid battery (ESU) in the EV. To charge and maintain a full charge on the ESU, PV power is used. If EV charging is required, the energy from the ESU is transmitted to the EV battery using a battery charger. Hydrogen is produced by electrolyzing water on a separate track using PV power (to refuel the fuel cell). This design allows the system to charge the EV both during the day and at night. A novel hybrid standalone charging system that makes use of ESU, super-capacitors, and fuel cells is described in another work [8]. Utilizing additional energy sources may improve the system's reliability [7, 17]. Theauthors use two control algorithms: one controls the power interface between supercapacitors and batteries, and the other controls the power interface between batteries and fuel cells. A brand-new PV charging method is suggested by the authors of [17] and is based on the flexible ac transmission system (FACTS) architecture. The management and power transmission capacities of the electrical network are often enhanced using FACTS [18]. This research makes use of a PV-EV charging station with a shared bus and a new dual-action regulator and green plug-filter compensator. Each regulator uses a tri-loop error managed by a modified PID controller to quickly remove the dc side inrush and transient changes. This approach is distinctive in that the dc common bus is stabilized using FACTS devices.

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Figure 8(c) in [19] shows a mathematical model of a PV-standalone charging station that uses solar energy at the home level. It is also recommended that the PV current be used to charge the home ESU until it reaches full SOC. Using fitting techniques designed for this purpose, the model parameters of the PV panel and the lead acid ESU are found, and their models are experimentally verified. In order to generate the most PV electricity, the MPPT control is employed. This kind of system is not completely reliable to satisfy EV demand during the winter or bad weather because to the poor solar irradiation. This work's Section 5.1 provides evidence of the failure of this kind of system.

Using the PV cells implanted in the EV body to charge is another brilliant idea put up by the authors in [20]. This notion is known as the vehicle-integrated PV concept (VIPV). Thin film cells are often put on the EV's roof, and an on-board dc-dc converter is used to charge the batteries. In a different work [21], a VIPV using a brushless permanent magnetic dc motor is shown. However, the authors contend that the limited space of the PV cells renders the method inapplicable. The propulsion system cannot be powered by the energy being extracted. Despite this, a secondary charger using the VIPV concept might boost efficiency by 10% to 20% [20]. The embedded PV cells may be utilized as an additional power source to run the air conditioning system when the vehicle is parked [22]. At the very least, the VIPV system can run auxiliary devices like fans, music players, and igniters [23, 24]. In a more sophisticated attempt, the silicon crystal with fixed quantum locations is mixed with special paints that may be painted on the car body. This is an interesting development despite the solution's dubious trustworthiness. The system's effectiveness is low (less than 2%), yet it has exciting promise for the future.

4.5 Fuzzy Logic Controlled Charging System:

A novel decentralized charging station management strategy built on a medium-voltage direct-current (MVDC) bus was unveiled by Pablo Garca-Trivio and colleagues [25]. These charging stations are a component of a microgrid that also include two quick charge units, a local grid connection, a battery energy storage system, and a PV system. The main contribution of their research is the mentioned decentralized control strategy based on fuzzy logic, which uses the battery energy storage system's level of charge as a control variable. In order to maintain the MVDC voltage and battery energy storage system state-of-charge within acceptable thresholds as well as a stable power balance between the fast charge units and the other components of the charging station, this control contains two independent fuzzy logic systems (one for the battery energy storage system and the other for the grid). The new control method was tested in 200 cases under different conditions of sun irradiance, initial state-of-charge of the battery energy storage system, and number of EVs connected to the charging station in order to demonstrate its correct performance in all of the scenarios taken into consideration.

The control system regulates the BESS SOC, maintains the MVDC bus voltage, and keeps track of component power balance. All of these procedures are completed in the absence of a centralized system that collects the most important variables for each component and bases each component's reference power on these details. This style of control is intended to be replaced by a DCM based on independent fuzzy logic controllers. This structure eliminates the theoretical and practical constraints of power supply dependability and makes large-scale generator access easier [27]. Each component is able to operate independently without being aware of the condition of the other parts of the system.

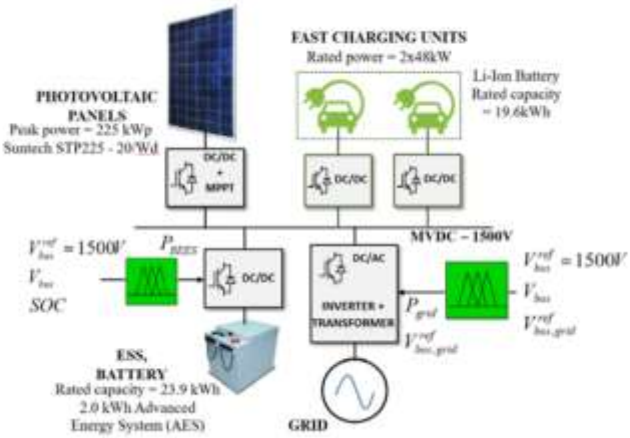

Figure 9: Fuzzy Logic Controlled Charging System

4.6 Wireless Electric Vehicle Charging

The high power and track stability of an electric vehicle are often provided by a system made up of many components. The majority of these parts are wired to the charging mechanism. Dynamic wireless power transfer is an effective way to reduce range anxiety in this situation while simultaneously reducing the price of the onboard battery. Pure electric cars have long offered wireless charging, which enables charging even while the car is moving. However, this method's complex working philosophy, which takes into account a lot of variables and circumstances, makes analysis difficult. Additionally, the state of the vehicle—whether it is moving or not—determines a number of attributes, including vehicle speed and the widths and diameters of the coil receivers.

A novel strategy was created by Naoui Mohamed et al. [28] to enhance the functionality of the dynamic wireless recharging system. In order to increase charging power, receiver coils have been added to the system. These coils provide a dynamic mathematical model that can define and measure source-to-vehicle power transmission while the vehicle is moving. The mathematical model gave and described all of the model's physical parameters.

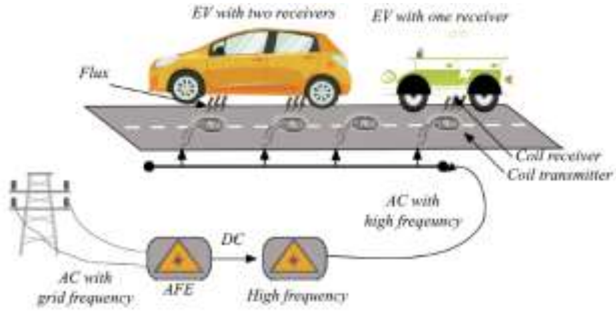

Figure 10: Wireless EV Charging System

One part of the system is for the road, while the other part is for the automobile. The transmitter is the part of the route that is always present. The second part, which is situated underneath the car, is the moving receiver. The two components have their own electronic systems and are separated by a vacuum. An alternating magnetic flux with a high frequency is produced by the transmitter block. This magnetic flux is connected to the receiver coil and converted to electric energy, which is subsequently used to replenish the battery of the electric car. Figure 10 shows two instances of wirelessly charged electric cars (EVs) parked on a road. The other has two receivers, whereas the first has only one [29].

As shown in Fig. 10, the transmitter part is attached to a number of electrical components that allow for flexibility between the receivers and the AC power source and put on the road. It demonstrates how the active front end (AFE) converter, which creates a programmable DC voltage, is connected to the original energy AC power. By keeping an eye on the reactive power going from the source to the transmitter, a power factor corrector (PFC) block is added to this section of the transmitter block to preserve grid stability.

The transmitter coil is then activated using a high-frequency (HF) full-bridge inverter to provide a strong excitation current. The system's total profitability is greatly influenced by two factors. The first element has to do with the compensatory method used to guarantee the accuracy of the voltage and current waves. The transmitter surface is linked to the coil shape, whether circular or not, in the second crucial element's coil design, which is related to the coil construction. The following two subsections go into further detail on these topics.

4.7 Multiport EV Charging Station

In the conventional design of DC bus charging station with PV integration, figure 11, all three power sources, including PV and EV charger unidirectional sources and AC grid bidirectional source, are linked by three separate converters.

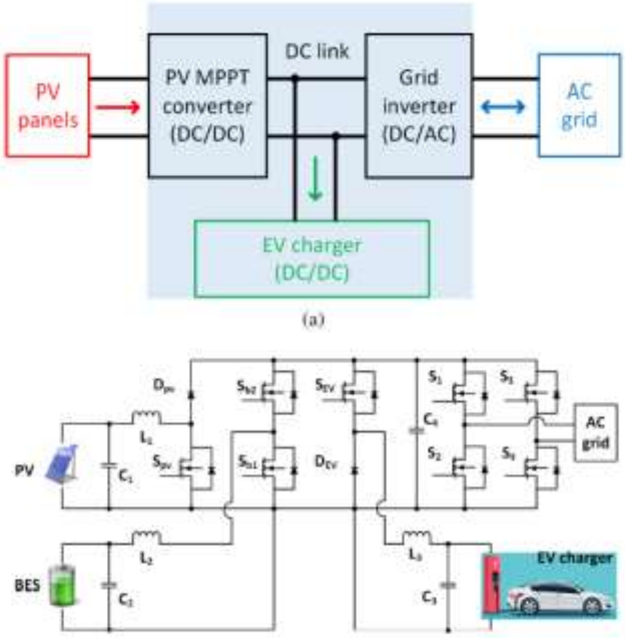

Figure 11: Multiport EV Charging System

One additional two-way power supply In the planned DC bus charging station shown in figure 11, BES utilizes the same DC vehicle. Figure 11 shows how the BES balances PV power surpluses and shortages and maintains the DC connection voltage. Following are some detailed explanations of the setup's function and operational modes.

(mode 1) PV to EV

The switches Spv, Sb1, and Sb2 are off when SEV is on in this mode. PV therefore provides the load with direct power delivery.

EV to BES in mode 2

When Spv and SEV are switched on while Sb1 and Sb2 are off, BES is discharged to the EV load.

PV to BES (Mode 3) When Sb2 is switched on and Sb1, Spv, and SEV are off, the PV excess energy is used to charge the BES.

The other modes are PV to Grid, Grid to EV, and PV to BES.

The operating tenets of different modes, such as PV to BES, grid to EV, and PV to grid, are summarized in Table II.

Table 2. EV Charging Operating Modes

S_{pv}	S_{b1}	S_{b2}	S_{EV}	**Power flow**
OFF	OFF	OFF	ON	PV to EV
OFF	OFF	ON	OFF	PV to BES
ON	OFF	OFF	ON	BES to EV
-	ON /OFF	OFF/ ON	ON	Grid to EV
OFF	OFF	OFF	OFF	PV to Grid

5. CONCLUSION

To provide a deeper understanding of EVCS technology, this research looked at various energy transfer kinds, charging levels, and processes, as well as the existing worldwide standards for EV charging. The various parts of the charging stations are compared and explained. In conclusion, when more functions are integrated into the system, the solar charging structure becomes more complex, requiring sophisticated controls in each block as well as real-time station administration.

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