Battery Charge and Discharge Optimization for Vehicle-to-Grid Regulation Service

Wook Won Kim, Hong Yeul Shin, Je Seok Shin and Jin O. Kim*
Department of Electrical Engineering, Hanyang University, Seoul, Korea

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Abstract: Electric vehicles should be connected to power system for charge and discharge of battery. Besides vehicle's battery is charged for a power source, it is also reversibly possible to provide power source from battery to power system. Researches on battery usage for regulation resources have been progressed and could cause cost increase excessively because they distribute regulation capacity equally without considering the battery wear cost of SOC, temperature, voltage and so on. This causes increase of grid maintenance cost and aggravate economic efficiency. In this paper it is studied that the cost could be minimized according to the battery condition and characteristic. The equation is developed in this paper to calculate the possible number of charge and discharge cycle, according to SOC level and weighting factors representing the relation between battery life and temperature as well as voltage. Thereafter, the correlation is inferred between the battery condition and wear cost reflecting the battery price, and the expense of compensation is decided according to the condition on battery wear-out of vehicle.

1 INTRODUCTION

Interest in energy conservation and the environment increases, the technology (Electric Vehicle, EV) of electric vehicles has been developed rapidly, attempt of practical use have been carried out consistently. Cooperation of the power grid connection for charging the battery as a power source in the practical use of electric vehicles is essential. Therefore, vehicle to grid has been studied about the characteristics of the battery of an electric vehicle and utilization of charging and discharging. Especially, it is possible to improve the quality of power by using battery for ancillary service. For ancillary services such as regulation is required fast response time. And it provides the actual power is as small as about 10% compared to contract capacity ratio. Therefore, EV battery is suitable for providing the regulation service. Thus, when it comes to providing regulation service using the battery of an electric vehicle, additional charging and discharging are needed without charging and discharging for running EV. Additional charging and discharging of battery is responsible for the reduction of battery life time. Cost for the decrease in battery life due to additional operation is compensated in the form of incentives for vehicle system operator is participating in V2G services. Providing regulation service using EV leads to a reduction in revenue by increasing the operating costs. Therefore, in this paper, life time cost is estimated by using the relationship between battery life according to voltage, temperature and cycling characteristics of the DOD(Depth of Discharge) of the lithium-ion battery. And regulation service scheme that minimizes life time cost is proposed.

2 MODELING OF EV

2.1 Battery of Electric Vehicle

In this paper, the characteristics of lithium-ion batteries which are used the most widely in EV are considered for simulation. Capacity of lithium-ion battery has 10-20kWh generally. This capacity makes it possible to drive about 150km. The charging time of battery takes 6-7 hours from 20% to 100% of SOC. The number of cycle is evaluated about 1000. And price of battery is $800 per kWh.

*Corresponding Author

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2.2 Cycle Characteristics of Lithium-Ion Battery

The main factors that affect the lifetime of the lithium-ion battery are a level of SOC charge and discharge, temperature, voltage, and time. In this section, equation is shown in the cycle of the battery considering four factors described above.

The possible number of times of charge and discharge of an electric vehicle battery is dependent on the SOC. And it is shown as in (1).

$$L = 694(1 - SOC)^{-0.795} \quad (1)$$

Battery cycle is assumed 1 cycle when battery is repeated charge or discharge as 20% of SOC. It is possible to calculate the number of cycles when the SOC is increasing or decreasing linearly by using (1).

The equation of battery cycle can be changed by the form of equation about the number of cycle using (1) and assumption. And it is shown in (2).

$$n_{i,t} = 0.5 \times (0.8)^{-0.795} \left| \frac{1}{1-(SOC_i(t))^{-0.795}} - \frac{1}{1-(SOC_i(t+1))^{-0.795}} \right| \quad (2)$$

Life factors are associated with the temperature of the battery, voltage and time to use that is represented by (3), (4) and (5).

$$\frac{C(t)}{C_{init}} = 1 + c_a c_V^{\frac{V-V_0}{\Delta V}} c_T^{\frac{T-T_0}{\Delta T}} \sqrt{t} \quad (3)$$

$$V(SOC) = -1.031e^{-35SOC} + 3.685 + 0.2156SOC - 0.1178SOC^2 + 0.3201SOC^3 \quad (4)$$

$$T(x,t) = T_{av} + T_{am} \times \exp\left(-x \times \sqrt{\frac{\omega}{2a}}\right) \times \cos\left(\omega t + 0.77 - x \times \sqrt{\frac{\omega}{2a}} + C\right) \quad (5)$$

It is possible to obtain the integrated expression of the cycle of the battery (6) in consideration of the temperature, voltage and time at which the SOC is changed.

$$N_{i,t} = n_{i,t} c_V^{\frac{V(SOC)-V_0}{\Delta V}} c_T^{\frac{T(x,t)-T_0}{\Delta T}} \sqrt{t} \quad (6)$$

2.3 Lifetime Cost of Battery

Lifetime cost of battery is calculated by (7).

$$C_{total} = \sum_{t}^{T} \sum_{i}^{n} \frac{N_{i,t} P_{bat}}{L_{20\%}} \quad (7)$$

P_{bat} is the mean cost of EV battery. And $L_{20\%}$ means the total possible number of battery cycle.

The minimum SOC is required because of the unexpected use of EV and decreasing the battery life time from full discharge. Therefore, the constraint of SOC is show in (8)

$$SOC_{\min,t} = \frac{0.8}{T_{charge}}(t - T_{off}) + 1 \quad (8)$$

3 REGULATION SERVICE BY EV

3.1 Estimation of Regulation

In order to keep the balance at all times, power generation is controlled automatically to compensate supply and demand for the difference between the predicted demand and the actual demand. In this paper, the calculation of regulation demand is estimated by the actual loads and 5-minute schedule model to compensate difference.

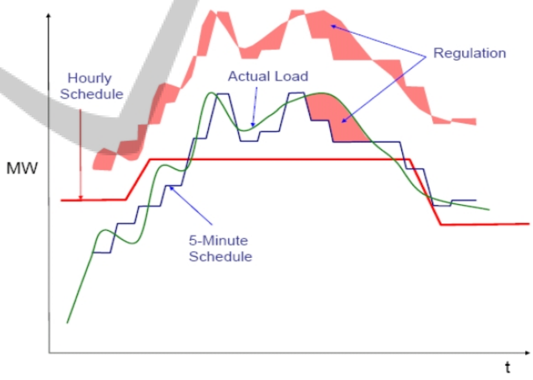

Figure 1: The Concept of Regulation.

3.2 Algorithm for Regulation Service

Figure 2 shows flow chart about charging process of the battery management and the provided regulation power. As shown in the flow chart, each plug-in EV has the order of priority to supply regulation service according to voltage, temperature and SOC when a regulation signal is provided every minute. Then, regulation power is provided differentially according to the order of priority if SOC is satisfied $SOC_{min,t}$. At the end, it starts operation again without the vehicle removing the plug-out the system. If vehicles are newly connected, the process is repeated. In the proposed process, there is a difference to distribute the amount of regulation service to each vehicle to compare with the conventional method.

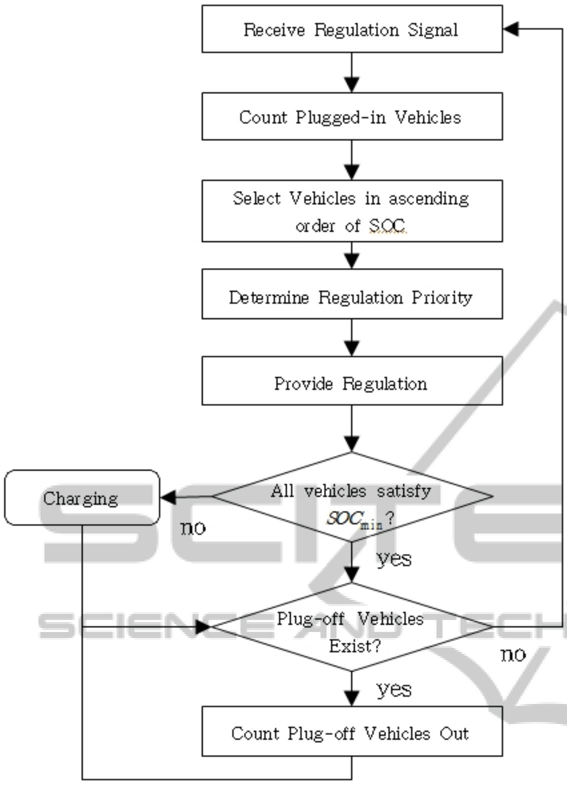

Figure 2: The Proposed Flow Chart of Regulation.

4 CASE STUDY

4.1 Background of Case Study

In the case study, it was applied to a vehicle of 12,329 units that provides battery power regulation of the electric vehicle for simulating the operational scheme. There are three scenarios in the case study that is shown in table2.

Table 1: Characteristics of EV.

Scenario	A	B	C
Time to start regulation service	As soon as (connected to grid)	According to SOC	According to SOC and condition of battery
Amount of regulation to EV	equally	differentiall y	differentiall y

To simulate by applying the operational scheme that was presented in this paper, consider the operation situation that target the users of the EV. The total number of vehicles is 12,329 units. 58% are used for commuting, 30% are used for leisure, remainder are used for business. Assuming the vehicle is used for commuting to be interconnection to the grid from attendance to closing hour during the week and is not connected during the weekend. The vehicle used for leisure is always connected except weekend. It was assumed that commercial vehicle, did not participate in the regulation service because works always use the car. Thus, considering time to connected, estimated number of grid-connected EV is shown in figure 3 using normal distribution. And regulation demand is also shown in figure 4.

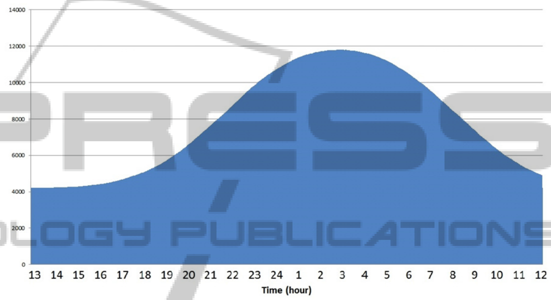

Figure 3: The number of grid-connected EV.

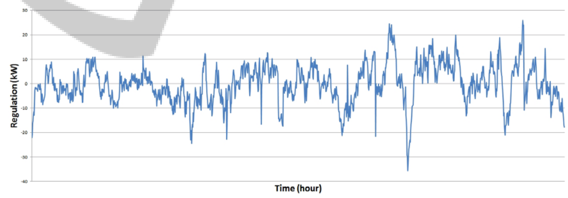

Figure 4: Regulation Demand.

4.2 Results of Scenarios

Figure 5-10 show that change of SOC and cycle of battery by each scenario.

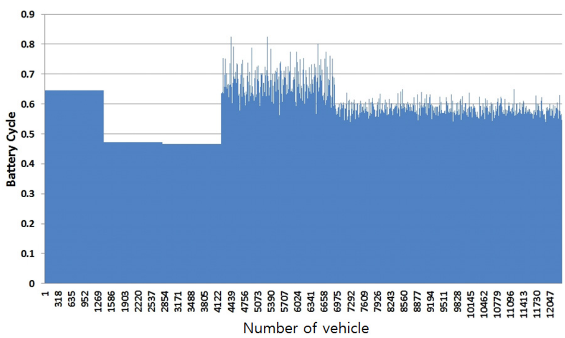

Figure 5: Battery Cycle(Scenario A).

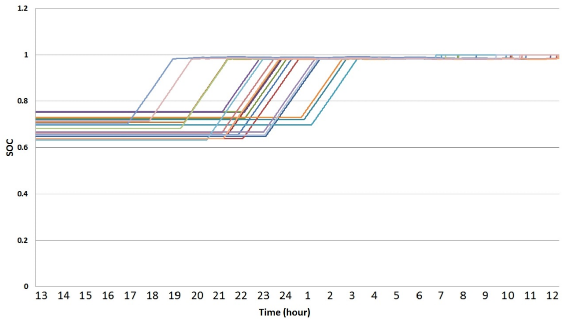

Figure 6: Change of SOC (Scenario A).

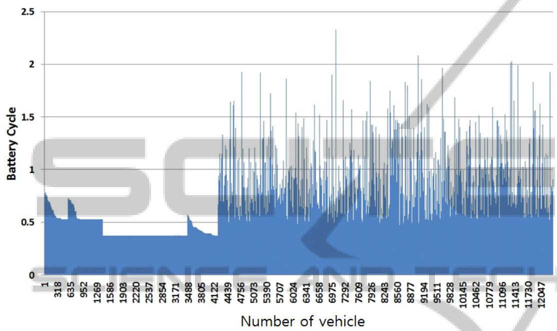

Figure 7: Battery Cycle(Scenario B).

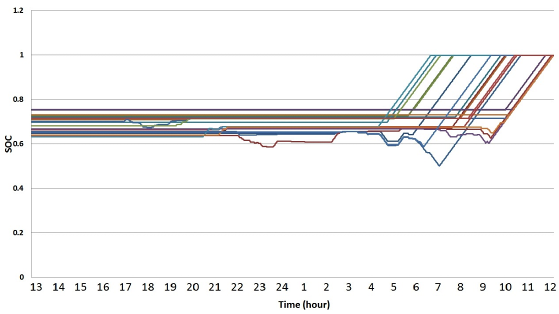

Figure 8: Change of SOC (Scenario B).

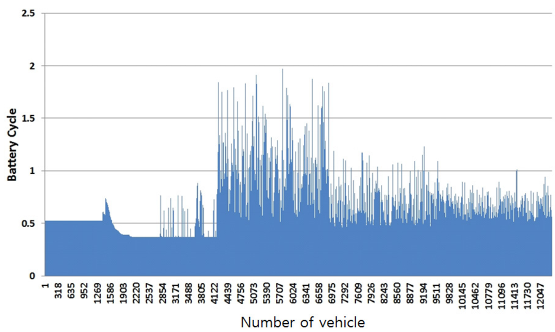

Figure 9: Battery Cycle (Scenario C).

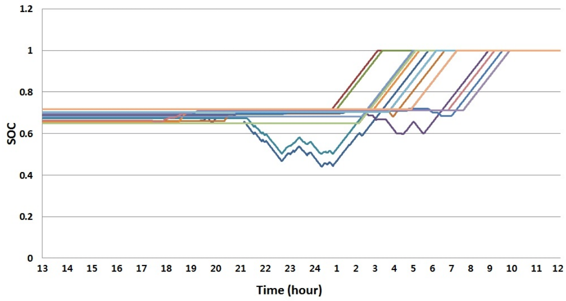

Figure 10: Change of SOC (Scenario C).

Figure 5-10 show that charge and discharge schedule is changed in various ways depending on each scenario. According to previous studies, the repetition of charge and discharge in high level of SOC adversely affects to the battery life. However, the proposed method brings a reduction life cost because it provides the regulation service while the level of SOC is low. The overall results are represented by the tables 2 and table3.

Table 2: Lifetime Cost.

Scenario	A	B	C
Battery cycle	6,497.7	6,073.8	5,987.8
Cost($)	97,465	91,108	89,817

Table 3: Benefit between Each Scenario.

Scenario	A/B	B/C	A/C
Deference of Benefit($)	6,357	1,291	7,648
Improvement(%)	6.52	1.42	7.85

It was confirmed that the differentially division of regulation service corresponding to the SOC has a major impact on reducing life time costs through the improvement ratio between each scenario. And additional reduction of cost occurs according to consider voltage and temperature.

5 CONCLUSIONS

In this paper, life time cost is estimated by using the relationship between battery life according to voltage, temperature and cycling characteristics of the DOD(Depth of Discharge) of the lithium-ion battery. And management scheme for regulation service to minimize the cost of battery life time is proposed. The proposed method decreases total cost without additional investment of infrastructures. Also, it can be applied to batteries of other types according to its characteristics. In addition to regulation service, it can be extended to another ancillary service, load levelling and cost optimization.

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