Comparsion of modern EVs charging system and charging infrasturcture

Chuyi Jiang*

University of Bristol Bristol BS8 1TH, UK

*Corresponding author: ir19714@bristol.ac.uk

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Abstract: The electrical vehicle (EV) is trend in the future because of its clean energy. Following by the developing of the market of the EVs, more and more types and amounts of EVs will be used in next several decades. Obviously, charging EVs is a vital and tremendous work. This paper will mainly discuss the existed method for charging EVs, including charging types and charging infrastructures. In addition, the comparison of different methods of the charging system will be listed. Dominant charging methods have their own advantages and disadvantages and the influence on the grid or society could not be ignored. Based on the research, people could clearly gain the problems of the charging system, which may push the developing of the charging system. Hopefully, the completed and mature charging system will be built as soon as possible.

1. Introduction

Considering the climate changes caused by the emission of greenhouse gas. This greenhouse gas is unavoidable through the using of fossil fuel, especially gasoline. As a result, electric vehicle (EV) has been developed to alleviate the speedy climate changes and tremendous consuming of fossil fuel. [1] The development EV could trace back to early 1900s. EV and related vehicle like HEV will become more and more popular in the future due to the rising gasoline price and environmental factor. [2] Undeniably, EVs have already been used in several countries with a relative charging system for household or on the road. Some companies like Tesla and Siemens also constructs different types of charging station based on the standard of different countries and the international Electrotechnical Commission (IEC). [3] However, various types of EVs exists in modern society. They have different charging system and charging methods with different charging facilities. Also, following by the increasing of the comprehensive usage of the EVs, the grid could be influenced by the charging for their batteries. This paper will conclude the main charging system recently and their relative charging equipment with their properties and impact.

2. Modern charging method for EV

Totally, the modern charging methods can be divided into three parts: wireless charging, battery swapping and plug-in charging. [3], as shown in Figure 1. Different form wireless charging method, the other two charging methods, especially the plug-in charging system is relatively mature and has been utilized in city and grid.

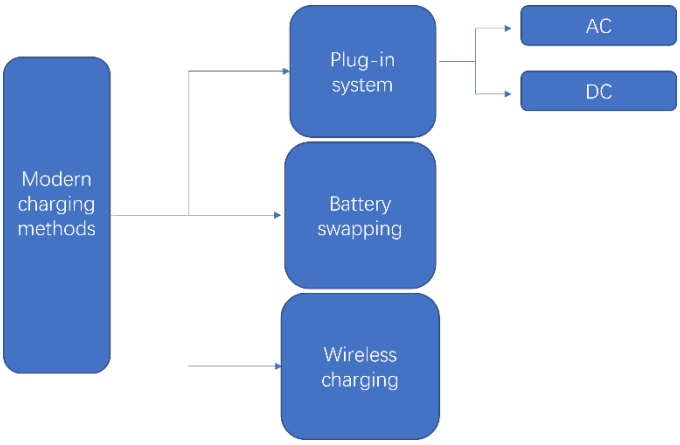

Figure 1. Classification of modern charging system

2.1 Plug-in system

Plug-in charging system is used to charge battery electric vehicle (BEV) and Hybrid electric vehicle (HEV). Normally, the power is supplied by the grid and transfer the electric power into the domestic charging point or charging station, which can be concluded as Grid-to-Vehicle(G2V). The difference between the charging point and charging station will be discuss in section III. The plug-in system is consisted of several parts: plug, socket, inlet, and connectors. [3] Ultimately, The EV and individual charging point are connected by plugs and cable. The charging process is shown in Figure 2.

Figure 2. Process of a plug-in charging system

Based on various type or mode of charging methods, some differences such as plug type, pin number, power range are existed in the plug-in charging system. The research [4-6] shows the main different plug-in EV charging type, mode, and levels, which is concluded roughly in Table 1.

Table 1. Classifaiction of charging system

Identification	**Property**	
	Name	***Description***
Charging Level	Level 1	Home charging / Slow AC charging 1.5kW~3kW 8h – 14 h
	Level 2	Fast AC charging (charging station) 5kW~25kW 3h
	Level 3	Fast DC charging (charging station) 50kW 30min charge 80% of battery
Charging Mode	Mode 1	A cord extension for charging at home Under 16A and 250V ac and 480V three-phase ac no safety measures
	Mode 2	A special in-cable EVSE for charging at home Under 32A and 250V ac and 480V three-phase ac Medium level safety
	Mode 3	A specific socket at a common place or at home (wired-in AC charging station) Higher power level and safety level than mode 2 and
	Mode 4	Fast charging with DC current (wired-in DC charging station)

The plug-in system already has its own standard and they have been applied in the market. There are also several types of sockets depends on the area and standard, for example the 'SAE1772', used in Japan and U.S and 'Mennekes', used in Europe.

The plug-in charging system could be separated into two main methods, which is AC and DC. Based on the different charging principle, the charging system can be identified by the charging places and charging equipment. Considering the AC and DC charging, 4 modes and 4 types are also shown in table 1. Obviously, the DC charging method is much faster than the AC charging method. However, both have different principles and application scenarios, which will be illustrated with more details in next two sections.

3. AC charging system

The AC charging system can also be called as the on-board charging system. [7-9] The construction shows roughly shows in Fig3. Normally, the system is consisted of rectifier, DC/DC converter, control and protect part. AC/DC converter can transfer the three-phase ac current into a dc current. DC/DC converter could transfer the high-level dc current which is from the grid into a suitable level of current for the battery. In Piasecki' s research [8], there are several types of dc/dc converter, for instance flyback converter, single active bridge (SAB) and dual active bridge (DAB). In addition, bidirectional dc/dc converter is more efficient and safety.

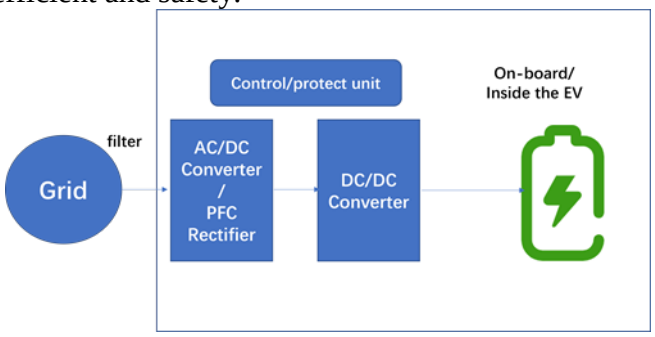

Figure 3. Structure of an AC charging system

The AC charging system is usually used at home or domestic range because of its power. (LEVEL 1 and LEVEL 2 in Table 1). The charging period is ranging from 5 hours to 10 hours, which is appropriate for an individual EV that is charged at domestic car park by using the power supply from the home inlet at night. The total distance that can be supported after one-night charging is around 30 miles. On the other hand, the infrastructure for an AC station point is cheap and easy to manufacture. The plug and sockets of the EV can directly connect to domestic grid.

4. DC charging system

The DC charging system is also fast charging and off-boarding charging [7-9]. The structure is different compared with AC charging station, shown in Fig.4. Similarly, the component that in the AC charging system is needed in the DC fast charging system, such as the rectifier and the DC/DC converter. The placement and position are quite different while the component in the DC charging system is mainly placed in a charging point rather than placed in an inner charger on vehicle. In another word the power can transmit directly into the battery on the vehicle.

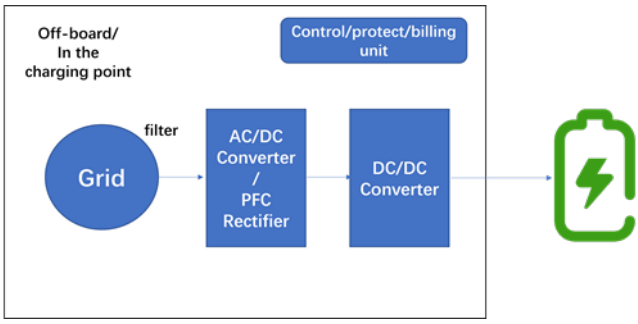

Figure 4. Structure of a DC charging system

Obviously, the fast charging or DC charging system could be comprehensively utilized on the road and highway. Based on the enormous power in fast charging, it takes around 30min to charge 80% of the battery which can support the vehicle on the highway. The DC charging equipment is usually built in a charging station on the side of road, which includes a billing charging unit, similar with the gasoline billing in the petrol station. Compared with the AC charging, drivers should cost more for charging their EV. Nevertheless, the fast-charging system may cause degradation and damage on the battery due to the thermal effect and the electrodes. [10]

4.1 Battery swapping

Battery swapping is a novel method after the developing of the conductive charging system for the EV. The unique feature of battery swapping method is flexibility and uniformity.[11] The process is shown in Fig5. When the battery on the EV is exhausted, the empty battery could be change to another full charging battery in certain battery station. These empty batteries will be charged uniformly with the grid. This system can also be called as Battery-to-Grid (B2G) and Grid-to-Battery (G2B). The battery swapping EV do not need to plug-in charging system to get power which means these vehicles do not be limited by the charging level, charging mode, and charging type that mentioned in Table 1. In [7], modern plug-in system and various kinds of sockets have been concluded, ranging from SAE1772 for single phase, Tesla for fast charging and CCS for combined charging method which including both of AC and DC charging. The diversity of the type of conductive charging methods seems to be a burden of the market. [12]

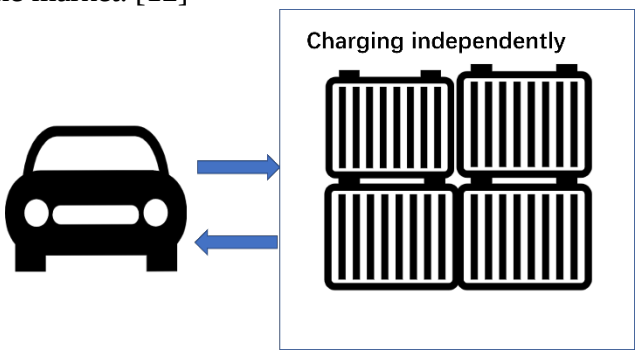

Figure 5. Structure of a battery swapping system

In fact, the charging principle of the batteries are same as other charging for the lithium battery for EV. The empty can be charged at any time with the grid. This can eliminate the time limitation compared with the long period for the AC charging system.

4.2 Wireless charging

Wireless charging system (WCS) is another new method which could even replace the plug-in charging system in future. To dealing with the plug-in charging system like the space constrain, the WCS charge with the battery without contact based on the transmitter, coils and electromagnetic. The important principle is Faraday's law of induction. Nowadays, the WCS system are separated into two main trends: stationary and dynamic. The power transfer principle can be separated into four parts:

inductive, capacitive, permanent magnet and resonant inductive by the price, power level, volume, complexity, and stability. [13, 14]

The process of the WCS is quite different which is consisted by AC/DC converter, two DC/AC converters which are placed in the charger and the vehicle respectively and transmitter, which is shown in Fig.6 [13] The power is also supplied by the grid. After filtering and rectifier modifying, the electrical energy and the magnetic energy can change and transmit by the coils.

The efficiency of the wireless charging system is not low. In Zhang's research [15], the coils design can directly influence the efficiency of the power transferring. In Zhu's research [16], the Kilowatt level resonant WCS could achieve around 90% efficiency. However, this method is still in the research step, especially for dynamic WSC.

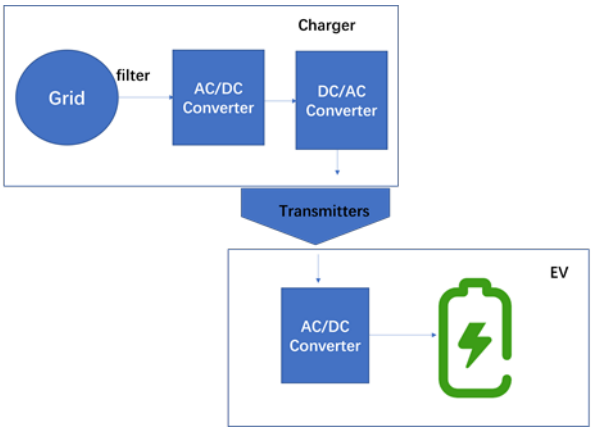

Figure 6. Structure of a wireless charging system

4.3 Comparison

The advantages and disadvantages of different charging systems are compared in the following table.

Table 2. Comparsion of different charging system

Methods	**Comparison**	
	Advantage	***Disadvantage***
AC charging	Safty, cheap	Slow
DC charging	Fast	Degradation on battery
Battery swapping	Flexibility	Expensive
Wireless charging	No space limitation Efficiency	Expensive, Complexity

According to the discussion in section II, the plug-in charging system, including both ac and dc charging is the dominant method for charging the commercial and public EV. The ac charging is slow with low current and voltage level, compared with the fast dc charging with a tremendous power level (50kW). Because of the charging period, both can apply in certain environment, home, or highway. The battery swapping can charge the EV through changing batteries, which can reduce the long time for charging. However, the uniformly manufacturing batteries for every brand of cars is a huge work. As for the wireless charging, it is a novel way that get the rid of plug and socket but similarly with the battery swapping, the construction of the WSC is also a complex and lucrative work.

5. Modern charging infrastructure

Based on the different charging methods that mentioned in section II, each charging system has their own charging infrastructure and equipment.

5.1 Charging point

The charging point is the basic unit in the plug-in charging system. In Fig.7, there are two type of charging point.

As for (a), which is a household charging point. It applies the ac charging system and has a simple construct, which is a plug for EV and a connecter that can be directly connected with the home grid. This household charging type is convenient and cheap to manufacture. In addition, because of using the home grid power supply, the charging period is quite long, and it merely is used in at small range.

In (b), the figure shows a charging point with a larger size, which includes synthetical charging type. This machine can be ac charging system or dc fast charging system. Also, different types of plugs could equip in one charging point, and this can charge different EVs. These charging point usually appear in charging station or public car park which is connected to the grid. This charging point can charge the EV which is on the road with a shorter charging period. The inner constructure is also more complex, which means it is more expensive.

(a) Single charging pile (b)Charging point with various plugs

Figure 7. Different types of charging point

5.2 Charging station

A charging station is a huge public facility which includes several charging points. [17] Considering the petrol station with various types of gasoline, a charging station include both ac and dc charging station. Almost commercial EVs can be charged on the road. In each charging point, a billing system is unavoidable which is used to calculate how much electricity used and paying it. Different with the petrol, the charging service can be divided into peak hour and off-peak hour. The price is cheaper during the off-peak hour.

Following by the development of the EVs, the peak load will raise to 30GW in next decade.[19] Obviously, an array of charging points in a charging station are connected to the grid and an increasing number of charging station will be built on the road. There are several impacts on the grid. [18,20] First, the tremendous charging supply at peak time will press the grid and the voltage may be not stable. Then, the harmonics could distort the voltage and current waveform, which may influence other facilities under the grid. In addition, the energy loss cannot be ignored. The more charging EV means the more energy loss in long term. However, developing the smart control system and V2G system can efficiently improve the charging quality and reduce the impact on grid.

5.3 Battery swapping station

The battery swapping station is similar with the charging station, which is also a public facility that swap the battery for the on-road EVs, which is shown in Fig.8. The size may be a bit smaller than the charging station. The unique part is the battery storage, a place that exhausted batteries can be stored and charged again.

Battery swapping method leads a novel BBS concept. Compared with the traditional charging methods, battery swapping could reduce the charging time significantly. Customers do need to consider the charging problem such as how to charge, which type of plug and level should be used and the waiting time. Furthermore, as for emergency, the BBS system can also provide external energy to the grid through the batteries stored in the Battery charging station. [21]

On the other hand, battery swapping method faces two main challenges: 1）how to uniform the different company's EVs battery which is an enormous job. 2) manufacturing many batteries and how to charge them and storing them with little degradation and high efficiency. If all unused batteries are charging at the same time, the grid can also be influenced and even broken due to high power supply at once.

Figure 8. A battery swapping station

5.4 Wireless charging point and dynamic wireless charging

The infrastructure of wireless charging could be mainly separated into two parts: The wireless charging point and dynamic wireless charging.

Based on the stationary wireless charging system, a small charging point is applied for EV charging as shown in Fig.9. The size is smaller than the charging point so that it using range is comprehensive, from home using to on-road charging station. The wireless charging point exclude the complex charging plug, machine, and cable, which can solve the problem of the plug-in system.

Figure 9. A stationary wireless charging point

Another type of wireless charging system is the dynamic. This method aims to charge the EVs without stopping and waiting. In another word, the EVs can be charged when they are driven on the road. This technology can be applied in the automatic industry, automatic EV, and wireless charging road. [22] The dynamic wireless charging system is difficult to be achieve due to the enormous work on the city rebuilding. In Fig.10, it shows a design of the wireless charging road on highway. It requires numerous transmitter coils under the road with high cost. Besides, the efficiency and impact of this method is merely uncertain. There is a relatively realistic way to achieve the dynamic wireless station which is a taxi and a bus can be charged at any waiting time. [23] This method can also apply for other EVs, for example the wireless point at crossing when waiting for the traffic. However, the distance influence between the EVs and charging point may influence the charging efficiency. Besides, the damage of the electromagnetic is also an uncertainty in the smart city.

Figure 10. A wireless charging road

5.5 Comparison

The comparison of different charging infrastructures is shown in the table below.

Table 3. Comparsion of different charging infrastructure

Infrastructure	**Comparison**		
	COST	***RANGE***	***Impact to Grid/society***
Charging Point	Low	Household	No
Charging Station	High (charging fee)	On-road	Grid damage
Battery swapping Station	High (Batteries)	On-road	B2V Energy loss
Wireless charging System	High (complex constructure)	Home or on-road	Difficult to build, Electromagnetic wave, Efficiency (dynamic)

Totally, the charge station is used comprehensively nowadays. Different charging system has different charging period. The less time used, the more money must be spent. The battery swapping station is an alternative method. However, whatever the methods used, plenty of batteries charging together can damage the grid, which can be dealt with smart control system. As for the wireless charging system, the stationary and dynamic methods will become the trend in next several decades. By the developing automatic vehicle, this technology will play an important role in the smart city.

6. Conclution

The modern charging system is multifarious, and they could be used in different environments, from home to highway. This paper concludes the three charging methods, typically is four charging methods, which is AC, DC, battery swapping and wireless charging. Comparing their advantages, the AC charging is relatively safety and simple, DC charging could support high power for short charging time, battery swapping is an alternative of plug-in system and wireless charging is a novel method which is used the electromagnetic and without the physical equip limitation. This paper also concludes the 4 kinds of charging infrastructure. The household charging point is used in small range, especially for the daily driving. The charging point is the basic unit of charging system in city, but the tremendous usage at the peak hour could damage the whole grid. The battery swapping station can be a temporary electric storage while it is used for the charging of EVs. The wireless charging system is not mature. In the future, the dynamic wireless charging system with the automatic vehicle technology may be used in future smart city. This is also a developing trend for the future---charging the EV everywhere.

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