V2X typical scenarios and optimization system analysis

Zihan Meng *

Shenzhen Foreign Languages School, Shenzhen City, 518000, China

* Corresponding author: zongyikun@ldy.edu.rs

Abstract. With the aggravation of global environmental problems and the growing concern for sustainable development, the electric vehicle industry is rapidly emerging as an important part of the transportation and energy sectors. By systematically analyzing the background of the invention of electric vehicles, their technological development, and their impact on the environment, this paper explores the working principle of electric vehicles, their positive impact on the environment, and the multiple uses of batteries. It is found that electric vehicles not only excel in reducing carbon emissions and energy consumption but also demonstrate their great potential in energy management through technologies such as vehicle-to-grid interaction (V2G) and vehicle-to-load (V2L). With the continuous advancement of technology, EVs will play a more important role in future green transportation and smart energy systems. This study provides theoretical support for the further development of electric vehicles and also calls for joint efforts to promote the sustainable development of this industry.

Keywords: Electric vehicle, vehicle-network interaction, typical scenario, optimization scheme.

1. Introduction

The invention of the first electric vehicle is attributed to many people. In 1834, Professor Sibrandus Stratingh of Groningen, the Netherlands, and his assistant Christopher Becker created a small-scale electrical car, powered by non-rechargeable primary cells [1]. As the world population grows and the environment changes, more and more people focus on environmental protection, therefore stimulating the development of the electric automobile industry [2]. In 2019, 4.8 million electric cars were in use, marking the rapid development of the electric vehicle industry [3]. Nowadays many famous electric vehicle companies like Tesla, BYD, Volkswagen Group, BMW, Mercedes-Benz, etc. are trying to increase the driving range for their electric vehicles by producing more and more advanced batteries. So, this study aims to make a comprehensive overview of how electric vehicles function, how they impact the environment, some usages for their batteries, and some future expectations.

This study aims to provide a comprehensive overview of the development of electric vehicles (EVs), focusing on the following aspects: first, analyzing the basic working principles of EVs and clarifying how their power systems operate; second, exploring the multiple uses of EV batteries; and third, looking ahead to the future direction of EV development and further exploring the potential of EV applications. Through an in-depth study of these issues, this paper hopes to provide a reference basis for the future development of the electric vehicle industry and further promote the understanding of the important role of electric vehicles in sustainable transportation and green energy transition.

2. Theoretical basis analysis

2.1. EV Charging

An electric vehicle charging station (EVCS) is an assembly designed to transfer electrical energy from a source to an EV. It involves interfaces, connectors, and cords. It involves interfaces, connectors, and cords. The charging process is divided into several steps, starting with the connection of an external power source to the EV through the interfaces in the charging station, and the transfer of electrical energy to the vehicle through connectors and cables. Typically, AC power is converted to DC power by an on-board charger (OBC), which adapts to the voltage and needs of the on-board battery. Meanwhile, the Battery Management System (BMS) monitors the state of charge of the battery in real-time to ensure that the charging voltage, temperature, and rate are maintained within safe limits to prevent overheating or overcharging, thus improving charging efficiency and battery life. Depending on the charging power, EV charging stations provide both alternating current charging (AC charging) and direct current fast charging (DC charging), the latter of which can significantly shorten the charging time and enhance the user's experience [4]. EVCS can be divided into mainly three kinds: inductive charging, conductive charging, and swapping.

2.1.1. Inductive charging

Inductive charging, also known as wireless charging, is a new type of charging based on the principle of electromagnetic induction. Its core working principle is to realize energy transfer by establishing a magnetic field between the transmitting coil of the charging station and the receiving coil of the vehicle. In this case, the transmitting coil is usually embedded on or below the floor of the charging station, and when the electric vehicle drives into the charging area, the receiving coil, located at the bottom of the vehicle, senses the electromagnetic field generated by the transmitting coil and converts it into electrical energy to charge the battery. Since inductive charging does not require physical contact, it has the advantage of making the charging process more convenient, reducing the wear and tear of conventional chargers, and in future applications, inductive charging has the potential to enable dynamic charging of EVs while driving [5]. However, inductive charging still faces the problem of low charging efficiency, and the technology needs to be further optimized.

2.1.2. Conductive charging

Unlike inductive charging, conductive charging is a traditional and more established charging technology that relies on physical contact between metal conductors to transfer electrical energy. When an electric vehicle enters a charging station, the driver connects the vehicle to the charging station via a charging connector, usually in the form of a plug and socket contact to achieve charging. The advantage of conductive charging is its efficient energy transfer, as the current is passed through a direct metal contact point, reducing energy loss. Conductive charging is faster than inductive charging, making it ideal for users who need to replenish their batteries quickly. However, conductive charging requires that the vehicle must remain stationary during the charging process, and in public environments, wear and tear on the metal contact points and cleaning and maintenance need to be prioritized.

2.1.3. Swapping the batteries

Battery replacement technology offers an innovative way of charging. Unlike traditional charging methods, battery replacement does not charge the vehicle through the transmission of electrical energy but rather directly replaces a depleted battery with an already fully charged one. This method relies on specialized battery replacement stations where automated equipment removes the old battery and installs a new one in a short period of time. The biggest advantage of battery swap technology is the speed of charging; by eliminating charging wait times, vehicles can be "recharged" within minutes, greatly improving the user experience, especially for long-distance driving or frequent use of the vehicle [6]. However, there are still challenges to the diffusion and adoption of battery replacement technologies, such as the need for standardized battery specifications and significant infrastructure investments.

2.2. Vehicle to everything (V2X)

The term Vehicle-to-everything (V2X) refers to the practice of utilizing the batteries of EVs to offer energy services and derive extra value from the battery asset during times when the EVs are not in use. V2X services are designed to generate profit from battery assets by implementing dynamic uni-directional or Bi-directional control charges. V2X not only allows EVs to draw power from the grid but also to feed the stored energy in the battery back into the grid at the right time or to power homes and communities. The core of this technology is to help balance the supply and demand pressures on the grid, especially during peak hours, by intelligently interacting with the grid system, thereby optimizing energy efficiency, reducing grid operating costs, and promoting the integrated application of renewable energy [7]. Through rational scheduling and management, V2X services can not only bring additional economic benefits to vehicle owners but also enhance the overall value of EVs to the power system, further promoting the deep integration and synergistic development of the energy and transportation sectors.

As the number of electric vehicles increases, the grid is under increasing pressure. Traditional grid design does not take into account such large-scale distributed power demand and supply. V2X technology, however, is able to connect thousands of electric vehicles through an intelligent regulation system to form a large distributed energy storage network, helping the grid manage energy distribution more efficiently. This two-way interactive mechanism not only improves the efficiency of energy use but also reduces the reliance on centralized power facilities, driving the energy system in a more sustainable and intelligent direction.

3. Electrical energy usages in EV

3.1. Vehicle Power to Heat

In electric vehicles, the application of technology that converts electrical energy into heat is critical for improving vehicle energy efficiency and passenger comfort. Traditionally, heating systems in electric vehicles are mainly realized through resistance heaters. The operating principle of resistance heaters is based on the heat generated by the passage of an electric current through a resistor, following the equation

$$Q=I^2RT \tag{1}$$

Where Q is the amount of heat produced, I am the current through the resistor, R is the resistance value, and T is the heating time. The resistance heater is capable of converting electrical energy directly into thermal energy and supplying heat to the interior space of the vehicle. The conversion efficiency of this system can be calculated by the formula

$$\eta=\dot{Q}/W \tag{2}$$

Where Q denotes the heat supplied and W denotes the electrical power consumed.

However, although it is quite easy to produce thermal energy directly using electrical energy, it is not efficient enough when compared to a heat pump. Heat pump systems heat the vehicle cabin by transferring heat from the outside environment, which is significantly more energy efficient when compared to a heat pump. Instead of generating heat directly, heat pump systems utilize a refrigerant that absorbs and transfers heat through compression and expansion. This transfer of heat allows the heat pump to produce more heat for the same amount of electricity, significantly improving energy efficiency.

Scherer et al. developed R134a and R152a heat pump systems with a 3-way valve to control the refrigerant flow during the cooling and heating mode switches. During the heating mode, the engine coolant was used as a heat source, which eliminates the ice on the exterior surface of the heat exchanger. His study showed that the system could supply more than 9.0 kW heat capacity under room temperature -10°C conditions. In the warm-up testing, the R134a and R152a heat pump systems shorten the warm-up time to the comfortable cabin temperature compared with the original heater core heating system [8].

Figure 1 below is a simple demonstration of the R134a heat pump system structure and operation for electric vehicles, which is composed of one four-way valve, two expansion valves, and several check valves to reverse the direction of the refrigerant flow [8]. This system can achieve the following four functions: cooling, heating, dehumidifying, and demisting.

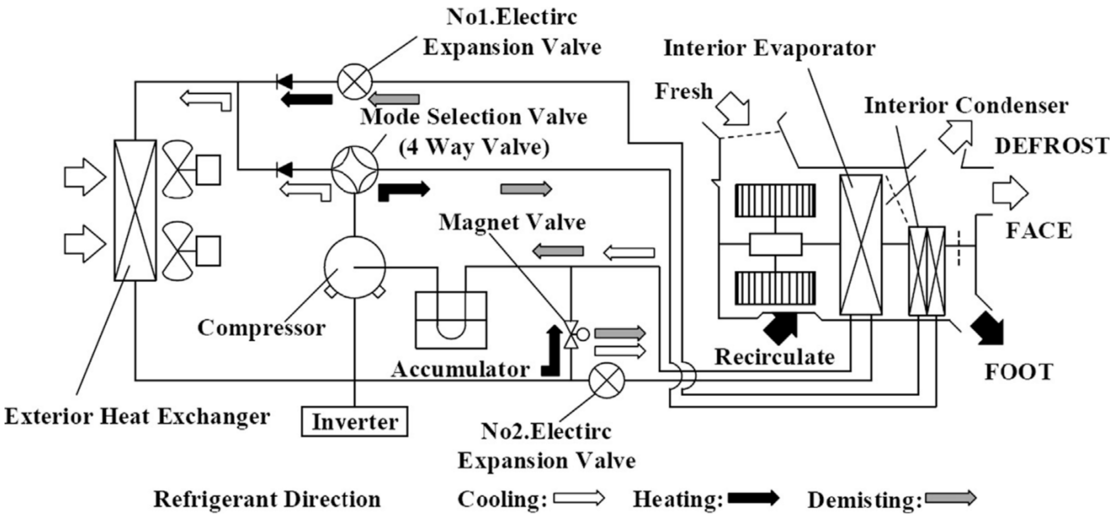

Figure 1. R134a heat pump system structure [8]

3.2. Vehicle Power to Cold

Refrigeration technology in electric vehicles is an important part of ensuring passenger comfort and keeping the interior temperature within a suitable range. Currently, both electric vehicles and Internal Combustion Engine Vehicles (ICEV) widely use a refrigeration system based on the Vapor Compression Cycle (VCC), which consists of a refrigerant, a compressor, a condenser, etc. It has a coefficient of performance (COP) ranging from 3.0 to 5.0, which is way better than adsorption cooling system (ACS), which COP is between 0.4 to 0.7, meaning that ACS cools down the air in the cabin slower than the vapor way do in a specific amount of space. However, ACS has now become the focus of the development for the cool-down technology in EVs, due to their characteristics of using much less electrical energy to decrease the cabins' temperature than a traditional compressor-driven AC system [9].

The unique advantage of adsorption cooling systems is that they utilize waste heat generated during the operation of electric vehicles, such as the operating heat of batteries, electric motors, and power electronics, rather than relying on conventional compressor-driven air conditioning systems. This approach significantly reduces the reliance on electrical energy for the cooling process of electric vehicles and improves the overall energy efficiency of the vehicle. At its core, adsorption refrigeration technology utilizes waste heat to drive the refrigeration cycle, thereby avoiding the need for energy-intensive compressor operation. This feature makes the application of adsorption refrigeration systems in electric vehicles very promising, especially in the pursuit of green, energy-saving transportation trends, adsorption refrigeration technology is expected to become a mainstream refrigeration solution [10]. Figure 2 below shows how an absorption chiller works, which is a kind of ACS.

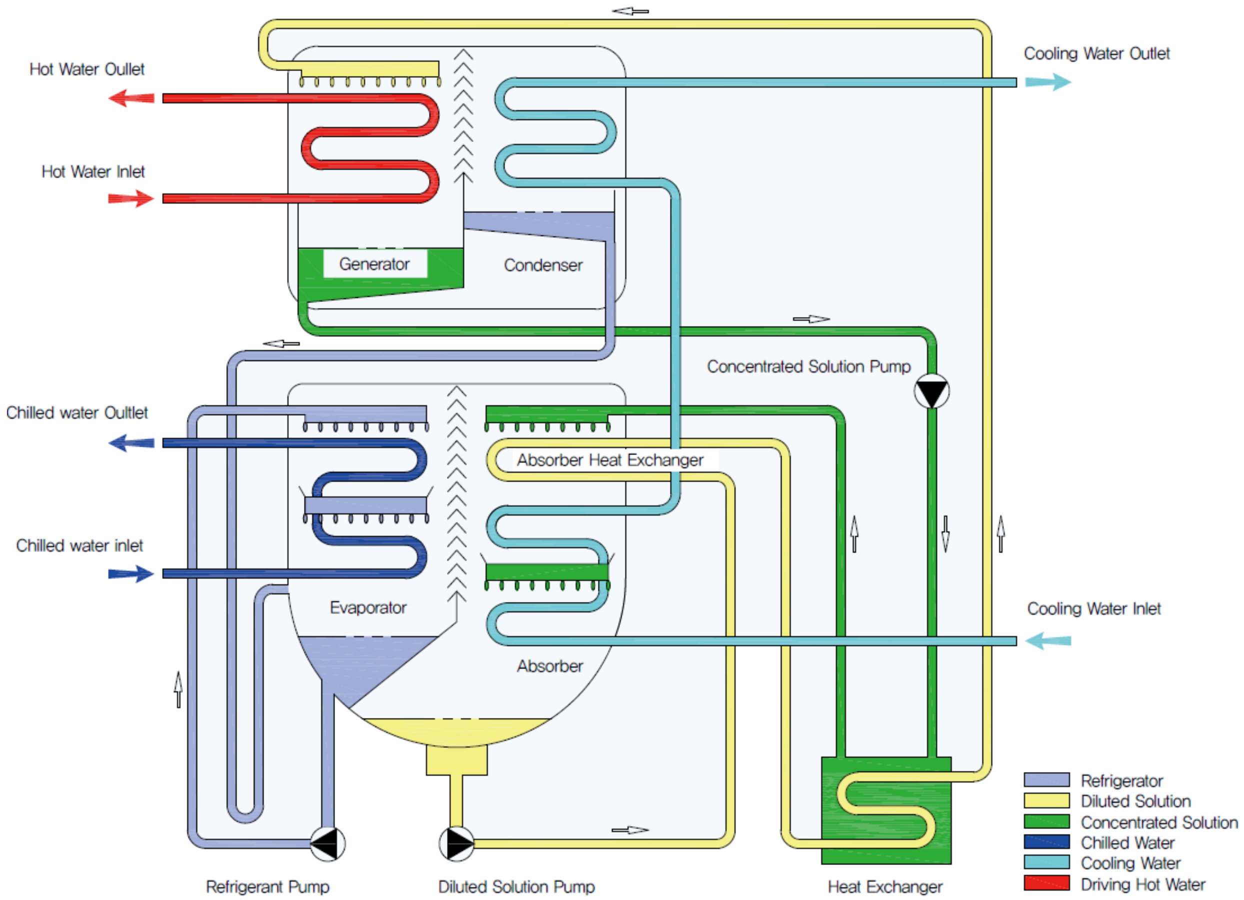

Figure 2. Absorption chiller works [11]

In an absorption chiller, a mixture of 50% lithium bromide and 40% water is pumped to the generator, where heat separates the water as vapor from the lithium bromide. The vapor rises to the condenser and condenses into liquid water, which then flows to the evaporator. In the evaporator, water evaporates due to low pressure, cooling to about 4°C (40°F). This "chilled water" absorbs heat from the building and cools down by transferring heat to the condenser water, which evaporates due to the low pressure. The water vapor is attracted to the lithium bromide in the absorber, creating a vacuum. Cooling tower water in the absorber helps condense the vapor back into liquid, which is then pumped back to the generator to repeat the cycle [11].

Adsorption refrigeration systems offer significant energy savings compared to traditional vapor compression refrigeration systems. Although its coefficient of performance (COP) is relatively low, the system has great potential to reduce vehicle energy consumption and extend range because it relies primarily on waste heat rather than electricity. In addition, as electric vehicle technology continues to evolve, adsorption cooling technology will further enhance its performance through the application of new materials and optimized system design. Particularly in hotter climates, adsorption cooling technology can effectively reduce electric power consumption in the summer cooling demand of electric vehicles, thus improving the overall energy efficiency of electric vehicles.

3.3. Vehicle to load (V2L)

Vehicle-to-load (V2L) technology is an important innovation that allows electric vehicles to provide electrical support to critical loads in emergency situations, especially when the power grid is disrupted by natural disasters or other causes. In any power system, critical loads such as those in hospitals, fire stations, and data centers are of great importance. A failure of power supply to these loads could result in significant financial losses for the government [12]. V2L are primarily used for emergency backups, that is, when the main grid is down for some reasons, like typhoons, earthquakes, and tsunamis. The best advantage of V2L for consumers is that it can be used as a moving camp.

Take Hyundai as an example, a V2L connector accessory is required, which connects to the vehicle’s charge port. Users must first set the battery discharge limit via the vehicle’s touchscreen interface, which allows up to 80% of the high-voltage battery capacity to be used. Once the discharge limit is set, the V2L accessory can then be connected to power external devices, such as computers, electric cookers, phones, etc.

The biggest advantage of V2L technology is its flexibility and convenience. Compared to traditional emergency power equipment, V2L does not require an additional generator or backup power source, and can simply utilize the electric vehicle itself to provide power support for various loads. In addition, the V2L can intelligently adjust the amount of discharge through the vehicle's battery management system, ensuring that the battery's stored energy is fully utilized in times of emergency without affecting the normal use of the vehicle. With the popularization of electric vehicles, V2L technology is expected to become the mainstream choice for emergency backup power supply, especially in areas prone to natural disasters, V2L will become an effective solution to ensure continuous power supply for critical loads.

3.4. Vehicle to Grid (V2G)

Bi-directional V2X transfers electrical energy between the grid and the electric vehicles. When the electric vehicles are being charged, the AC to DC converter acts as a rectifier, which changes the alternating current from the grid to direct current for the batteries in the electric vehicles. When electric vehicles are being charged, the DC to AC converter acts as an inverter, which changes the direct current from the batteries to alternating current [13].

V2G technology has a wide range of applications in grid management, especially during peak demand hours. Through V2G, EVs can participate in the "peak-shaving" power regulation strategy, i.e., to help reduce the pressure on the grid by returning power to the grid during peak demand hours, and to fill in the gaps in demand by recharging from the grid during low-demand hours. This not only improves the stability of the grid but also provides additional economic benefits to EV users. In addition, V2G can provide other additional services such as active power regulation, reactive power support, frequency and voltage regulation, and other ancillary services. These services are crucial to the smooth operation of the grid, especially in the context of the gradually increasing proportion of renewable energy sources, and V2G technology can help the grid better cope with changes in the supply of fluctuating energy sources such as wind and solar.

Through V2G technology, electric vehicles, and the grid form an interdependent and interactive energy ecosystem. As the number of electric vehicles increases, the potential of V2G technology will be further realized. A large-scale group of electric vehicles can be used as a distributed energy storage system to provide a large amount of backup power for the grid. This new energy management model can not only improve the energy utilization efficiency of the grid but also play an important role in the future smart grid.

4. Challenges and Optimized Analysis

4.1. Challenges

Although the electric vehicle industry is growing rapidly, it still faces many challenges in the process of market expansion and full-scale promotion. First, when considered from an Economic point of view, it is clear to see the effects of ordinary people using electric vehicles. That is, the demand for electricity increases; as a result, its substitute, the demand for oil will decrease, which the oil company will not want to see and will do everything they can to prevent the rise of the EV industry.

Second, when considering the producing firms' point of view, it can be seen that the risks they need to take are enormous. From the high cost of building charging stations, around fifty thousand us dollars each to unpredicted social changes, like new innovations or changes in people's expectations [14].

4.2. Optimized Analyze

Despite the many challenges facing the electric vehicle industry, many of these problems can be effectively solved by optimizing strategies. First, governments can adopt more proactive policy support measures to promote the development of the electric vehicle industry. The government can reduce the cost pressure on manufacturers and consumers by providing subsidies, and tax breaks, and establishing a charging infrastructure construction fund. Encourage companies to make sustained investments in technological innovation, charging network expansion, and user service experience enhancement to ensure that the electric vehicle industry can maintain its leading position in the future competitive environment.

From the perspective of technological innovation, companies can improve the energy efficiency and user experience of electric vehicles by increasing R&D investment. The development of more efficient and longer-lasting battery technologies can significantly extend the range of vehicles, thereby reducing users' charging anxiety. Intelligent management and optimized layout of charging infrastructure can also further improve the utilization rate and service level of charging stations. Through big data and artificial intelligence technologies, charging stations can be intelligently dispatched according to user demand and power supply and demand, realizing efficient energy management and resource allocation, thus reducing overall construction and operation costs [15].

Market education is also crucial, as is the enhancement of consumer awareness. EV companies need to strengthen their communication with consumers and enhance public awareness of the environmental and economic benefits of EVs by promoting their advantages. By organizing test-driving activities, providing long-term after-sales service guarantees, and promoting the convenience of charging networks, companies can gradually dispel consumers' concerns about the use of electric vehicles and enhance their market acceptance.

5. Conclusion

Electric vehicles are not only green vehicles, but also a flexible energy management device, and the two-way energy transfer (V2X) technology of electric vehicles further expands their applications in the energy system. The electrical energy stored in the electric vehicle can be used for heating, cooling, supporting the main grid, and charging individuals' electronic devices. This versatility allows electric vehicles to play a more important role in the overall energy system than just transportation.

Despite the enormous technological potential of electric vehicles, there are still a number of barriers to their marketing and large-scale adoption. The rise of the electrical vehicle industry is a collaborative effort that requires governments to implement relevant policies, and firms to increase their investment in foundational equipment and each individual's supports.

If can work together to advance the electric vehicle industry in the future, the world will be a cleaner, healthier place and closer to realizing the goal of sustainable development. With continued technological advances and policy support, electric vehicles are expected to become an important part of the transformation of the global energy mix, creating a greener, low-carbon, and sustainable future.

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