A New Design of Battery Swapping Station

Shangchen Wu
2-1303, 8 Huayuanlu Road, Haidian, Beijing, China

E-mail: tougao20210125@163.com

Abstract. Electric vehicles have developed rapidly in recent years, and have made tremendous contributions to energy conservation, emission reduction, and green travel. However, the long charging time limits the further promotion of electric vehicles. Based on the idea of power exchange instead of charging, this paper puts forward the design plan of the power station and the battery design program suitable for the power exchange mode. A verification analysis was conducted.

1. Introduction
With deterioration of global environment and over-extraction of crude oil and ceaseless air pollutions, petroleum cars will face dilemma of no fuel to burn in near future. Calculation according to relevant data reveals that total explored crude oil can sustain exploitation for only 20 years. In order to avoid exhausting of fossil fuels, electric vehicles seem to be the sole solution to the problem.

Propelled by the development of battery technology, a boom of EVs occurs at the end of the 20th century and the beginning of 21st century. In the year of 1996, the first generation of electric vehicles, “EV1”, was manufactured by General Motors. EV1 utilized lead-acid batteries for its electricity storage. Lead-acid batteries are widely used and manufactured, so it seemed a good idea to apply them to electric automobiles [1-3].

Figure 1.1 Petroleum vehicles’ high exhaust emission
Nonetheless, lead-acid batteries had some fatal disadvantages: although they are cheap to produce, their specific energy and power are extremely low; furthermore, repetition of the cycle of recharge and discharge can severely curtail their service lifespan, making lead-acid batteries an uneconomic choice. A fully-charged General Motors EV1 can only travel for 70 km on average, and this is far beyond the reach of conventional power vehicles. As expected, EV1 was withdrawn from the market due to its lack of competitiveness [4-6]. Meanwhile, using technology of Ni-MH battery, hybrid electric vehicles (HEVs, vehicle that utilizes both conventional power and electricity) manufactured by Toyota accumulated attention from the public because of its high driving mileage per charge and low displacement; therefore, Ni-MH batteries were considered by the mass public as the most suitable type of battery for EVs, which is somehow true: even for now, most of HEVs are still using Ni-MH batteries as their main energy source. Until 2006, the rapid popularization of Li-ion batteries give birth to the modern pure-EV industry—they are small in size, but contain tremendous amount of energy per volume, not to mention their long lifespan. With the vigorous development of battery technologies, follows the advance of EVs. A comparison of several types of battery is shown in the diagram below.

![Comparing different types of batteries](image_url)
As a conclusion from above, batteries are the most crucial part in an EV, and it is possible to say that development of battery determines development of EVs. After many years of development and advancing, the major problem perplexing EV industry nowadays is still on recharging batteries. As we know, the most popularized recharging method of EVs in 2021 are charging stands and charging stations. A regular Li-ion battery adopts a charging current of 10 amperes; with such current, almost 10 hours are needed to charge an empty battery to its full capacity [7]. A large number professional charging and power distributing equipment are needed for fast charge, so they are usually conducted in specialized charging stations; fast charge provides a current of 50-60 amperes, generating power approximately 10 times greater than a normal charging [8-10]. But even so, it takes approx. 2 hours to fully charge a battery; a fossil fuel car, in contrast, takes only 5 minutes to refill its gas tank. From this point, we can figure out a significant disadvantage of EVs, not to mention fast charging itself is somehow detrimental to battery’s lifespan. However, the debuting of battery swapping station can alleviate this major drawback in a great extent. Battery swap, as its name suggests, is the practice to directly swap a used-up battery to a fully-charged one; withdrawing the process of charging, there will be no need for customers to wait, the whole swapping process can be finished in about 5 minutes.

Battery swapping stations can serve a great purpose in both urban and non-urban areas (such as rest areas on highways). In urban area, battery swapping stations can serve as an alternative and substitution to regular charging station for customers having no access to private charging stands or for those who want to instantly recharge their automobile; besides, mass charging on power consumption peaks can overload the power grid, making it impracticable. Battery swapping stations, however, can keep replaced batteries in reserve, and charge them when power consumption is low. This plan can not only release burden for power grid, but also make profit considering price difference for peak and valley electricity. In non-urban areas, battery swapping stations act like the counterpart to gas station for petroleum vehicles, enabling drivers to instantly replace discharged batteries with a new one, and continue their trips. With the unification of battery technology, EV industry will also need to develop new types of replaceable battery in order to follow up the conveniences and benefits brought up by battery swapping mode.

Currently, the main difficulty on battery swapping stations is how to ensure old battery and replaced battery are consistent in condition. There are two solution to the problem, but each one is flawed, excluding them from the mainstream. The first solution is proposed by BJEV, aiming to ‘nationalize’ car batteries, i.e., all the batteries are owned by the company; with this solution, no matter how batteries are swapped and exchanged, the total battery possession of BJEV stays the same. The second way is proposed by Tesla Motors. Tesla considers battery swapping as an emergency service, similar to that of roadside assistance—after customer swapped to Tesla-owned battery, the customer’s battery is retrieved by Tesla. The customer can reclaim their old battery when they finished their trip. The main drawback of the first solution is customers tend to exchange for a newer battery, given that they are able to choose battery for swapping. Indeed, no one wants to use a scrapped old battery, but this will result in idle of old battery, expensing enormous storage and maintenance costs. Moreover, due to the high price of EV batteries, it is hard for a company to turn around batteries without support. For Tesla’s solution, it simply just avoided the main problem without giving a practical scheme to regulate batteries, so it is destined to be an emergency service.

For all deficiencies above, this paper takes a new approach by designing a new type of battery swapping station. Through underground storage and charging, this battery swapping station conserves precious urban land, curtailing land cost. By utilizing RFID (radio frequency identification) technology, it is able for batteries to have their own identity tags, recording their own information. A mathematical model will be used to calculate swapping fee for each exchange, making the valuation more humanize and avoid forementioned problems.
2. Results of the Research

2.1 Drawings and Models of Battery Swapping Facility

In the beginning, this paper utilizes SketchUp to model for the new generation battery swapping station. The idea of designing is to build a large basement under the main building, serving as a battery storage. The basement is divided into 3 parts: the storage area, the charging area and the swapping area. The storage area simply stores uncharged batteries; the charging area is where all the batteries get charged; and the swapping area is right beneath the overground swapping post, serving as a transformation zone for charged battery waiting to be installed on to users’ cars. Controls such as battery movement between areas are conducted by computers and manipulated by conveyors. Employees of the station can inspect working condition of swapping facilities and manipulate manually by using the stairs in office area.

Similar to those of an ordinary gas station, the drivers need to park their vehicles in certain area for the ease of battery swapping. When a vehicle is parked in the right place, an elevator will carry a fully-charged battery from underground swapping area to ground level swapping post; then, a pair of mechanical arms will do the job of detaching the old battery and install the new one. After their payment, the vehicles are able to drive away safe and sound. The empty battery will be carried down to basement by the same elevator, to the storage area and waiting to be charged. The model and drawings and other precise facilities of this battery swapping station are shown below.

![Figure 2.1 3D model of the battery swapping station](image1)

![Figure 2.2 Ground level of the station](image2)

![Figure 2.3 Underground level of the station](image3)
2.2 Design of New Batteries

By identifying data plate on batteries, this new generation of battery swapping station can read and rewrite data such as aggregate service hour and battery power percentage. With those data, computer can process and choose the best suitable battery for swapping, and by using the price function mentioned later in the paper, to calculate price of battery swapping. The data plate utilizes RFID technology to deal with reading and overwriting data. RFID is a specific type of wireless communication technology, used in wide range of applications and is capable to operate under most conditions, a very dependable technology. The carrier of information is a small electronic tag, a small and petite device implanted deep inside the core of battery set. Using electromagnetic waves, the RFID device can operate without human intervention and without contacting, similar to that of an IC card. Also, attributed to its simple structure and unbreakable nature, RFID devices can work in harsh environment, such as high-moisture, haze and dirt and other conditions. The whole RFID device is consisted of three parts: e-tags, a reader device and an application system (computer), as shown below.
In this program, the reader and its antenna can be implanted into mechanical arms used to assembly batteries, after detecting and receiving data from the data plates on batteries, readers will send those data right into the EV battery management system. By setting up this system, we can acquire any information of any particular battery through searching its serial number. Else than information of swapping, this EV battery management system can also record batteries’ service hours, fault record, customer comment and even further information, in order to evaluate their degree of safety and reliability, scrapping unqualified batteries in time, preventing danger and accidents at all cost.

Another problem faced by battery swapping station is that most EV batteries are undetachable; in order to make sure the practicability of battery swapping station, the paper conducted a survey on Tesla’s detachable battery design.

Firstly, as illustrated in the photo above, Tesla Model S has its battery panel directly installed on its chassis. The whole battery panel weighted more than 900 kilograms (in comparison to Model S’s total weight: 2100kg), consisting 40% mass overall.

![Figure 2.8 Overlook of Tesla Model S battery](image1)

In order to ensure batteries’ safety, eradicating possibility of burning and explosion, the whole battery panel is covered with fire-retardant coating and plates; beneath those anti-fire stuffs are serials of batteries, bolted to its outer plate, covered in adhesive sealant.

![Figure 2.9 Model S battery’s detail diagram](image2)

Secondly, Tesla Model S utilizes 18650 Li-ion battery. 18650 Li-ion battery have 50% higher energy density than other Lithium battery, and they are also mature in manufacturing, with around a billion 18650 Li-ion battery produced every year. Another advantage for 18650 battery is that malfunction of a single battery has almost zero influence on the whole battery panel; however, it will still be displayed on the vehicle to inform and alarm the driver. The whole battery panel is consisted
with 7104 Li-ion batteries: every 74 Li-ion battery are connected in parallel into a battery pack, and 6 of these packs are connected in a larger series, finally, 16 of the series joined together, ensuring its safety and integrity.

![Figure 2.10 Constitution of Tesla battery](image)

This marvellous hazard-proof system and safety measures are able to lower accident possibility to nearly zero, and the integration of battery panel is in favour of modular installation and disassembly; in addition, neither of them is expensive. This suggests for the vigorous future development of EV industry, these successful technologies or similar ones are compulsory to utilize.

### 2.3 Unit Number, Pricing Function and Charging Control

As for the calculation of the number of batteries, this paper designed a nonlinear programming model, which cannot be directly calculated due to the uncertainty of swapping. After approximating according to the simulation results, this paper simplifies the problem to a linear programming model, and obtains the maximum number of battery units $n$ when the number of units is about $50\lambda$, where $\lambda$ is the parameter value of Poisson distribution of traffic flow within 2 minutes. Then, this paper uses MATLAB to start from $50\lambda$ and conduct Monte Carlo simulation to the larger direction, then it utilizes annealing algorithm to determine $n$ when the profit is maximized.

The pricing function should control the price of electricity changing within a small range, so that there will be no high price of battery swapping, nor negative price. After regulation, the following pricing function is obtained in this paper:

\[
\text{COST} = (\text{equipped battery remaining capacity} - \text{unequipped battery remaining capacity}) \times 50 \times 1.4 + (\text{number of charging cycle of equipped battery} - \text{number of charging cycle of unequipped battery}) \times 125 \times 0.8 + 400
\]

The histogram of price of multiple simulations is shown in Figure 11. It can be seen that the probability of less than 0 and greater than 800 is negligible, so it can be generally considered that there is no negative value or sky-high price.
In terms of recharging swapped batteries, because of value n can better satisfied the need of customers, the battery can be changed immediately. Therefore, it is designed to charge all newly replaced batteries during peak power period and charge all batteries during valley power period, so as to meet the function of regulating city power grid to reduce the power consumption during peak power period.

3. Prospect Analysis
From observation of nowadays situation, number of EVs keeps increasing. Driver’s demand of EV’s quality and its convenience will increase in the same pace; however, EVs have extremely prominent problems on recharging. The first one is that the utilization rate of public charging stations is only 12%; one of the main reasons is unreasonable arrangement of charging stations, some of them are crowded with drivers and customers, while other of them barely used from their construction to the end of their life period. The second problem is new technologies consistently set new standards for charging infrastructure: the charging stations need to improve its facility for new charging technology; thus, it’s hard for charging facility to have a universal standard. Thirdly, charging companies and enterprises failed to achieve interconnection. In China, State Grid, star charging and several other commercialized charging firms run different charging network, which brings drivers and customers inconvenience. Fourthly, a conventional charging station will take 1-2 hours to fully charge a car battery, and a slow and steady charge will take 10 hours. A fast charge will cause damage to battery’s service life. In addition, charging ports in many places are not unified, making it difficult for electric vehicles to travel across regions. For most drivers and travelers, 2 hours of charging is unacceptable. These problems make EVs uncompetitive and acts as a great worry for customers. However, the emergence of battery swapping station can steadily solve these problems for EVs, enabling long-distance travel for them, and grants convenience for EV travelling. In service areas on highways, a functionally battery charging station only need 300 square meters to establish, such a conservation of land. When EVs arrive at service stations, they can stop and swap their battery at the swapping station, the time taken of battery swapping can be as short as 2 minutes and 46 seconds, which is even faster than traditional gasoline cars, and even a greater improvement to charging stations that will take customers several hours to fully recharge.

Additionally, battery swapping stations can not only reduce the burden on power grid by charging when power consumption is low, but also conduct a fully examine of every single battery by balancing internal units of the battery. This can help them to avoid damage caused by fast charging, and improve batteries’ safety performance.
Advancements of battery swapping station can guarantee long endurance of EV battery, in turn solve the problems on long distance traveling of EVs. Even in urban areas, battery swapping station still serves a great function. To avoid inutility, the construction department should arrange sites for battery swapping stations in city regarding its road network, which can help drivers to quickly refuel their cars and continue their journey. Unlike non-urban areas, battery swapping station serves as an alternative choice of charging pile and charging stations, mainly solving the problem of fast endurance and providing energy for users who cannot have their own charging piles—as the number increasing for EVs, this “priority charging auxiliary swapping” recharging scheme can better fit modern EV’s demand for energy. In addition, battery swapping can also regulate city power grid. In modern cities, power grids are often overloaded during peak consumption of power, so it is unrealistic to charge all EVs during the busiest hours, as this paper previously mentioned; in battery swapping stations, however, even if the battery is swapped during busy hours, the charge can still be done during low periods of power consumption. The main way for battery swapping stations to make profit is through peak-valley electric price; furthermore, it can cease car owner’s charging on power consumption peaks to regulate the city power grid. According to statistics, the construction of a conventional battery swapping station will cost about 10 million Yuan; each station should at least have a stock of 28 batteries, costing another 3.22 million Yuan (115 thousand Yuan each). This is relatively cheaper than funding for a charging station, so is expected to see a skyrocketed growth in battery swapping station industry. Accordingly, the demand of battery will also increase, leading to the boom of both industries. Base on analysis, there is a bright future waiting for battery swapping stations.

4. Conclusion
With diversified residents’ consumption level and awareness of environmental protection, the market demand of EVs will keep rising, and it is expected to surpass that of traditional gasoline vehicles. However, the unsustainable quality of batteries and restrain of power grids have severely hampered the development of EV industry. In order to promote EV industry to its apex, and to overpass aforementioned obstacles, to lower construction cost, to conserve land occupied by infrastructure construction, to save customers’ time spent on charging batteries, and most importantly, to improve efficiency and convenience of EV travels, it is certainly the best choice to adopt the plan of battery swapping stations.

A car that can’t travel for long distance can only be viewed as green toys in the city; a car battery that can’t be properly used can only cause more devastation to this environment we live in. This paper proposed a new type of battery swapping station by plotting and modeling using AutoCAD and SketchUp, evaluates the practicability by conducting analysis on internal structure of EV batteries, simulates peak valley price according to power distribution, and designs functions to calculate price and battery stocks. These methodologies guarantee battery swapping stations can develop simultaneously with urban construction and road traffic planning. With new generations of battery swapping stations, traveling in EVs will be as convenient as traveling in gasoline vehicles by solving EV’s recharging problems on recharging, and it will construct a solid foundation for the promotion and popularization of EVs.

References
[1] Zhao Yue. Progress and development trend of electric vehicle technology [J]. Shandong Industrial Technology, 2019 (15): 148.
[2] Lin Caizhen. On New Energy Vehicles [J]. Modern Marketing (Management Edition), 2019 (06): 62.
[3] Xia Wei. Research on the development strategy of China's new energy automobile industry [J]. Automotive Practical Technology, 2019 (09): 232-234.
[4] Yang Yongbiao, Huang Li, Xu Shiming, Wei Zhinong, Sun Guojiang, Wang Dong, Discussion on the business model of electric vehicle replacement, Jiangsu Electrical Engineering [J]. 2015, 34 (3): 19-24
[5] Zhou Junqiao, Safety architecture design of electric vehicle replacement station, Fire Science and Technology [J]. 2019, 38 (90): 1255-1258
[6] Jia Long, Hu Zechun, Song Yonghua, Zhan Kaiyu, Ding Huajie, Optimization of the layout of electric vehicle charging stations on the expressway, Electrical System Automation [J] 2015, 39 (15): 82-90
[7] Zeng Chengbi, Liu Guang, Miao Hong, Wang Ya, Han Feng, Cheng Pingfan Planning of electric vehicle charging stations considering urban traffic flow [J], 2019, 34 (4): 101-107
[8] Su Shiwei, Yang Xuan, Cao Shen, et al. Research on the orderly charging of electric vehicles considering new energy consumption [J]. Journal of Three Gorges University (Natural Science Edition), 2019, 41 (5): 84-89.
[9] Jiang Yanping, Chen Peijun, Chen Haiyan Design and Research of Intensive Power Exchange Facilities for Electric Vehicles. Power Generation Technology [J], 2019, 40 (6) 535-539
[10] Hu Libiao. Safety is the bottom line that must be maintained in the development of electric vehicles [N]. China Quality News, 2019-05-22 (008).