Journal of Engineering and Applied Sciences 13 (5): 1148-1153, 2018
ISSN: 1816-949X

Development of Smart Fusion Charge Devices for Small Electric Vehicles

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Abstract: Currently because of the exhaust gas of motor vehicles and serious environmental pollution occurs as a solution due to this development of electric vehicles is urgently needed. The purpose of this study is to design and develop a critical battery charging device in an electric car. A small electric car for the smart on-off board to design to try to develop a charging system. This study of goal the on-board charger as well as the development raised to 5 kW at 3 kW is to develop in the industry standard rack system. In this study is applied to the electric car strongly to vibration and shock during operation by the effective heat dissipation design it has excellent cooling properties and high density 3 kW-class on-board charger 30 kW class high efficiency to design a quick charging device to manufacture. Because of the paper more favorable technical system perfection of the implementation the charge. Discharge test of on-board charger that is designed/manufactured for the development of rapid off board charger was completed.

Key words: Smart charge system, quick charge system, sequence selection treatment, state of charge, open circuit voltage, serious environmental pollution

INTRODUCTION

Given the efficiency of energy use and environmental issues along with the comfort, convenience and low noises of electric vehicles, global electric vehicle markets are expected to grow greatly hereafter. Therefore, in the markets of automobiles that have relied on fossil fuels, electric vehicles are expected to get the lime light not only because of issues such as high oil prices, fuel efficiency and reinforced environmental regulation but also government’s policy support recently added to the foregoing.

Although, electric vehicles were originally developed earlier than internal-combustion engines they could not be commercialized as they lagged in terms of technologies. However, as they have been newly receiving attention recently as a rising star for low carbon-green growth due to environmental and energy issues such as responses to climate change, global competition for development of them has been becoming serious (Park and Lee, 2013).

Consequently, the area of charging infrastructures has been rising as a prerequisite in electric vehicle markets. Competition surrounding charging infrastructure related business following the supply of electric vehicles has been developing rapidly. Fuji camera in Japan forecasted that the volume of global markets of charging infrastructures for electric vehicles or plug in hybrid cars in 2010 would reach 204.3 billion yen with rapid growth by 53.8 times compared to 2010.

Electric vehicle sales volumes are expected grow by 30% on average every year from 1 million vehicles in 2011 to 6.78 vehicles in 2015 and to 10 million vehicles in 2020. Among major electric vehicle markets, those in the Asia/Pacific region account for 50%, those in North America account for 25% and those in Europe account for 25%. In the Asia/Pacific Region, China and Japan are leading the growth of the markets.

Although, the automobile industry in South Korea is the number one export industry that accounts for the largest portion of national economy and has the largest forward-backward related effects it has been experiencing environmental changes since the beginning of the 2000s due to environmental regulations, global economic recession and reinforced safety regulations. Therefore, the construction of infrastructures for environment friendly electric vehicles has become a survival condition of the automobile industry and the development of related technologies is essential for the automobile industry to survive as a future growth engine.

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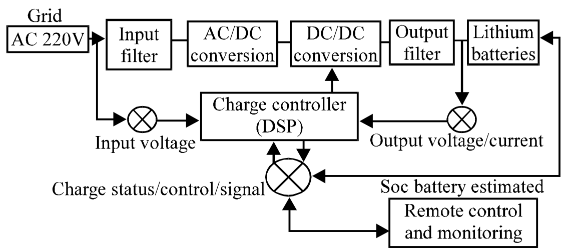


Fig. 1: Charger block diagram

Figure 1 is a block diagram of the on-off board charger to be developed in the present study. In the present study, a smart on-off board for small electric vehicles will be designed firsthand to develop charge systems. In the present study, high density 3 kW grade on-board chargers and 30 kW grade high efficiency quick charge devices that are strong against vibrations and impacts when installed on actual vehicles and have excellent cooling characteristics achieved through effective heat dissipation designs will be designed and fabricated.

MATERIALS AND METHODS

Quick charge system: For uses that require high capacity power sources such as Neighborhood Electric Vehicles (NEV) or Hybrid Electric Vehicles (HEV), battery power sources in the form of single batteries connected in series/parallel are constructed and used. However, the features of those single batteries that constitute battery power sources are degraded as charge/discharge are repeated due to their life spans, current waveforms, temperatures and minute differences in features made while they were manufactured leading to declines in the features and life span of the entire battery power source. Declines in the features of battery power sources may affect the operation characteristics and control of Electric Vehicles (EV) or HEVs. The present task related to the modeling of Ni-MH battery power sources when multiple Ni-MH single batteries are connected in series/parallel and used as power sources and chargers for such power sources. To obtain Ni-MH single battery model an Ni-Cd Model that has similar charge/discharge characteristics are basically used and the data obtained through Ni-MH battery charge/discharge experiments are used to correct the parameters of the Ni-Cd Model to fit Ni-MH batteries. However, this Ni-Cd Model cannot express the deterioration characteristics of single batteries due to repeated charge/discharge. Furthermore, to expand a single battery model to apply it to battery power sources in which single batteries are connected in series/parallel,

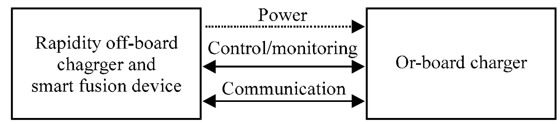


Fig. 2: Configuration of smart charger

the precondition that all the charge/discharge characteristics of individual single batteries should be the same should be satisfied (Fig. 2).

Ni-MH batteries are made using the same anode and electrolyte as those of Ni-Cd batteries but using a hydrogen-storage alloy on the cathode considering the environmental problems due to the cadmium in Ni-Cd batteries. Since, Ni-MH batteries have approximately 30~40% higher energy densities compared to Ni-Cd batteries, long life spans and large capacity they are watched as battery power sources for electric vehicles. Since, Ni-MH batteries are very sensitive to overvoltage while being charged, attention should be paid to full charge, overvoltage, high temperatures and excessive temperature fluctuations for efficient charging of these batteries. Ni-MH battery models for simulations include mathematical, electrochemical and electrical models. The mathematical models can be analyzed with relatively simple equations for ideal batteries but calculation formulas become complicated and separate calculation programs become necessary for calculation when various characteristics of actual batteries. The electrochemical models provide better analysis results for existing experimental results but these models also have very complicated structures compared to necessary battery models. Therefore, Zimmermann and Peterson's Ni-Cd Model is used in the present study.

Li-Cd Model: Due to problems of electric vehicle batteries such as environment problems and the problem of energy price increases, studies of lithium-ion batteries have been studied swiftly. Electric vehicles require performances that can produce large outputs momentarily and last long and also require light-weighted batteries for long-distance travels. Lithium-Ion Batteries (LIBs) are expected to be used in electric vehicles and hybrid electric vehicles and attract great attention as a next generation growth engine.

Fuller *et al.* (1994) developed a mathematical model for lithium-ion batteries for the first time to consolidate the foundation of interpretation theories. Thereafter, many related studies were conducted (Fuller *et al.*, 1994; Smith and Wang, 2006; Doyle *et al.*, 1993). Santhanagopalan *et al.* (2008) separated factors that affect life cycle deterioration using optimizing techniques and identified the levels of contribution of individual factors.

Each lithium-ion battery consists of two electrodes (anode and cathode) into/from which lithium ions can be Intercalated/deintercalated, organic solvent electrolyte in which lithium-ions can move and a porous separator through which only ions can pass. Each electrode contains an active material which is a lithium compound, a binder and a conductive agent for improvement of conductivity.

The current densities formed on the surfaces of the active material and electrolytes in both electrodes are determined through electrochemical reactions which can be expressed by the Butler-Volmer as follows. These current density j_n are formed by oxidation and reduction reactions in the process of ion intercalation/ deintercalation:

$$j_n = \frac{i_0}{F}\left[\exp\left(\frac{\alpha_a F\eta}{RT}\right) - \exp\left(\frac{\alpha_C F\eta}{RT}\right)\right] \quad (1)$$

Where:

- η = The overvoltage on the electrode surface and expressed as follows
- i_0 = The exchange current density of the electrode that relies on the lithium concentration in the electrolyte and the electrode surface
- F = Refers to Faraday constant
- T = Refers to Temperature
- R = The universal gas constant
- α = The transfer equilibrium constant for which 0.5 was used for all cases here

The subscripts a and b represent the anode and the cathode:

$$\eta = \phi_s - \phi_e - U(C_s) \quad (2)$$

$$i_0 = k(C_e)^{1/2}(C_{s,max} - C_s)^{1/2}(C_s)^{1/2} \quad (3)$$

Where, U represents the open-circuit potential on the electrode that can be measured using the function of the lithium concentration and the State of Charge (SOC) = Cs, max. The value varies with anode and cathode substances. In the present analysis, measured values were interpolated for this value. K is a chemical reaction rate constant. As mentioned earlier, electrochemical reactions occur between the electrolyte that constitutes the electrodes and the surface of the active material and are determined by the electric potential ϕ_e and concentration C_e in the electrolyte and the electric potential ϕs and concentration C_s on both electrodes as shown by Eq. 1. Therefore, to calculate the current density formed, four governing equations to solve the above four variables ϕ_e, ϕ_s, C_e, C_s are necessary. The four equations consist of two charge transfer equations for calculation of electric potentials and two mass transfer equations for calculation of concentrations.

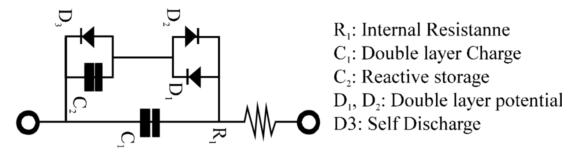
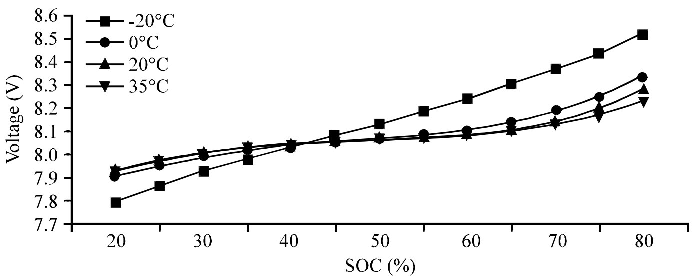


Fig. 3: Circuit model for simulation

SOC measuring algorithm: Ni-MH battery models for simulations include mathematical, electrochemical and electrical models. The mathematical models can be analyzed with relatively simple equations for ideal batteries but calculation formulas become complicated and separate calculation programs become necessary for calculation when various characteristics of actual batteries. The electrochemical models provide better analysis results for existing experimental results but these models also have very complicated structures compared to necessary battery models. Therefore, Zimmermann and Peterson's Ni-Cd Model is used in the present study.

R_1 in Fig. 3 represents internal resistance of batteries. Diodes D_1 and D_2 in anti-parallel connection show nonlinear effects on the hysteresis characteristics of electrochemical internal resistance of batteries. This element is a function of the direction of charge/discharge currents and the Depth of Discharge (DOD). Diode D_3 represents the leakage current occurring during charging and the conductive leakage current occurring at overvoltage. C_1 represents the linear effect of the capacitive element stored between anode plates and C_2 represents the storage effect by the chemical action of the battery. The mathematical formulas that represent individual elements of the battery model are derived from the study by Zimmermann and Peterson.

The State of Charge (SOC) of a battery is one of important elements. The SOC is generally achieved by diverse methods such as those using battery voltage, current integration or internal resistance of batteries. However, in the case of these methods, the range of errors may become large depending on conditions. In particular, in the case of the method using internal resistance, a long time is required for the relief of the polarization



Q: capacity at key off
$Q_{self/dis}$: self-discharge capacity
Q_{curr}: discharge capacity based on current intergration
α: current integration
Intrnal resistance = $|V_1\text{-}V_2/|I_2\text{-}I_1|$ [mΩ]
SOC[%] = $Q\text{-}Q_{sel/dis} \pm \alpha\, Q_{curr}$

Fig. 4: SOC estimation algorithm calculation formula

phenomenon depending on the size and duration of charge/discharge and in the vicinity of the reference SOC, even minute voltage or internal resistance occurred leads to large differences in the SOC.

If OCV (Open Circuit Voltage) is measured over time based on cases where charge/discharge were implemented at the initial SOC and the SOC followed, it can be seen that OCV gradually decreases over time to be stabilized. However, a long time is required to reach a certain voltage. In the case of SOC achieved by internal resistance, the charge/discharge can be calculated using the DC measuring method. In the case of this method, the internal resistance of batteries is measured through the relationship between internal resistance and voltage decrements following the internal resistance when the current changes. Therefore, this method cannot be applied to systems in which charge/discharge currents are alternated frequently. In the case of this method, the value of internal resistance changes according to the sizes of charge/discharge currents.

In the present study, a method was selected in which SOC is obtained based on the current integration method and error rate α is corrected based on the battery voltage. The correction based on voltage is made when the range of errors of SOC due to voltage errors is small. The voltages necessary for correction were determined by conducting tests at various currents and temperatures in advance, making a table of the results and referring to table. The method was configured, so that, SOC would be revised when the upper or lower limit voltage had been reached under the same condition. The slope of the graph is slow in the vicinity of the reference SOC, so that, the fluctuation of SOC is large even at a small voltage error and the slope of the graph becomes relatively large in the vicinity of the upper and lower limit SOC, so that, the occurrence of errors is reduced and the time to block battery power supply in order to prevent overcharge or over-discharge of the battery can be accurately detected. Figure 4 shows the calculation formula for the SOC estimation algorithm.

RESULTS AND DISCUSSION

Development of quick on-off board charge device for small electric vehicles

Fabrication and test: The on-board charger which is the objective of the present study was developed with 5 kW which is larger than the planned capacity 3 kW as well as developing into a 19’ industrial standard rack system to achieve technology development closer to industrialization and standardization. More advantageous technical and systematic completeness was implemented for development of quick off board chargers which are the final objective of commercialization in the present study. Figure 5 shows a view of charge/discharge testing of the fabricated on-board charger and Fig. 6 shows the completed lithium secondary battery pack (259 V/10.4 Ah).

Tests of the charge/discharge characteristics of the lithium secondary battery pack: For standard charge tests of the configured 259 V/10.4 Ah battery pack, a test environment was constructed as follows and the charge/discharge characteristics of the lithium secondary battery pack were conducted (Fig. 7).

Test equipment:

- Equipment name: DC power supply, DC electronic load
- Model name: XDC300-40(Xantrex Co.), PLA5K-400-400(Amrel Co.)

The 259 V/10.4 Ah lithium secondary battery pack was Constant Current (CC mode) charged with currents of 0.1C (1A), 0.3C (3A) and 0.5C (5A). The entire charge profile was constant current charged and the cutoff was set to the voltage before charge (270 V). Discharge was also tested through CC mode discharge with currents of 0.1C (1A), 0.3C (3A) and 0.5C (5A) until the final discharge voltage 230 V in the battery characteristics test (Table 1).

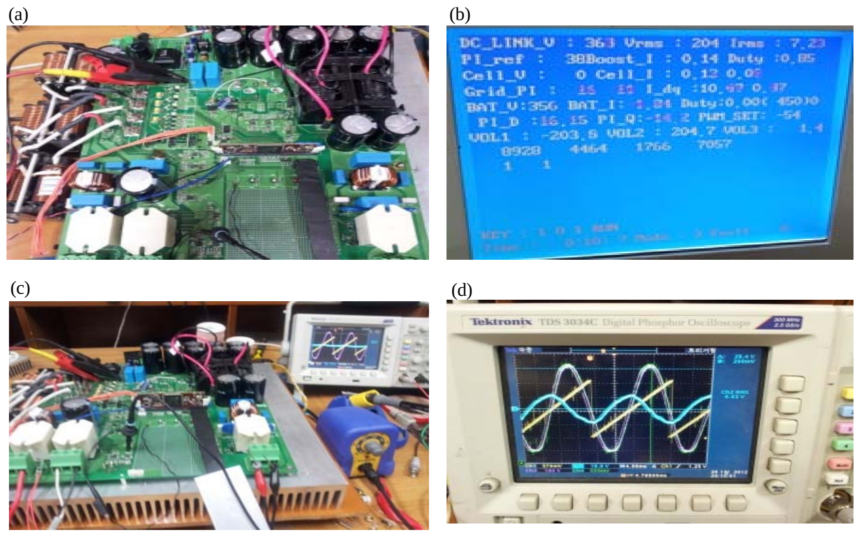


Fig. 5: Charge/discharge tests of the fabricated on-board charger: a) Charger fabrication; b) Charge/discharge test; c) Charge/discharge test and d) Charge/discharge test waveform

Fig. 6: Fabrication of lithium secondary battery pack (259 V/10.4 Ah)

Fig. 7: A view of lithium secondary batteries battery pack (259 V/10.4 Ah) charge, discharge tests

Table 1: Results of charge/discharge tests

Constant current	Setting voltage	C-rate	Charge, discharge time (min)
Charge-1	280	0.1 C (1A)	127
Discharge-1		0.1 C (1A)	143
Charge-2	280	0.3 C (3A)	34
Discharge-2		0.3 C (3A)	35
Charge-3	280	0.5 C (5A)	17
Discharge-3		0.5 C (5A)	19

CONCLUSION

Neighborhood Electric Vehicles (NEV) are zero emission vehicles with very high possibility of bulk production and related technologies should be urgently developed. Accepting this requirement, in the present study, high density 3 kW grade on-board chargers and 30 kW grade high efficiency quick charge devices that are strong against vibrations and impacts when installed on actual vehicles and have excellent cooling characteristics achieved through effective heat dissipation designs were designed and planned for fabrication.

In addition, to prepare performance test criteria for on-off board chargers for electric vehicles that employ lithium batteries, diverse performance test criteria are necessary including those for not only electric characteristics such as the efficiency and power factor of the on-off board charger, charge voltage/current and charge time but also environment resistance such as on-board vibration resistance and temperature/humidity resistance, battery protection performance, temperature detection performance, SOC estimation precision and remote monitoring/control and convenience in billing systems.

In the present study, the on-board charger was developed with 5 kW which is larger than the planned capacity 3 kW as well as developing it into a 19' industrial standard rack system thereby achieving technology development closer to industrialization and standardization.

RECOMMENDATIONS

In addition, the present study should be quite meaningful in that it prepared criteria for elements that affect the overall performance factors of on-off board chargers and electric vehicle systems such as battery protection performance and SOC estimation performance in addition to the existing electrical/mechanical performance and environment resistance characteristics.

REFERENCES

Doyle, M., T.F. Fuller and J. Newman, 1993. Modeling of galvanostatic charge and discharge of the lithium/polymer/insertion cell. J. Electrochem. Soc., 140: 1526-1533.

Fuller, T.F., M. Doyle and J. Newman, 1994. Simulation and optimization of the dual lithium ion insertion cell. J. Electrochem. Soc., 141: 1-10.

Park, S.I. and J.G. Lee, 2013. Design of smart off-board charge system for neighborhood electric vehicle. J. Korea Ins. Electron. Commun. Sci., 8: 1499-1504.

Santhanagopalan, S., Q. Zhang, K. Kumaresan and R.E. White, 2008. Parameter estimation and life modeling of lithium-ion cells. J. Electrochem. Soc., 155: A345-A353.

Smith, K. and C.Y. Wang, 2006. Solid-state diffusion limitationson pulse operation of a lithium ion cell for hybrid electric vehicles. J. Power Sources, 161: 628-639.