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Research Article

A Study on the Fire in Charging Facilities of Electric Vehicles

[1]Jin A Choi, [2]Joon-Seong Lee
[1]*Department of Mechanical Engineering, Graduate School, Kyonggi University, 154-42 Gwangkyosan-ro, Yeongtong-gu, Suwan, 16227, Korea*
[2]**Professor, Department of Mechanical System Engineering, Kyonggi University*

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ABSTRACT

Recently, as environmental regulations have been strengthened, automobile manufacturers are putting all their efforts into developing eco-friendly cars, and the government is also supporting various subsidies and benefits to encourage the purchase of eco-friendly cars. Internal combustion engines are still the mainstream, but recently, with the emergence of electric cars, hybrid cars, and hydrogen fuel cell cars, consumer choices have diversified, and the performance of eco-friendly cars is no less than that of internal combustion engine cars, and the Ministry of Environment and local governments are sparing no expense in establishing systems and budgets for the construction of charging infrastructure. Accordingly, this study aims to examine the current status of electric vehicle charging facilities to prepare for the continuously increasing number of electric vehicle fire accidents and to establish response measures to prevent large-scale property damage and casualties caused by fire. This study focused on the types of fire extinguishing methods that can be applied in the event of an electric vehicle fire accident, and in particular, on the systems that should be applied first in the field.

Keywords: Charging facility, Electric Vehicles, Fire characteristic, Lithium battery

1. INTRODUCTION

In this era, in order to respond to climate change caused by global warming, each international society has set a carbon neutral policy as a core value, and is rapidly transitioning from internal combustion engine vehicles that used existing fossil fuel energy to eco-friendly vehicles.

If existing automobiles are structured to obtain energy from combustion of internal combustion engines, electric automobiles are automobiles with motors that are driven by electric energy. Since they obtain power from electric energy, there is almost no concern about exhaust gas or environmental pollution, and the advantage is that the noise from the motor is much lower than that of internal combustion engines.

The European Union declared a ban on the sale of internal combustion engine vehicles starting in 2035, and the Biden administration in the United States finalized and announced the “Electric Vehicle Charging Action Plan” with the goal of having half of new vehicles be electric vehicles by 2030. In Korea, along with the pledge to “ban new registrations of internal combustion engines by 2035,” the government is also spurring the expansion of electric vehicle distribution and charging infrastructure by setting a goal of achieving a cumulative distribution of 1.13 million electric vehicles and 200,000 hydrogen vehicles by 2025[1].

According to Statistics Korea, as of June 2022, the number of registered pure electric vehicles in Korea increased by about 30 times compared to 2016, reaching 298,633 units, and the number of electric vehicle charging facilities increased by about 75 times compared to 2016, reaching 131,870 units. The 「Act on Promotion of Development and Distribution of Environmentally Friendly Vehicles (abbreviated as the Environmentally Friendly Vehicle Act)」, which has been in effect since January 28, 2022, has expanded the target and ratio of mandatory installation of electric vehicle charging facilities, and has set a grace period of up to 3 years for existing buildings, and accordingly, the number of electric vehicle charging facilities is expected to increase rapidly in the coming years. As electric vehicles increase, vehicle fires are also increasing every year. In the past five years, there have been a total of 45 electric vehicle fires (1 in 2017, 3 in 2018, 7 in 2019, 11 in 2020, and 23 in 2021), and 17 cases occurred as of the end of June 2022. Of these, 16 cases (36%) were fires that occurred during charging or parking.

Electric vehicle fires have different risks from fires in internal combustion engine vehicles, such as thermal runaway of lithium-ion batteries inside the battery pack and generation of hydrogen fluoride, and it is difficult to effectively extinguish them with existing firefighting facilities or suppression methods. In particular, fires during charging or parking recently account for 36% of electric vehicle fires, but related laws and safety measures to ensure the safety of charging areas are still insufficient. Therefore, the purpose of this study is to analyze the problems of the installation status of charging facilities where electric vehicle charging areas are installed and to suggest alternatives to protect electric vehicle users from fire accidents and minimize the development of large-scale disasters or damage to public property[2].

Since the emergency report surge does not occur all the time, it is necessary to analyze the situation when it occurs, and research is needed on how to receive the maximum number of emergency reports and how to respond situation room in cases where the emergency report surge occurred in each region.

2. OVERVIEW OF ELECTRIC VEHICLES

Among automobiles, vehicles that meet zero-pollution or low-pollution standards and have excellent energy consumption efficiency are called eco-friendly vehicles. Among eco-friendly vehicles, electric vehicles (EVs) are cars that run on electricity as a power source. Electric vehicles commonly use high-voltage electricity for the purpose of reducing exhaust gases or reducing fuel efficiency. There are several types: hybrid vehicles (HEVs) that have two or more engines that use both an electric motor and an internal combustion engine; plug-in hybrid vehicles (PHEVs) that are basically powered by an electric motor but use an internal combustion engine when large power is needed and can be charged externally; electric vehicles (EVs) that are powered solely by an electric motor; and hydrogen fuel cell electric vehicles (FCEVs) that, like electric vehicles, are powered solely by an electric motor but obtain electric energy from a fuel cell[3].

2.1 Electric vehicle

Electric vehicles (EV) are cars that are powered by electric energy, and the driving energy is not obtained from the combustion of fossil fuels, but rather, they are cars that move by rotating a driving motor with electric energy stored in a battery. Electric vehicles are generally described as including hybrids and hydrogen fuel cell cars, but here, an electric vehicle (EV) is a car that moves purely with electric energy as a power source, and it is a vehicle that supplies electric energy from a large-capacity, high-voltage battery to a motor, converting the electric energy into kinetic energy to generate driving force. Since this method does not operate an internal combustion engine, it does not emit exhaust gases that pollute the environment, and it is almost noiseless. The electric vehicle, which was manufactured in 1873, was manufactured before cars with internal combustion engines that use fossil fuels. However, it was not put to practical use due to the heavy weight of the battery and the long charging time.

Since the end of the 20th century, when environmental pollution and resource shortages became serious issues, major automobile manufacturers around the world have been fiercely competing to develop lightweight batteries. Electric vehicles are not only environmentally friendly because they do not have internal combustion engines that use fossil fuels when driving, so they no longer emit carbon dioxide (CO_2) or nitrogen oxides (NOx), but they are also economical because they have lower operating costs when driven only by electric motors. In addition, since there is no internal combustion engine, there is less risk of explosion due to collision in the event of a traffic accident, and the lifespan of the vehicle is relatively long. In addition, batteries can be charged at home using electricity at night, and driving is easy because only the rotational ratio of the motor can be adjusted[4].

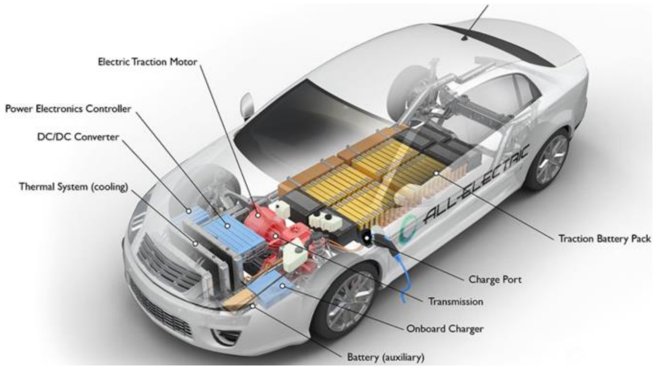

Figure 1 Structure of electric vehicle[4]

Fig. 1 shows the structure of an electric vehicle. After the first commercial electric vehicle was released, there were the Ford Ranger, Toyota RAV4, and Honda EV Plus, but the battery capacity was large, it was heavy, took a long time to charge, and the maximum driving distance was short, exposing limitations in practicality. Accordingly, batteries became increasingly compact, and 'hybrid vehicles (HEVs)' and 'fuel cell vehicles (FCVs)' that were powered by a charged battery with an auxiliary engine for charging were researched and developed. In order to establish the practical use of electric vehicles, many advanced countries including the United States supported large-scale investment at the government level and also promoted mandatory distribution policies. Currently, Japan is the country with the most accumulated technology related to secondary batteries in electric vehicles. Among them, Mitsubishi Motors designated government offices and corporations as priority distribution targets in 2009 and released the world's first electric vehicle, the 'i-MiEV', and began selling it to the general public in April 2010. In addition, Nissan Motor Company launched the world's first mass-produced electric car, the 'Leaf', in 2010, which was more competitive than the iMiEV, and thus began full-scale commercialization. In Europe, BMW and Volvo unveiled compact electric cars, and in the US, GM unveiled compact electric cars. In Korea, Hyundai Motor Company produced 17 units of the country's first electric car, the 'BlueOn', through government procurement in September 2010, and then Hyundai-Kia Motors launched the high-speed electric car, the 'Ray EV', in December 2011, marking the beginning of commercialization in Korea as well[5].

2.2 Components of an electric vehicle

Until now, automobiles have been made up of more than 20,000 parts and complex structures, but electric automobiles are powered by secondary batteries and motors, so the structure is relatively simple, such as the absence of a transmission, and the number of parts has been reduced to one-third compared to previous internal combustion engines. The series of processes that transmit power produced by the automobile's power unit to the wheels is called the powertrain. In electric automobiles, the powertrain[4] includes a motor that generates power, a regenerative braking device that changes the direction of energy from the generator, and a battery pack that stores electric energy, unlike internal combustion engine automobiles. The biggest difference between the powertrains of electric automobiles and internal combustion engine automobiles is the method of generating power. While internal combustion engine automobiles generate power with an engine, electric automobiles generate power with a motor. The method of transmitting power is also quite different from that of internal combustion engine automobiles and electric automobiles. Electric automobiles generate and transmit power much more simply than internal combustion engine automobiles.

1) Motor

The power source of a car is a motor. If the heart of an internal combustion engine car is the engine, then the heart of an electric car is the motor. Some people say that the core component of an electric car is the lithium-ion battery, which is also used in smartphones, but the driving performance of an electric car varies depending on how well the battery and motor are made, so the role of the electric motor is also very important.

The motor used in an electric car is an AC motor. The battery of an electric car is a DC battery, but the reason for using an AC motor while using an inverter is because of the durability of the DC motor. The DC motor has a simple structure and high torque. However, the disadvantage is that the brush motor of the DC motor has a short lifespan due to friction, so it must be replaced frequently, and it is noisy and is not suitable for electric cars that prioritize stability and durability.

In contrast, an AC motor does not have brushes, so it does not require periodic maintenance, and its durability is longer than the lifespan of the car. In addition, a DC motor can adjust the torque or RPM in proportion to the current, so the control method is simple to implement and the cost is low. In contrast, an AC motor has a more complex control method than a DC motor. Thanks to the development of control technology, its technological perfection is high, it has fewer heating problems than general DC motors, and above all, it has a long lifespan.

2) Battery

he battery is the most essential component of the secondary battery used in electric vehicles, and it is the standard for consumers to choose the type of electric vehicle. Currently, lithium-ion batteries, a type of rechargeable secondary battery, are recognized as the most efficient battery and occupy most of the battery market worldwide. Batteries used in electric vehicles are largely divided into cylindrical, square, and pouch types. Lithium-ion batteries are generally manufactured in cylindrical and square shapes. Pouch types are lithium-ion polymer batteries, and polymers are known to be more versatile than lithium-ion in terms of stability and energy efficiency. Looking at the pros and cons of the battery type for electric vehicles, cylindrical batteries have the disadvantage of being difficult to make lightweight due to the limitations of the cylinder, and the resulting limitations in the cooling method cause rapid performance degradation due to heat, resulting in a short battery life. Pouch types are lighter than the same capacity, have a large surface area, and are easy to dissipate heat, making the cooling method convenient, and have the advantage of a longer lifespan than cylindrical batteries. The most commonly used batteries for electric vehicles so far have been secondary batteries. Batteries are divided into primary and secondary batteries. Primary batteries are disposable batteries, such as dry cells, that are commonly used in daily life. Secondary batteries are rechargeable batteries that can be used repeatedly. Types include lead-acid batteries, nickel-cadmium (Ni-Cd) batteries, nickel-metal hydride (Ni-MH) batteries, lithium-ion batteries, and lithium polymer batteries. Since the electrolyte of lithium polymer batteries is made in solid or gel form, even if the battery is damaged in an accident that may occur, the electrolyte does not leak out, so there is almost no risk of explosion or ignition, ensuring safety.

3) Regenerative braking system

Regenerative braking system is a system that recharges kinetic energy consumed by friction through braking into electric energy, thereby increasing the driving distance and reducing the rotational speed. Regenerative braking system refers to a method of applying braking force by converting frictional kinetic energy generated when a running vehicle slows down into electric energy from a generator mounted on the wheels and recovering power.

In electric vehicles that use electric motor power units, the driving motor can be used as a generator in reverse when the brake is applied, converting the frictional kinetic energy lost when the car decelerates into electric energy, and storing this converted electric energy in the car's battery pack.

An electric motor is a device that converts electric energy into rotational kinetic energy by using the power generated when current flows in a magnetic field. In the regenerative braking section where electricity is not used, it operates as a generator, which is the opposite function of an electric motor. When braking, rotational friction is used as braking force, and the remaining rotational kinetic energy is converted into electric energy to recover energy. When a car runs on a road, it accelerates and decelerates, so kinetic energy changes, and when it goes up a hill, potential energy changes. When you step on the brake, the drive motor changes to a generator, which in turn charges the battery, which increases driving efficiency, especially in urban areas where there are many braking cycles.

2.3 Characteristics of electric vehicle fires

Among the types of electric vehicles, let's look at the characteristics of fires in pure electric vehicles, excluding fires in the internal combustion engines of hybrid vehicles. Electric vehicles have a relatively high rate of fires caused by electrical causes. In addition to mechanical causes, there is a possibility that a fire caused by a high-voltage battery malfunction may lead to an explosion of a part of the vehicle, and we must also pay attention to the possibility that a fire may occur after a certain period of time has passed after the fire has been extinguished or after an accident.

According to overseas media, BYD, a representative brand, accounts for the largest number of electric vehicle fire accidents occurring in China, which sells the most electric vehicles in the world[6]. However, as can be seen in Fig. 2, other brands also account for a portion of the 2022 Chinese electric vehicle fire statistics.

Chinese media reported that there were only 86 electric vehicle fires in the past two years, which is an average of one accident per week. However, according to data recently released by the Chinese Ministry of Emergency Management, there were 640 electric vehicle fires in the first quarter of 2022, a 32% increase from the previous year, and an average of more than seven fires per day. The 86 fire accidents reported by Chinese media can be divided into the following four types: 1) Parking fire 2) Charging fire 3) Driving fire 4) Collision fire

If we break down these four types of fire accidents, excluding seven cases of unknown causes, there were 31 cases while parking, 22 cases while charging (including fires in charging areas or charging facilities), 20 cases while driving, and 6 cases after collisions. According to Chinese media, 38.5% of fire accidents occurred when static electricity was generated, and 27.5% of fire accidents occurred when the device was charging.

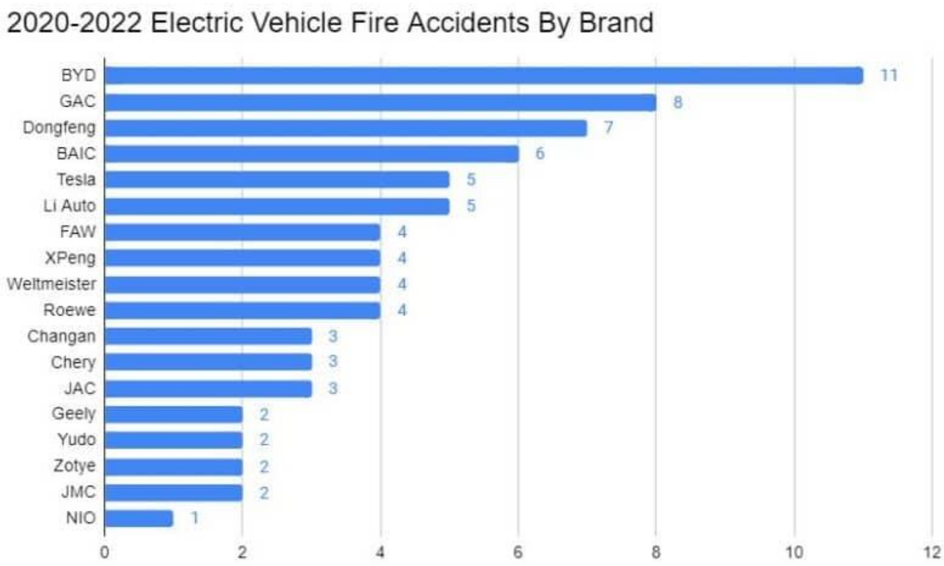

Figure 2 China electric car fire accident

1) Fire during charging in Dongguan City, China

On May 8, 2020, at around 2:23 PM, a fire broke out in a vehicle being charged at a charging station in Dongguan City, China. Five vehicles were damaged in an area of about 30㎡, and four of them were severely burned, but there were no casualties (see <Fig. 3>).

Figure 3 Fire during charging at charging facility in Dongguan, China

The vehicle in question was a small passenger vehicle. While charging, smoke and noise were emitted from the bottom of the vehicle. In particular, a loud noise was heard and the battery exploded. Eight fire trucks and about 40 firefighters were dispatched to extinguish the fire.

As a result of this fire, 48 charging stations in China were closed and measures were taken, such as investigating the cause, conducting self-inspections, and presenting corrective action requirements. According to an investigation by relevant organizations, it was found that the charging station used transformers exceeding the capacity required.

2) Garage fire in Virginia, USA

Fig. 4 shows a fire that broke out in a garage in Ashburn, Virginia, on May 6, 2021. Five adults and two children were displaced by the fire, and property damage of approximately 300 million won, including 100 million won in vehicle damage, was incurred.

The vehicle was an electric vehicle of GM Chevrolet Bolt, and the exact model year has not been disclosed. However, Chevrolet stated that certain Chevrolet Bolt EV vehicles from the 2017 to 2019 model years have a safety-related defect, stating that "there is a risk of fire when fully charged or nearly full."

Following this incident, GM announced a recall of nearly 69,000 Bolts worldwide in November 2021, and U.S. safety regulators said that vehicles should be parked outdoors until the recall repairs are completed[7].

Figure 4 Garage fire in Virginia, USA

3) Danigo EV Van Fire in Dongrae-gu, Busan, South Korea

This is a fire in which an electric vehicle (Danigo EV Van/produced in 2021) parked in the parking lot of a ground-level electric vehicle charging station behind an apartment in 2022 experienced a thermal runaway phenomenon for an unknown reason after charging and then spreading to surrounding vehicles. Busan Geumjeong Fire Station received a report from a witness who saw smoke and flames along with a 'bang' explosion from the vehicle, and immediately dispatched 22 fire trucks and 69 firefighters to the scene. Upon arrival, the fire was spread to 5 vehicles, and was extinguished with foam waterproofing and a large amount of fire extinguishing water (see <Fig. 5>). Based on the analysis of the black boxes of surrounding vehicles and the apartment CCTV footage, the fire authorities presumed that the initial ignition point was the battery pack under the vehicle, as flames were first observed at the bottom of the vehicle, then rapidly spread to the left and right, and the flames were observed to be partially open on the driver's side[8].

Figure 5 Appearance of Danigo EV fire in Busan after ignition and complete extinguishment

According to the National Fire Agency statistics since 2017, the fire occurrence rate of electric vehicles is not particularly high compared to that of internal combustion engine vehicles. However, when an electric vehicle catches fire, there are several characteristics that are different from the fire behavior of internal combustion engine vehicles. This chapter emphasizes the risk characteristics that appear in a fire of a battery pack installed as fuel in an electric vehicle. In 2011, the National Highway Traffic Safety Administration conducted an ignition experiment due to a battery impact on a Chevrolet Volt electric vehicle [7]. The Chevrolet Volt electric vehicle was ignited by impacting its side, and five vehicles were fixed in a row at 1 meter intervals to test the possibility of a chain reaction caused by the ignited vehicle. In this experiment, the vehicle ignited the battery due to the impact, and the ignition of the battery caused a thermal runaway phenomenon and high heat, which caused a chain reaction due to radiated heat and ignition heat to surrounding vehicles. The results of this experiment suggest that the spread of radiant heat caused by an electric vehicle fire in a charging facility installed in an underground parking lot or before or after charging suggests that, from a firefighting perspective, if the initial fire is not extinguished, it is difficult to access the underground parking lot due to toxic gases and high flame temperatures, making it difficult to extinguish the fire and allowing it to last for a long time[8,9].

3. PROBLEMS WITH ELECTRIC VEHICLE CHARGING FACILITIES

3.1 Types and characteristics of electric vehicle charging facilities

The types of chargers for electric vehicles can be largely divided into rapid charging, slow charging, battery replacement, and non-contact charging. Rapid chargers must supply a large amount of power, so they charge using 3-phase AC 380V, and their capacity is 50kW or more. It takes about 30 minutes to charge from a complete discharge to 80%, and they are installed in rest areas or public institutions. Recently, there are also ultra-fast chargers, and there are facilities that can charge in about 20 minutes at 300kW or 350kW. Slow chargers charge using single-phase AC 220V, require about 4-5 hours of charging time based on 6-7kW, and are installed in houses or apartments. In addition, the battery replacement method is a method of replacing the electric vehicle battery as a whole, similar to the method of replacing a cell phone battery in the past. The Chinese electric vehicle company Nio's swappable battery strategy is representative. Lastly, the non-contact method charges by using the magnetic induction power generated by burying the magnetic material and power line together on the floor surface. Research is currently being conducted to increase efficiency and output[10].

In the event of a fire during charging of an electric vehicle, the fire may spread to the electric vehicle battery, causing thermal runaway, which may result in a very serious explosion. Therefore, it is very important to prevent the battery pack from overheating in order to respond to fire accidents at electric vehicle charging facilities. However, due to the lack of regulations on fire accident prevention in charging areas or regulations on the installation of fire extinguishing facilities, most cases do not even have basic fire extinguishing facilities for emergency measures.

3.2 Electric Vehicle Charging Station Installation Standards

Electric vehicle charging facilities consist of power supply equipment, chargers, interfaces, and charging information systems, and in general, the concept of charging facilities is limited to chargers. In this study, the installation standards for electric vehicle charging stations stipulated in the Enforcement Decree of the Act on Promotion of Development and Distribution of Environmentally Friendly Automobiles (abbreviated as the Environmentally Friendly Automobile Act) and the types of charging facilities are limited to slow chargers (facilities) and rapid chargers (facilities).

According to the Eco-friendly Automobile Act, owners or managers of public buildings, public housing, etc. must install eco-friendly automobile charging facilities appropriate for the target facility, taking into account the current status of electric vehicle distribution, distribution plans, operation status, and road conditions[8].

Looking at the main provisions, Article 11-2, Paragraph 1 of the Act on the Promotion of Development and Distribution of Eco-friendly Automobiles stipulates the relevant facilities that must install eco-friendly automobile charging facilities and exclusive parking areas.

1. It lists 15 facilities as public buildings and public facilities, as defined by the Enforcement Decree of the Building Act as types of buildings by purpose.

2. Apartment complexes with 100 or more households, including dormitories, are designated as such facilities.

3. Parking lots installed by local government heads.

4. Other buildings, facilities, and auxiliary facilities that need to be installed for the distribution of eco-friendly automobiles.

Next, Article ② stipulates that a dedicated parking area must be installed in the facility specified in Article 1 and that an environmentally friendly automobile charging facility must be installed in the dedicated parking area according to the standards set forth in the Enforcement Decree of the Environmentally Friendly Automobile Act.

In addition, Article 8-7, Paragraph 1 of the Enforcement Decree of the Act on Promotion of Development and Distribution of Environmentally Friendly Automobiles stipulates that environmentally friendly automobile charging facilities are facilities that charge the drive batteries of electric vehicles or externally rechargeable hybrid vehicles (hybrid vehicles that can be driven by electric energy charged from an external power source; hereinafter the same shall apply) by supplying current through a cable connected to the charger, and must be facilities whose structure and performance are suitable for the standards of the public notice established by the Minister of Trade, Industry and Energy, and their types are as follows:

1. Rapid charging facility: A facility with a maximum output of a charger of 40 kW or more, which charges using 3-phase AC 380 V.

2. Slow charging facility: A facility with a maximum output of a charger of less than 40 kW, which charges using 220 V single-phase AC.

3.3 Types of electric vehicle charging facilities

1) Classification by installation type

For the installation type, most are wall-mounted or stand-alone for apartment complexes, and there are also portable chargers for small-scale apartment complexes or private residences. The installation types of electric vehicle chargers are shown in Table 1.

Table 1 Installation Types of Electric Vehicle Chargers

Div	Wall Charger	Stand Type Charger	Portable Charger
Vol.	3~7kW	3~7kW	3kW
Charging time	About 4~6 hours	About 4~6 hours	About 6~9 hours
Characteristic	- Install a fountain box and foundation pad - If the location is outside and exposed to snow or rain, install a canopy - U-shaped bollard, vehicle stopper, lane marking ☞ Can be installed depending on conditions		- Charge by attaching the RFID tag to an outlet of 220V 10A or higher - Charging is also possible at other outlets with attached tags
사진			 

2) Types of charging facilities by manufacturer

A. Signet Charger [SC7K-F-WT-G2 (SK Signet 7kW)]

The product's operating status and charging information are displayed through the front LED of the product, and the charging time is 6 to 7 hours on average for 80% charging. The protection grade is IP44, which means it is a 4th grade waterproof grade that protects against solid objects the size of a thin wire (1mm or more) and liquids sprayed from 360 degrees. Table 2 shows the product types of Signet chargers.

Table 2 Product types of signet chargers

Div	Contents
Size(mm)	283(W)×306.5(H)×118.5(D)
AC Input	Single phase AC 220V(±10%), 60Hz
Output	Single phase AC 220V(±10%), 32A, 7kW
Charging type	Format: IEC611851-1, Type: C / 5m, Connector: SAEJ1772(5Pin)
Protection class	IP44
Protective features	Internal overtemperature, output protection, overvoltage/undervoltage, leakage current protection

B. Central Control (JC-6511JA-B-C-R1)

The central control charger can be installed as a wall-mounted or dedicated stand type, and has an IP54 protection rating, which means it has a dustproof rating of level 5 (protection against dust without causing damage to the internal structure) and a waterproof rating of level 4 (protection against liquid sprayed from 360 degrees). The product types of the central control charger are shown in Table 3.

Table 3 Product types of central control chargers

Div	Contents
Size(mm)	353(W)×337(H)×146(D)
AC Input	Single phase AC 220V(±10%), 60Hz(±1%), MAX 7kVA

Output	Single phase AC 220V, 32A, 7kW
Charging type	Type: B or C(Alter Type) / 5m
Protection class	IP54
Protective features	Over temperature protection, over voltage/over current protection, leakage current
	

C. Clean Ilex

Clean Ilex has a charging time of about 4 hours based on a 28kWh battery, which is shorter than other chargers. The charger is also ultra-small, smaller than an A4 sheet of paper, and Clean Ilex is currently starting construction under an agreement with LH to build a smart charging station for apartment complexes. The product format of Clean Ilex chargers is shown in Table 4.

Table 4 Product type of Clean Alex charger

Div	Contents
Size(㎜)	175(W)×250(H)×92(D)
AC Input	Single phase AC 220V, 60㎐
Output	Single phase AC 220V, 32A, 7kW
Charging type	Type: B or C / 5m, 10m
Protection class	IP44
Protective features	Over temperature protection, over voltage/over current protection, leakage current

4. ELECTRIC VEHICLE CHARGING FACILITY FIRE RESPONSE PLAN

4.1 Need for extinguishing agents and extinguishing systems

We aim to find out whether fire extinguishing agents applicable to electric vehicle fires and cooling extinguishing methods, suffocation extinguishing methods, and removal extinguishing methods can be adapted to electric vehicle battery fires.

4.1.1 Types and performance of extinguishing agents

General extinguishing methods for electric vehicles include physical extinguishing (cooling, suffocation, removal) and chemical extinguishing (subcatalyst). The most representative fire related to charging facilities in electric vehicle fires is a fire caused by an abnormal reaction of the battery. Therefore, we need to examine the fire adaptability of lithium-ion batteries and confirm what type of battery has effective performance.

First, lithium-ion batteries are largely composed of four parts: anode, cathode, electrolyte, and separator [9]. Specifically, the cathode is composed of lithium (Li) and oxygen (O) to form lithium oxide, which determines the capacity and average voltage of the battery. There are various materials for the cathode, but the most commonly used material recently is natural graphite. Graphite has a structure similar to multiple layers of paper, which is called a layered structure, and it stores lithium ions from the cathode between the layered structures and then sends them back to the cathode, allowing current to flow through the external circuit. The electrolyte is a medium that helps ions move smoothly, and the separator prevents the positive and negative electrodes from coming into contact inside the battery.

Some fire extinguishing agent manufacturers claim that since lithium, one of the main components of lithium-ion batteries, is a metal, fires can be extinguished with impregnating fire extinguishing agents or Class D fire extinguishers that are suitable for metal fires, but this is not true.

Of course, impregnating fire extinguishing agents (liquid) can be used by mixing 1% impregnating agents for Class A to C and 3% impregnating agents for Class D in water, and they can exert a cooling effect when they come into contact with metal fires. Class D fire extinguishers are also used to extinguish fires involving hydrophobic metals (which generate highly explosive hydrogen when they come into contact with water or moisture in the air). However, there is one thing that is overlooked here. The battery packs used in electric vehicles are covered with a cover that thoroughly protects them from fire and explosion, so the extinguishing agent does not flow into the battery pack, and thus has no extinguishing effect. Class D fire extinguishers should extinguish the fire by coating the contents with the extinguishing agent, but the battery pack has no extinguishing effect because the structure is sealed with impact-protecting metal on the outside. The chemical reaction inside the battery pack continues to progress.

4.1.2 Applicable extinguishing systems for electric vehicle fires

Generally, for internal combustion engine vehicle fires, you can use extinguishing methods equivalent to Class A fires or select extinguishing methods that can respond to Class B fires. However, for electric vehicle fire accidents, Class A fire extinguishing methods can only be used for combustion of combustibles in electrical devices or automobile interiors, not high-voltage battery pack fires, and Class B fire extinguishing methods will not be considered at all for electric vehicle fire accidents.

1) Cooling extinguishing method

A representative method for extinguishing electric vehicle fires, and among the methods studied so far, the most effective method is the water tank method that stabilizes the battery by submerging it. In general, it is known that firefighters can extinguish electric vehicle fires by maintaining a distance of 10 to 30 m in case of explosion of the vehicle, using an upward nozzle, etc. to extinguish the fire and lower the internal temperature of the battery pack to 80 degrees. However, according to guidelines published in the United States, more than 100,000 liters of extinguishing water are required to extinguish one electric vehicle. This is more than 10 times the amount required for a fire in an internal combustion engine vehicle.

In conclusion, it is certain that the cooling extinguishing method using water is the most effective and final extinguishing method, but the success or failure of extinguishing the fire can be determined depending on how the high-voltage battery pack of the electric vehicle can be cooled.

2) Suffocation extinguishing method

As previously studied, it can be said that Class D extinguishing agents are applicable to metal fires, but in reality, it was concluded that Class D extinguishing agents cannot effectively extinguish fires in electric vehicle high-voltage battery packs, especially when thermal runaway occurs. As a second reasonable alternative to electric vehicle fire suppression methods, suffocation extinguishing foam can be used by the first fire brigade to prevent combustion in the early stages of a fire, but in terms of effectiveness, it can be a general alternative that can delay the spread of a fire or extinguish it in the early stages in apartment management offices. Even ordinary people who have not received professional fire suppression training can use it easily with a little training on how to use it or how to deploy it, and the author argues that it is a fire extinguishing facility that must be equipped in electric vehicle charging facilities because it is very effective in preventing combustion in the early stages of a fire.

3) Removal extinguishing method

The removal extinguishing method is a little different from the extinguishing method examined above. It is a method of moving to ensure safety from the risk of re-ignition before full combustion occurs in the electric vehicle battery or when all combustion is finished.

This extinguishing method can only be considered when an electric vehicle fire is in its initial stage or when there is a risk of combustion in the surrounding area, and when conditions for movement are sufficient, so there may be significant restrictions on using it.

4.1.3 Electric Vehicle Fire Response Procedures (NFPA)

The NFPA Emergency Field Guide [11] is intended for emergency use at electric vehicle fire scenes and for educational and research purposes. It describes general procedures for initial response to electric vehicle crashes, fires, floods, and hazardous materials spills. The general procedure is divided into the stages of initial response, rescue, and fire suppression.

The initial stage focuses on securing and stabilizing the vehicle. Approach the vehicle at a 45-degree angle to stabilize the vehicle and stay away from the vehicle in case of sudden movement.

During the rescue stage, emergency responders should check high-voltage cables and components in preparation for activation of the high-voltage system and should not cut high-voltage cables.

In addition, the rescued person should be protected because the airbag may activate even if the high-voltage system is shut off. If the high-voltage battery is damaged, emergency responders should wear personal protective equipment and air-breathing equipment, and be careful of sparks, smoke, or bubbling noises from the battery, as these indicate a potential fire hazard due to battery overheating. Even if the manual service disconnect device (MSD) is removed, the high-voltage battery will not be discharged, so avoid contact with the battery to prevent shock due to electric shock.

During the fire suppression phase, all firefighters must wear personal protective equipment and air breathing apparatus. The difficulty of extinguishing a high-voltage battery fire is determined by the size and location of the battery, the size of the fire inside the battery pack, and the availability of extinguishing water.

High-voltage batteries are difficult to extinguish because they are protected by a case. To prevent the fire from spreading to adjacent cells, a large amount of water must be poured to cool the battery pack.

If the battery pack is opened, water or an applicable agent must be poured directly into the battery pack. If water is used, 2,600 gallons (approximately 10,000 liters) or more is required, so it must be continuously supplied from a fire hydrant or pond. A quick way to extinguish a fire is to pour water into the battery pack over a long period of time.

The NFPA Emergency Field Guide has detailed guides for 43 manufacturers and 195 electric vehicle models. The guides were developed in collaboration with the manufacturers and can be downloaded from the NFPA website. The guides provide diagrams and photos of the locations of high-voltage parts, airbags, and 12-volt systems in electric vehicles.

4. CONCLUSIONS

charging, in Korea, there are very few laws that consider fire risks in charging areas or regulations that can bind safety standards to installers. In addition, as the spread of electric vehicles increases, related regulations and installation of charging facilities are increasing, but fire safety standards in underground parking lots of apartment complexes are still inadequate.

In particular, in the case of electric vehicles, there is always a risk of fire accidents due to external impacts such as traffic accidents while driving, but more often than not, fire accidents are reported due to overcharging or overdischarging caused by charging equipment or thermal runaway caused by abnormal reactions of battery packs while parked. Therefore, installing charging facilities in an external safe area is the best safety measure, but in the case of most apartment complexes, they are installed in underground parking lots, raising concerns about the risk.

Therefore, this study analyzed electric vehicle fire cases and the characteristics of electric vehicle fires and reached the following conclusions regarding fire response measures in electric vehicle charging facilities.

First, as a management measure, it was suggested to install a dedicated CCTV for the charging area. By installing a dedicated CCTV, it was suggested to prepare for risks that may occur during 24-hour charging and to immediately notify the manager with an emergency alarm sound in the event of smoke or flames in the charging area.

Second, as a facility measure, it was suggested to install a separate ventilation facility in the charging area. It was clearly suggested to increase the evacuation time (ASET) by installing a smoke exhaust facility or allowing forced exhaust regardless of the charging area.

Third, as a firefighting activity measure, it was suggested to install a fire extinguishing agent. In particular, in the case of new construction, it was suggested to install a designated quantity of extinguishing agents so that they can be used by the company in the event of an initial fire or provided to the fire brigade to quickly support firefighting activities.

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