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工學碩士 學位論文

배터리 상태 점검용 전기화학적 임피던스 분광장치(EIS)에 관한 연구

Study on electronchemical impedance spectroscopy equipment for checking state of battery

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초록

최근 국제 해사 기구(International Maritime Organization) 에서는 온실 가스 및 대기 오염 물질 (NOx, SOx 등)에 대한 배출 제한을 강화하고 선박의 탄소 배출량 감축을 언급하고 있다.

오늘날 이러한 배출 가스를 줄이기 위해 대형 배터리를 동력원으로 사용하는 하이브리드 또는 전기 추진 선박과 같은 ‘친환경 선박’이 개발되고 있다.

하이브리드 선박에 사용되는 배터리는 계속 고조파에 노출되어 있다. 이러한 고조파들은 배터리의 수명에 영향을 주게 된다. 배터리의 상태에 이상이 생겼을 경우 전체 시스템에 영향이 미치게 된다. 이를 방지하기 위해서는 배터리의 수명이나 상태를 추정하여 이상이 있으면 사고가 생기기 전에 배터리를 교체하는 것이다.

본 논문에서는 EIS(Electrochemical Impedance Spectroscopy) 장비를 제작하여 배터리의 상태를 추정하고자 한다.

KEY WORDS: Electrochemical Impedance Spectroscopy, 배터리, 수명

Study on electrochemical impedance spectroscopy(EIS) equipment for checking state of battery

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Abstract

Recently, the International Maritime Organization has tightened emission restrictions on greenhouse gases and air pollutants (NOx, SOx, etc.) and has referred to reducing ship carbon emissions.

Today, eco-friendly vessels such as hybrid or electric propulsion vessels using large batteries as power sources are being developed to reduce these emissions. Batteries used in hybrid ships continue to be exposed to harmonics. These harmonics affect the battery life. If the condition of the battery is abnormal, the whole system will be affected. To prevent this, estimate the battery's life or health and replace the battery before an accident occurs.

In this paper, we propose an EIS (Electrochemical Impedance Spectroscopy) device to estimate the state of a battery.

KEY WORDS: Electrochemical Impedance Spectroscopy, Battery, Lifetime

1. Introduction

1.1 Background

Recently, the International Maritime Organization has been introducing the introduction and strengthening of greenhouse gas and air pollutant (NOx, SOx) emission regulations, and the reduction of all ships' carbon emissions. To satisfy the air pollution emission regulations, researches and commercialization of environmentally friendly vessels such as hybrid ships, electric propulsion vessels using dispersed power sources, and fuel cell vessels are intensively conducting. These eco-friendly vessels are mainly used to ESS using batteries for satisfy performance. Recently, attempts have been made to construct an ESS using a lithium battery with a high energy density and to use it in an electric propulsion ship. However, the energy storage technology of the battery is not suitable for the long-distance operation of the electrical propulsion vessel, and thus it is studied as a system constituting the hybrid system by the internal combustion engine, the fuel cell and the ESS. However, lithium-ion batteries and lithium-polymer batteries used as ESS have a higher risk of explosion and fire than other cells, so battery management must be thoroughly performed.

The lithium battery changes its battery voltage according to the SOC

(State Of Charge). The lower limit of the battery voltage that can be safely used is set to 0% of SOC and the upper limit of SOC is set to 100%. The battery voltage is measured for each SOC, and the battery voltage is measured after a certain period after stopping charging or discharging. The terminal voltage of the battery is different from the no-load voltage of the battery by the internal resistance and reactance of the cell, and the no-load voltage of the battery is called OCV (Open Circuit Voltage). The SOC of the battery is estimated based on the measured SOC-OCV curve. It is very important to determine the state of charge of a battery by overcharging or overdischarging a lithium battery as the lifespan suddenly drops or the risk of explosion and fire increases.

However, when the state of health (SOH) is near 0% when the battery is used, the capacity of the battery is rapidly reduced. A reduction in the capacity of one battery can lead to a reduction in the capacity of the entire battery, and a larger capacity reduction in the cell balancing circuit can have a bad effect on the overall system due to a single battery. To solve this problem, we can solve this problem by estimating the life of the battery and replacing it with a new battery in the future to find a battery with a large capacity decrease.

1.2 Market Status

The total installed capacity of ESS in the world is increasing from 0.7GW in 2014 to 1.2GW in 2015 and 1.6GW in 2016. Korea's installed capacity is the second highest in the world.

Recently, the Ministry of Industry has newly established a particular charge for charging new and renewable electric vehicles. When using ESS for power peak reduction at factories and shopping malls, we will increase the discount of the basic charge according to the ESS usage to 3 times and reinforce the incentive such as a 50% discount on the charge rate. In the case of public buildings with a power rating of 1000 kW or more, ESS is installed to comply with the requirements of 5%. Also, ESS special rate plans are being revised to accelerate ESS deployment. The expansion of the ESS market in Korea will accelerate through the diffusion system.[1]

According to the technology roadmap for environmentally friendly steering and systems at the SMBA, the hybrid propulsion system and the fuel cell propulsion vessel design technology, which use electricity with the internal combustion engine, increase by 10% every year in the world market, from $ 1,757 million in 2016 The market is expected to grow to $ 2,572 million.[1]

1.3 Purpose of Study

If the SOH is low or damaged according to the use of the battery, it is important not to cause a problem during operation by replacing it before the operation. As the capacity of the battery increases, it is necessary to manage the life of the battery thoroughly.

Lithium Iron Phosphate batteries are less likely to explode or catch fire than lithium-ion or lithium polymer batteries. However, the energy density is lower than that of lithium-ion or lithium-polymer cells, and lithium-ion batteries or lithium polymer batteries with high density are used mainly for electric propulsion ships and electric vehicles.

In the case of electric vehicles and electric propulsion vessels, if one of the batteries fails, the entire system will be adversely affected. To minimize these adverse effects, if you can estimate the life of the battery or the damage the cell receives, you should replace the battery before the problem occurs.

In this paper, measure the impedance of battery by fabricating electrochemical impedance spectroscopy(EIS) equipment.

2. Related theory of battery

2.1 Battery

A battery is a DC power source that can be obtained as electrical energy from chemical or physical energy. The cells using chemical energy include a primary cell, a secondary cell, and a fuel cell. Primary cells can convert chemical energy into electrical energy, but not from electrical energy to chemical energy. This means that the battery cannot be charged and used.

A secondary battery has been developed to solve the disadvantages of such a primary cell. A secondary battery is a reversible chemical reaction, which is converted from chemical energy to electrical energy at the time of discharge and can be charged by converting electrical energy into chemical energy at the time of charging. Ordinary secondary batteries include lead acid batteries, NiCd, NiMH, Li-ion, and Li-ion polymer batteries.

2.2 Type of battery

2.2.1 Primary battery

Manganese batteries and alkaline batteries are representative of Primary cells. Manganese batteries are characterized in that the battery voltage is restored when used repeatedly and repeatedly. When used in devices requiring large power, the voltage drop of the battery is large, which is not suitable for use in large electric power. It can be used in electronic devices with small power consumption and intermittent operation. Alkaline batteries can be used for electronic devices with relatively high power consumption due to their low voltage drop compared to manganese batteries.

2.2.2. Secondary battery

The Ni-Cd battery has low internal resistance and discharges a high current. The voltage drop is not large and the temperature characteristic is excellent. However, the Ni-Cd battery has an electromotive force of 1.2V, which is lower than the electromotive force of the alkaline battery of the primary cell of 1.5V. There is a memory effect that causes a capacity drop if it is 100% charged and not 100% discharged. And because the natural discharge rate is high, when the battery is stored for a long time, all energy stored in the cell is discharged. At present, the energy density is lower than that of other secondary batteries, so they must be made larger than the capacity, and the heavy metals used in the batteries cause the environment to be contaminated. After that, a nickel-metal hydride battery was developed that improved these disadvantages. Nickel-metal hydride batteries, like nickel-cadmium batteries, have an electromotive force of 1.2V and excellent temperature characteristics. Nickel-cadmium batteries have been used up to now due to improved memory effect and environmental aspect.

The lithium ion battery is a secondary battery, and it can be charged and discharged by moving lithium ions from the cathode to the anode during discharging and lithium ions from the anode to the cathode during charging. The energy density is so high that even if the same size of the same battery is produced, the capacity for storing energy is large, and there is no memory effect, so there is no need to completely discharge and charge the battery. However, it is very helpful from the point of view of the lifetime of the lithium ion battery to charge little by little and use it little by little.

Table 1 describes the Li-ion battery, Ni-MH battery, and Ni-Cd battery.

Table1. Characteristics of battery

	Li ion	Ni-MH	Ni-Cd
Capacity	Large	Large	Large
Natural discharge	Almost never	Nomal	Large
Memory effect	Never	Nomal	Large
Characteristic	Explosion risk exists	cheap price	Advantageous for charge and discharge quickly
Purpose	Digital camera, notebook	AA batteries	Electric drill, RC car

Lithium batteries are largely composed of three kinds of anode materials, anode materials, and electrolytes. Graphite is mainly used for the anode material, lithium-cobalt oxide is used for the lithium-ion battery and the lithium polymer battery, and lithium iron phosphate is used for the lithium iron phosphate battery. Basically, lithium is used, and the characteristics of the lithium battery are changed according to whether the anode, the cathode, or the electrolyte is made of a certain material or lithium oxide, thereby distinguishing the types.

Lithium batteries commonly use a battery protection circuit to manage the battery. Failure to install a battery protection circuit can seriously affect battery life and increase the risk of fire.[2]

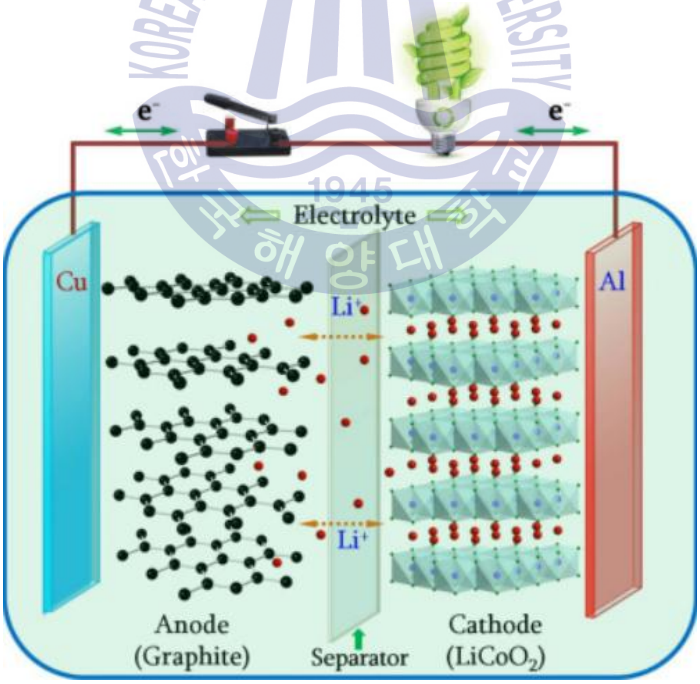

Fig 1. Basic principles of lithium battery

Fig. 1 shows the principle of lithium-ion battery. When the battery is used, lithium ions move through the electrolyte between the cathode material and the anode material as a result of charging and discharging. At this time, an electric resistance component is generated when the charge moves through the electrolyte. An electrical double layer is formed between the electrode of the battery and the positive electrode material and the harmful electrode material of the cell, and a voltage drop occurs when an electric current flows. This is shown in Fig 2.

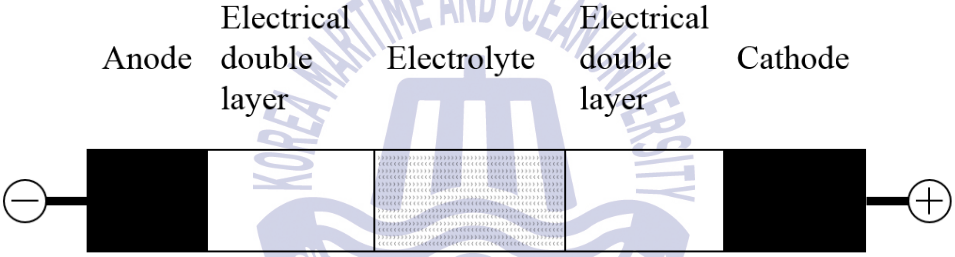

Fig. 2 Simple structure of lithium battery

The factors affecting the formation of the internal impedance of the battery are composed of an anode, a cathode and an electrolyte. An electric double layer is formed between the electrode and the electrolyte. This impedance is expressed as Fig 3.

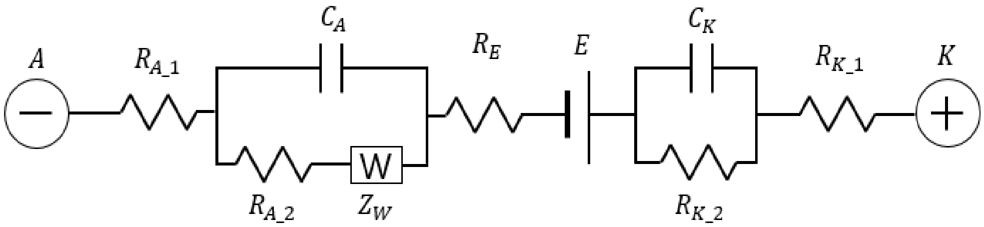

Fig. 3 Impedance of lithium battery

R_1 is a resistance corresponding to the battery electrode. R_2 and C are parameters corresponding to the electric double layer. Z_w is the impedance corresponding to the lithium ion diffusion rate and is called the Warburg impedance. The lithium ion diffusion rate is prolonged and the Warburg impedance Z_w is mainly observed at low frequencies.

If approximate Fig. 3, it becomes as shown in Fig. 4.

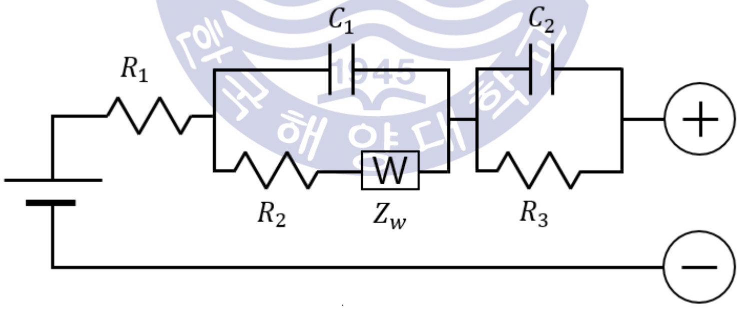

Fig. 4 Internal impedance of lithium battery

C_1 and C_2, and R_2 and R_3 can be interpreted as shown in Fig. 5.

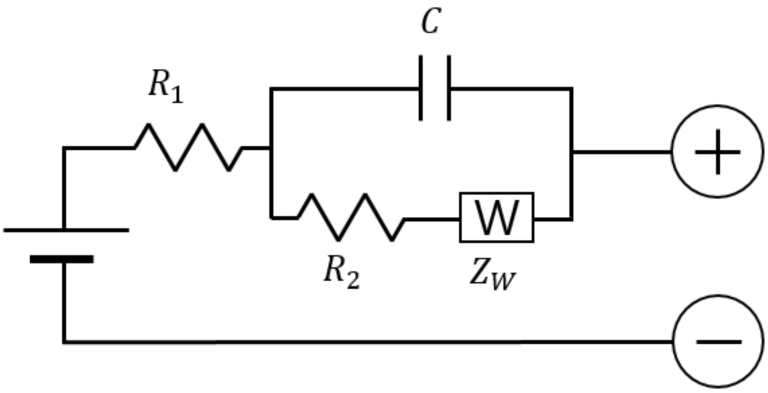

Fig. 5 Internal impedance of lithium battery

2.2.3. Fuel cell

Fuel cells are technologies that convert the energy generated by the chemical reaction between hydrogen and oxygen into electrical energy. Typical cells are sealed and then used to store chemical energy and convert it into electrical energy. Fuel cells, on the other hand, are batteries that generate electrical energy by the chemical reaction of the fuel.

2.3 BMS theory

Based on the real-time monitoring of the battery cell and the whole pack system, the BMS is based on the measured data (voltage, current, temperature) during battery monitoring, and the two indicators of the state of charge (SOC) (State of Health). To compute these two items, additional information is needed besides the measured data, which is the C-rate and the DOD.[3]

2.3.1 C-rate

The C-rate is the ratio of the current flowing in the battery cell to the battery capacity.[4][5] In the present paper, the 1C-rate will be abbreviated as 1C. 1C is used when a current of 1A is applied to a battery having a capacity of 1 AH, and 1 A is charged when a current is flowing at a capacity of 1 A. The formula is as :

$$C-rate(C) = \frac{Discharge\ current(A)}{Battery\ capacity(Ah)} \tag{1}$$

Most of the battery capacity is estimated as 0.2C capacity, which means the amount of charge and discharge for 5 hours, which is also referred to as the 5-hour rate. The battery capacity decreases as the C-Rate increases, while the battery capacity increases as the C-rate decreases.

The battery manufacturer may display the maximum charge current and maximum discharge current as A or C (C-rate Ampere). The graph below shows the voltage change of the battery by discharge C-rate. The X-axis of the figure is the C-rate divided by the C-rate.

In this figure, it is interpreted that C-rate analysis does not use more energy than discharging at 1C than discharging at 4.5C.

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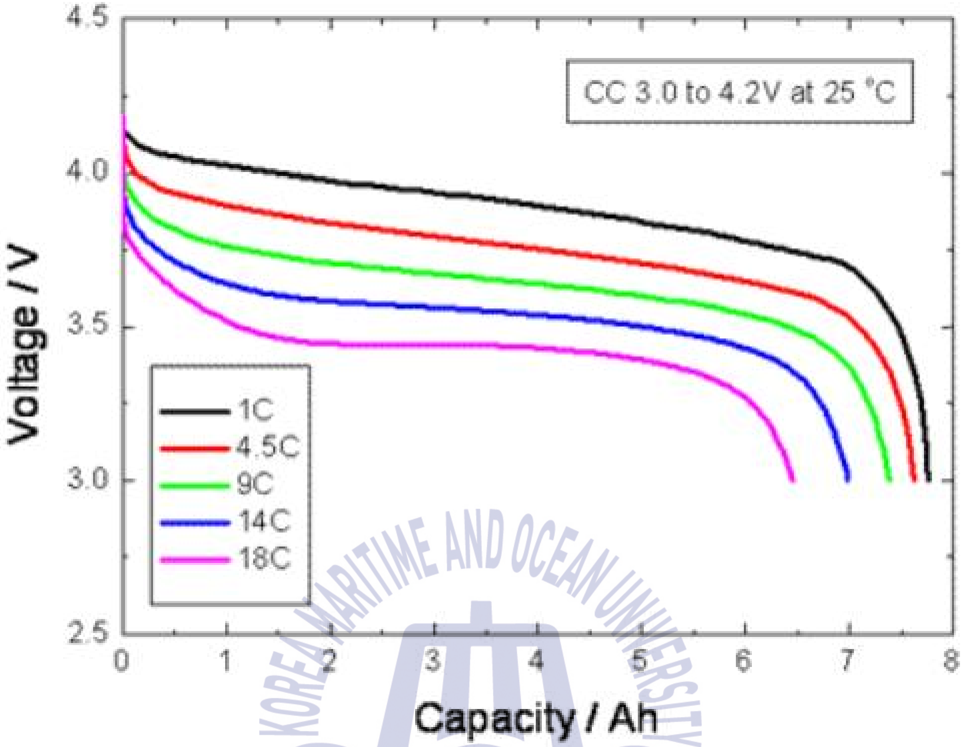


Fig. 6 Battery C-rate discharge characteristics

2.3.2 DOD(Depth of Discharge)

DOD (Depth of Discharge) refers to discharge depth. Discharge depth means the opposite of SOC and refers to the total capacity of the battery. For example, if 10Ah is used for a 10Ah battery, the DOC becomes 100% and the SOC becomes 0%. Since the battery stores and transfers electricity through an electrochemical process, it can be used even if the SOC reaches 0%. In this case, when the battery remaining capacity (SOC) is used as a reference, a unit called DOD (discharge depth) is used due to an error occurring when the calculation is performed. In addition, battery life varies depending on how much DOD is used.[3]

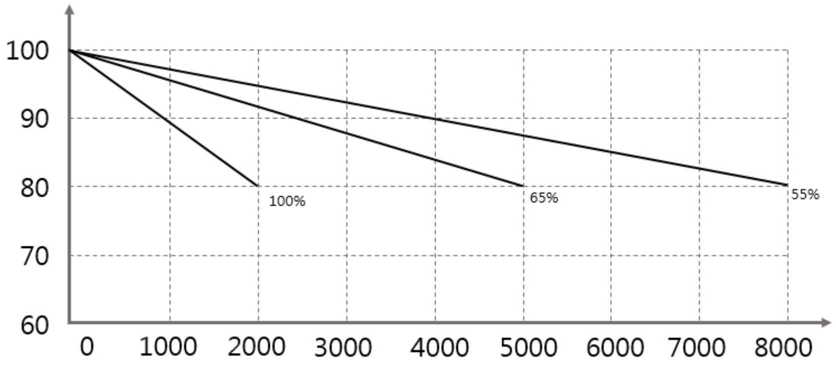


Fig. 7 Battery life characteristic test under normal temperature

Fig. 7, it can be confirmed that there is a difference in the number of charging / discharging cycles of 8 times when 0 to 100% interval is used when the DOD of the battery is 0 to 60%. [6]

2.3.3 SOC(State Of Charge)

The energy storage capacity of a battery can be defined as a capacity. The capacity of a cell is the total amount of energy that the battery can use stable.[7][8]

SOC is the charge state of the battery, which is the ratio of available energy to battery capacity. SOC 100% means that the battery is fully charged, and SOC 0% means that the battery is completely discharged.

The figure below shows the SOC-OCV graph of the battery. The OCV of the battery is measured for each SOC of the battery. It can be seen that the voltage of the battery changes according to the SOC of the battery, and the SOC of the battery can be estimated by using the OCV of the battery.

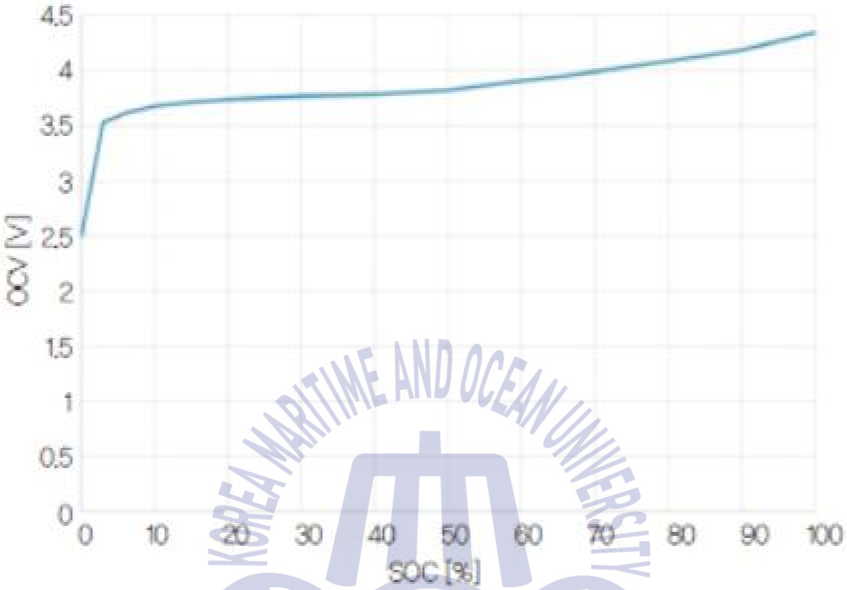


Fig. 8 Graph of SOC-OCV

2.3.4 SOH(State Of Health)

SOH means the life of the battery. A new battery that is not used is defined as SOH 100%, and a battery that has reached its end of life using a battery is defined as SOH 0%.Estimating the life of the battery is very important. Estimating the current state of the battery and estimating how far it will be available will increase the reliability of the battery and prevent accidents caused by the battery. However, accurate estimation of SOH is difficult because batteries store and use energy with complex chemical reactions. The SOH estimation of the battery includes a method of estimating the battery capacity and a method of measuring the internal impedance of the battery.[2][9]

The capacity of the battery gradually decreases as you use it. If the capacity of the battery is lower than 80% of the capacity of a new battery, the capacity of the battery will be sharply reduced. So we usually estimate 80% of new battery capacity at 0% SOH.

Batteries generate electrical energy through chemical reactions. As a result, the internal impedance of the battery becomes complex.

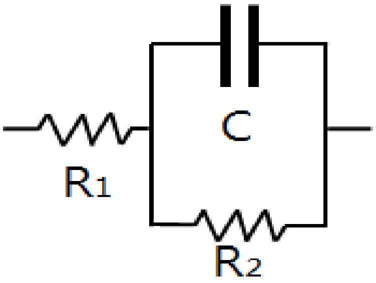


Fig. 9 Randles circuit schematic

Fig. 9 shows the impedance of the battery is the Randle circuit which is analyzed in terms of DC. The Randle circuit consists of a double layer capacitance C, an electrolyte resistance R_1, and an active charge transfer resistance R_2. When DC current flows through the battery, the terminal voltage of the battery rises by R_1 and the second voltage drop by R_2 and C occurs over time.[10][11]

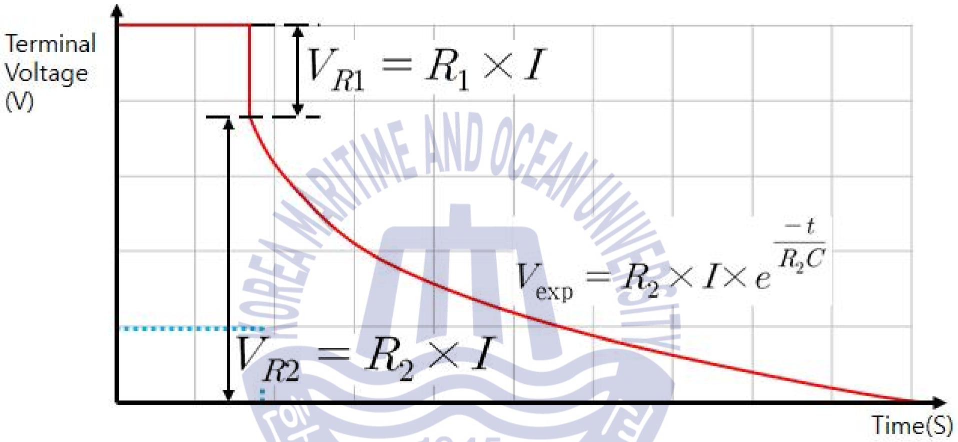


Fig. 10 Impedance estimation method using an open circuit voltage

Fig. 10 is a plot of the voltage change when the current I flows to the terminal of the battery. By estimating the internal impedance of the battery with these plots, V_{R_1} is measured in a short time and R_1 is easily and accurately estimated, while R_2 requires a long time to reduce the OCV of the battery during discharging. Usually, when the battery is enlarged, the value of C becomes large, so that the time for estimating R_2 and C also increases.[12][13]

2.4 EIS(Electrochemical Impedance Spectroscopy)

Electrochemical impedance spectroscopy is mainly used in electrochemistry where electricity and chemistry are combined. Electricity deals with current and voltage, chemistry deals with the change of material, and EIS is a way to estimate the state of the interface by measuring changes in the current and voltage of the terminal. Electrochemical measurement effectively explains chemical phenomena through the relationship of voltage-current. However, when a chemical event appears complexly, a simple voltage-current relationship cannot provide sufficient information. The complementary method is electrochemical impedance spectroscopy. This method analyzes the complex phenomenon by showing the relation of the voltage-current which reacts differently at various frequencies.

2.4.1 CV(Cyclic Voltammetry)

The potential sweep method is a method of recording a current flowing when a voltage is changed into a current-voltage curve. The cyclic voltammetry is called the CV curve when the potential is repeated several times.[14]

2.4.2 EIS theory

The electrochemical impedance spectroscopy is a method of recording the voltage-current relationship with different frequencies and estimating the state by measuring the resistive component and the reactance component corresponding to it.

Impedance is a measure of how much current flow has Interfered in an ac circuit. The larger the impedance, the smaller the current flows at the same potential difference. Impedance is represented by a complex number (R + jX), where R represents a resistance component and X represents a reactance component and includes a two-dimensional direction for a resistance component and a reactance component. This becomes a two-dimensional vector.

When the alternating current I flows through the battery, the electromotive force E of the battery changes according to the alternating current I. However, the current I leading the electromotive force E by the internal impedance of the battery. At this time, the time difference between the current I and the electromotive force E is called a phase angle θ.

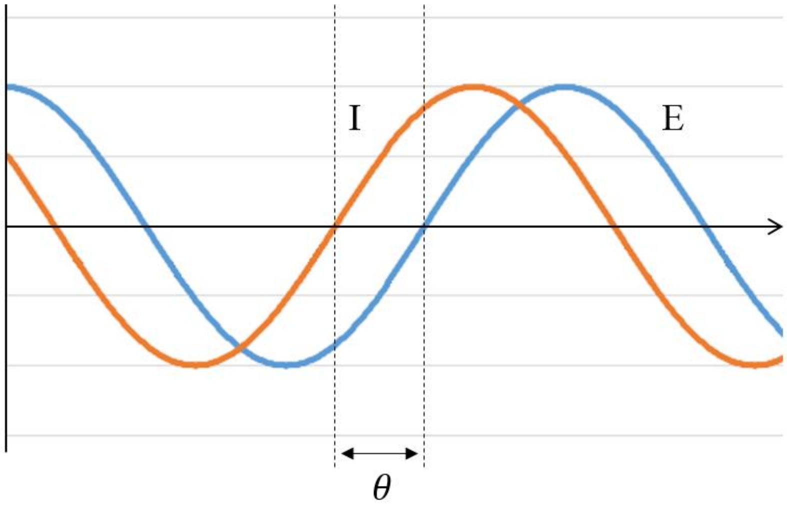


Fig. 11 Waveforms of electromotive force E and current I

The magnitude of the impedance Z is defined as the ratio of the change of the current to the change of the voltage. The formula is as :

$$Z = \frac{\Delta V}{\Delta I}$$

$$R = Z\cos(\theta)$$

$$X = Z\sin(\theta)$$

And the Z and are measured while varying the frequency.

Fig. 12 simulates the circuitry that can occur in the internal resistance of a battery using Multisim. Simulations show that the internal impedance of the battery can be estimated when using EIS equipment.

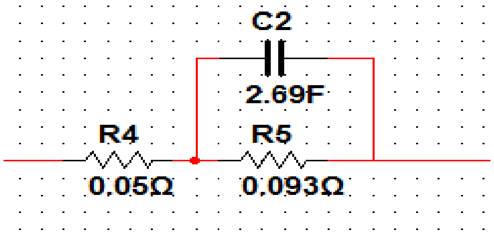
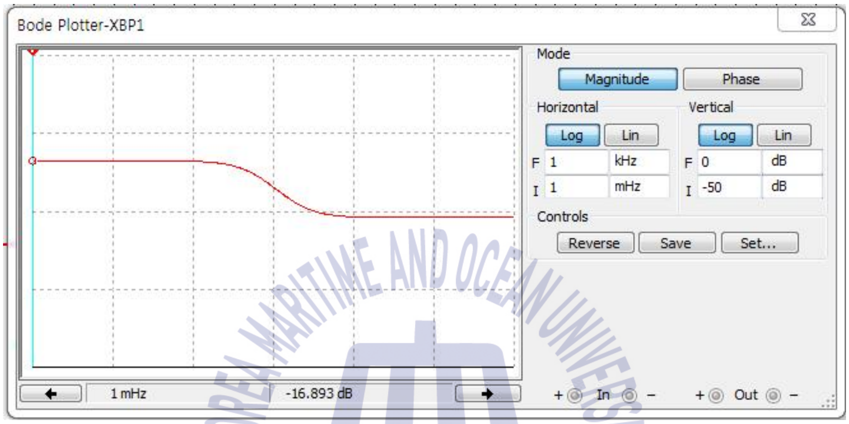


Fig. 12 Simulation example circuit

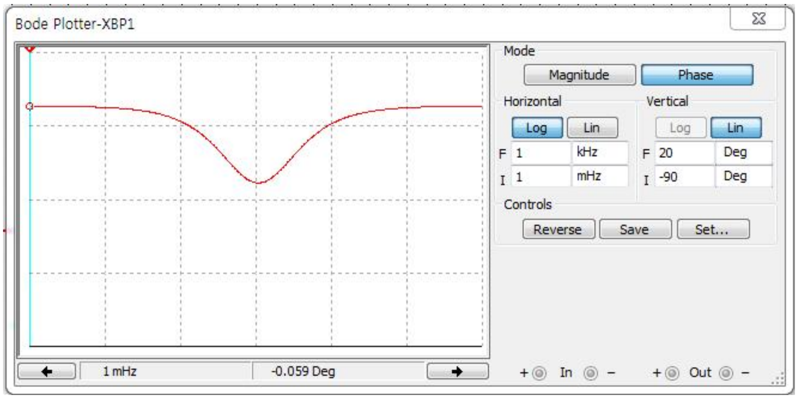
Fig. 13 is a plot of frequency and impedance magnitude. It is constant at -17dB from 1mHz to 100mHz and decreases from -17dB to -26dB from 100mHz to 10Hz. Impedance does not change with increasing frequency.



Horizontal: F 1 kHz, I 1 mHz
Vertical: F 0 dB, I -50 dB
1 mHz
-16.893 dB

Fig. 13 Frequency – Impedance(dB) plot

Fig. 14 is a plot of frequency and phase angle. The phase angle varies from 0 ° to -28.8 ° and the phase angle is largest at about 1 Hz.



Horizontal: F 1 kHz, I 1 mHz
Vertical: F 20 Deg, I -90 Deg
1 mHz
-0.059 Deg

Fig. 14 Frequency - Phase(θ) plot

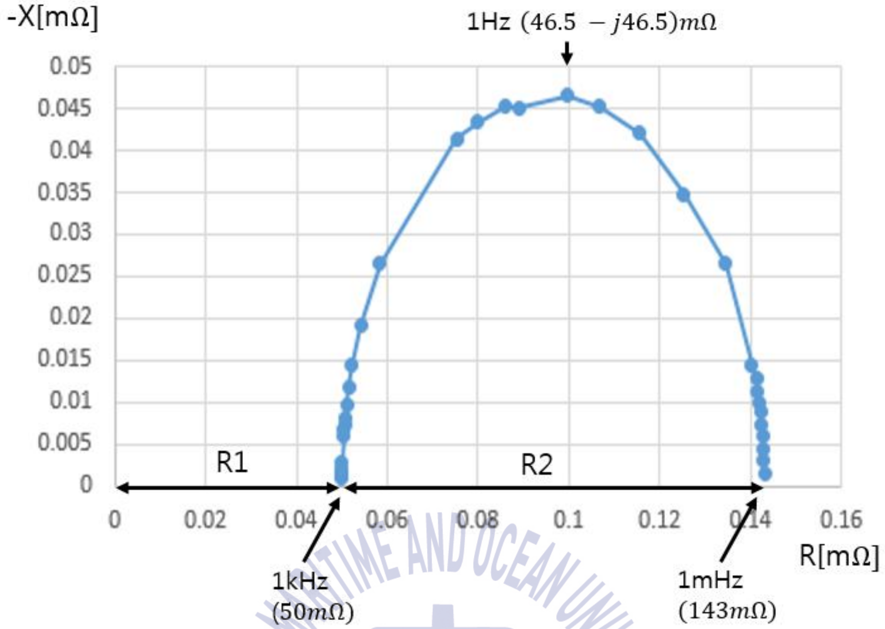


Fig. 15 Impedance on Nyquist plot

Fig. 15 replaces the board plot with a Nyquist plot. On the X-axis, you can see R_1 and R_2 values, and you can see that the impedance changes in a semicircular shape due to the capacitance. The diameter of the semicircle is the size of R_2, and the resistance close to zero points is equal to the size of R_1.

The point at which the imaginary value is highest is the same as the value of R_2 and the reactance value of C. The value of R_2 // C is 47-j47Ω and the value of C is as follows:

$$X = -j\frac{1}{wC} = -j\frac{1}{2\pi fC}$$

$$C = j\frac{1}{2\pi fX} = \frac{1}{2\pi(0.62)(0.093)} = 2.73F$$

3. EIS equipment configuration for battery condition estimation

The battery test was performed by measuring the impedance of the battery using the manufactured EIS equipment and PC monitoring. Data collected from the battery can only measure voltage, current, and temperature. This is used to measure the impedance of the battery and estimate the state of the battery.

When using the EIS module to measure the impedance of the battery, the EIS module is powered by the secondary battery.

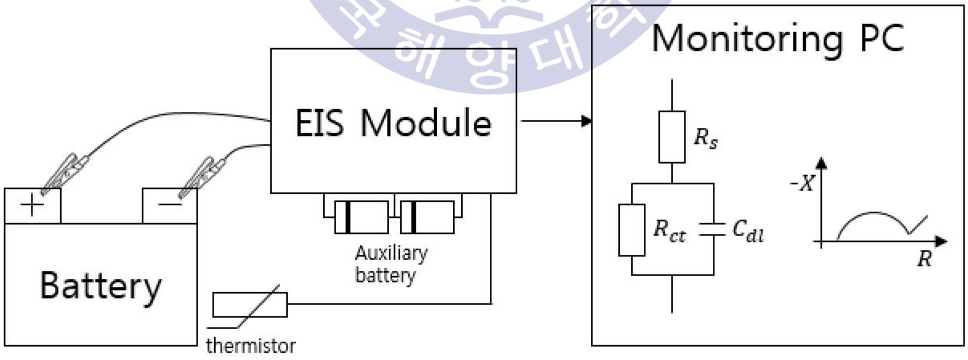


Fig. 16 Block diagram of EIS equipment

3.1 Hardware

The EIS module consists mainly of MCU, auxiliary circuit, battery AC induction circuit, voltage and current measuring circuit, and the communication circuit.

The battery AC induction circuit sets the frequency through the SPI communication in the MCU to induce the AC current to flow through the battery at the set frequency. On the battery bases, alternating current can be interpreted as repeated charging and discharging. The measurement circuit consists of a circuit for amplifying and offsetting the AC current to be measured by the MCU.

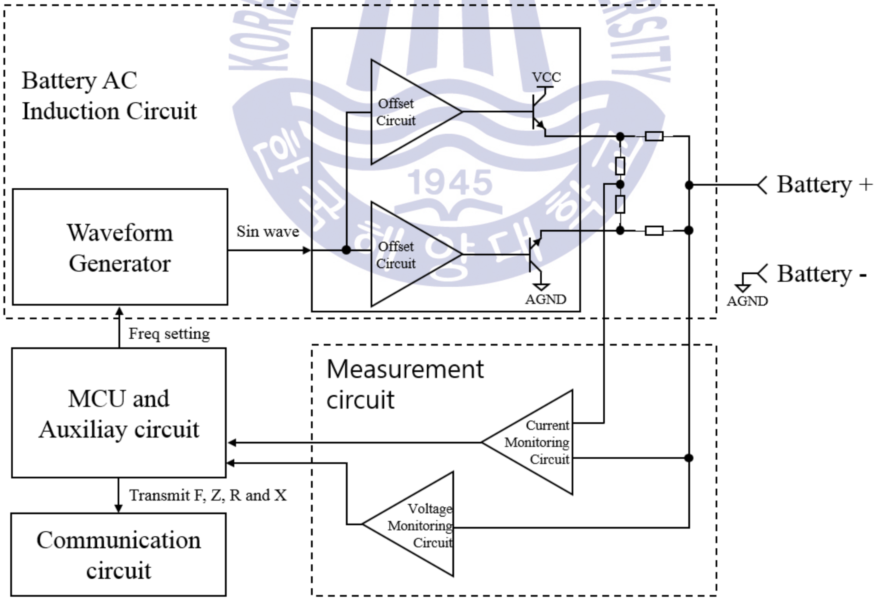


Fig. 17 Block diagram of the circuit

3.1.1 Battery AC Induction Circuit

The function of the AC induction circuit is to communicate alternating current to the battery at a predetermined frequency by communicating with the MCU. It consists of a waveform generator that generates AC sine waves, a BJT that performs AC switching, and an offset circuit that adjusts the potential to enable AC switching.

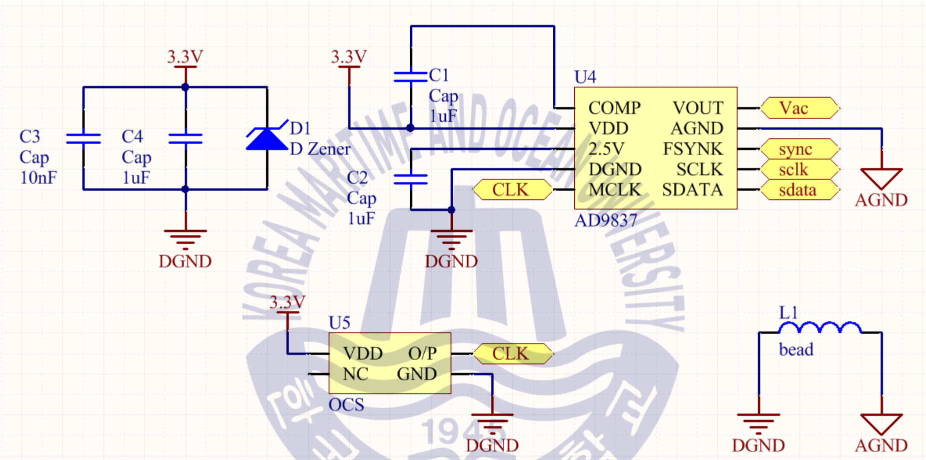


Fig. 18 Waveform generator

Fig. 18 is a circuit corresponding to Waveform generator and AD9837 IC is used. The AD9837 can output the AC voltage corresponding to the specified frequency to the VOUT pin through the SPI communication with the MCU. When the oscillator is used at 16MHz, the frequency of the output voltage can be 60mHz ~ 16MHz, and when 2MHz is used, the frequency of the output voltage can be 7.5mHz ~ 2MHz.

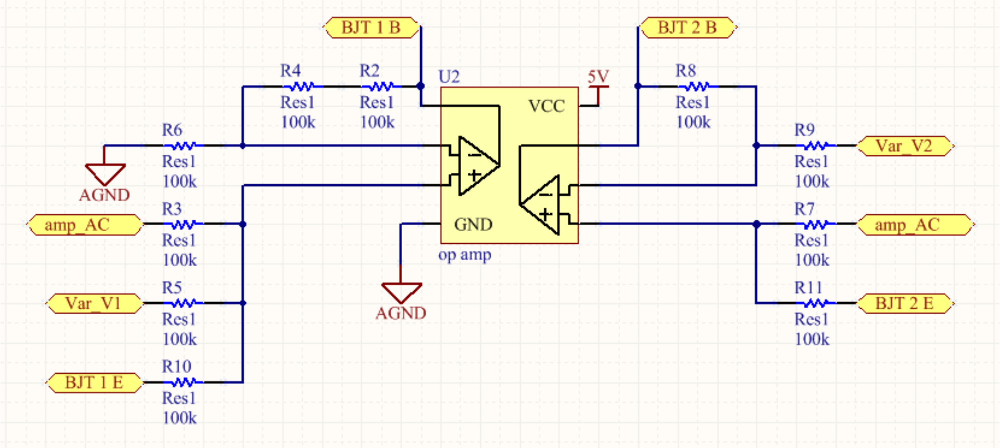


Fig. 19 Offset circuit

Fig. 19 Shows the circuit corresponding to the offset circuit. It is designed to add an offset so that the AC voltage output from the AD9837 can be switched at the BJT using an opamp. The input to this circuit is the output AC voltage of the AD9837, the emitter of the BJT, and an additional offset adjustment voltage. Based on the above circuit, the amplification factor is 1: 1.

When the output voltage is the voltage of BJT 1 B and the voltage of BJT 2 B, the voltage value is as follows.

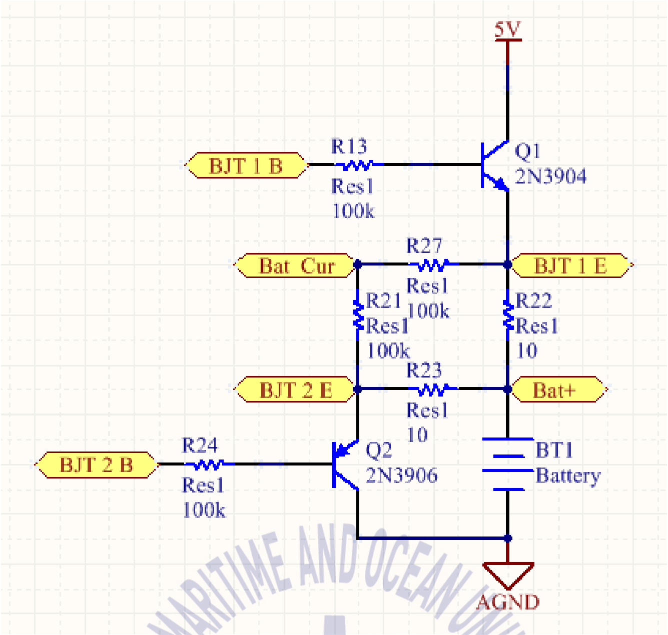


Fig. 20 Charge / discharge and current measuring circuit

Fig. 20 Is a circuit that uses an alternating voltage output from the offset circuit to induce alternating current to flow through the battery. Q_1 is an n-type BJT, and Q_2 is a p-type BJT. Resistance R_{22} is used for measuring the charging current, R_{23} is used for discharging current measurement, and R_{21} and R_{27} are the average of charging current and discharging current.

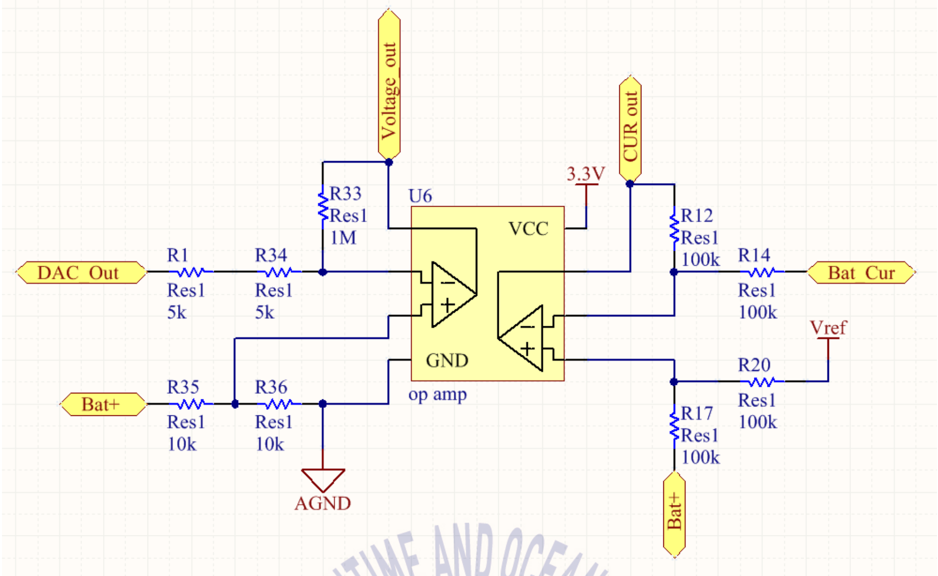


Fig. 21 Current and voltage monitoring circuit

Fig. 21 Is a circuit for measuring the current flowing through the battery and the change in the battery voltage through the MCU. The voltage change is output through Voltage_out, the battery voltage is amplified 50.5 times, and the offset is removed through the DAC. The change amount of the current is outputted through CUR_out and the current value is outputted as the voltage based on Vref. The ratio of the measured current to the output voltage is 5V / A.

3.2 Software

Fig. 22 is an algorithm to measure the impedance of the battery running on the MCU. First, set the frequency of the current flowing in the battery to 5kHz in the MCU. When the frequency is set, the voltage and current are measured after a slight delay. Sampling of voltage and current is done in 1500 pieces. Based on the MCU used in this paper, the 3/2 period of the voltage and current waveform of 166 Hz can be measured with 1500 samples. At frequencies higher than 166 Hz, more cycles are included in 1500 samples, and at frequencies slower than 166 Hz, delays are added to measure 3/2 period waveforms in 1500 samples.

The measured current and voltage calculate the resistance component R and the reactance component X by calculating the change point of the current, the change value of the voltage, and the zero point of the voltage and the current. Continue to measure the impedance while reducing the frequency.

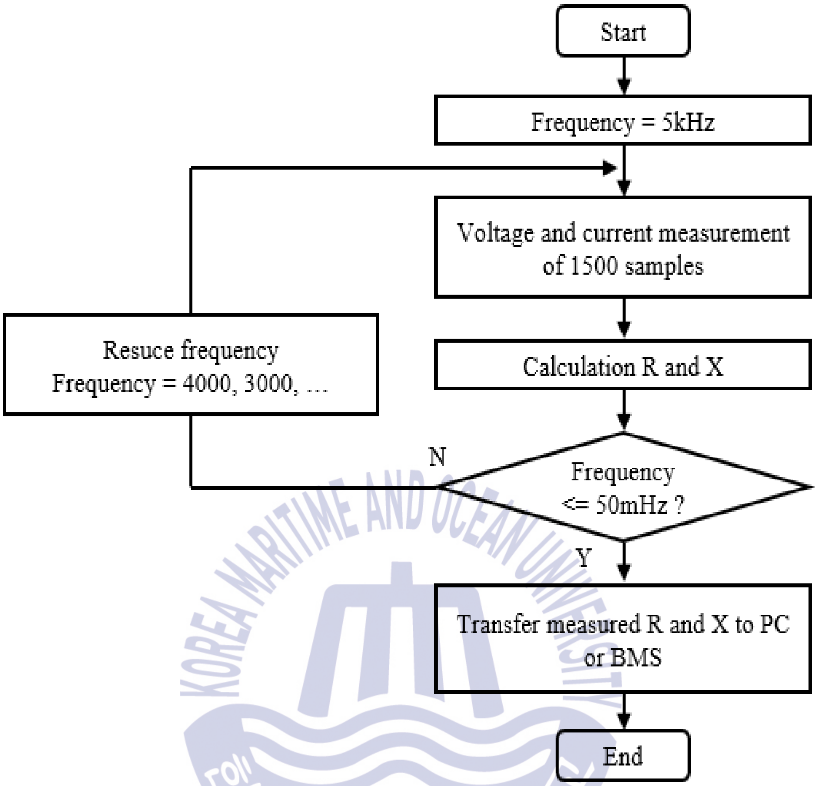


Fig. 22 Impedance measurement flow chart

3.3 Temperature measuring equipment

Fig. 23 Temperature sensor with steel head

The temperature sensor used was IM120628010 from iteadstudio and NTC type temperature sensor was used. NTC (Negative Temperature Coefficient-thermic resistor) is a sensor whose temperature and resistance value are opposite to each other. The lower the temperature, the higher the resistance value. The higher the temperature, the higher the resistance value. There is a way to process all the data by Lookup Table. However, it can affect SOC estimation or SOH estimation calculation for MCU.

However, unlike in MCU, PC can have enough computation amount. 30, the MCU version has a formula of the PC version as the cubic equation, and the equation of the PC version is set as the fifth equation, so that the PC version can be judged as the approximate temperature in the MCU which needs to increase the precision and check the abnormality through the terminal.

3.4 Battery impedance measurement experiment

Fig. 24, Fig. 25 Shows the waveforms of voltage and current when 22 Hz and 100 Hz current flow through the battery. The upper waveform is the current waveform and the lower waveform is the voltage waveform. The situation for two frequencies shows that at 22Hz the current waveform is ahead of the voltage waveform. At 100Hz, the phase angle of the current waveform and the voltage waveform is smaller than that of 22Hz.

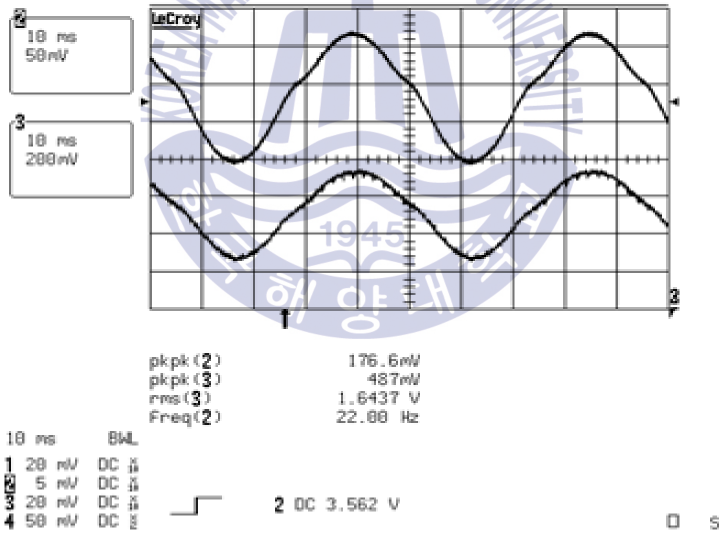


Fig. 24 22 Hz alternating current flows through the battery

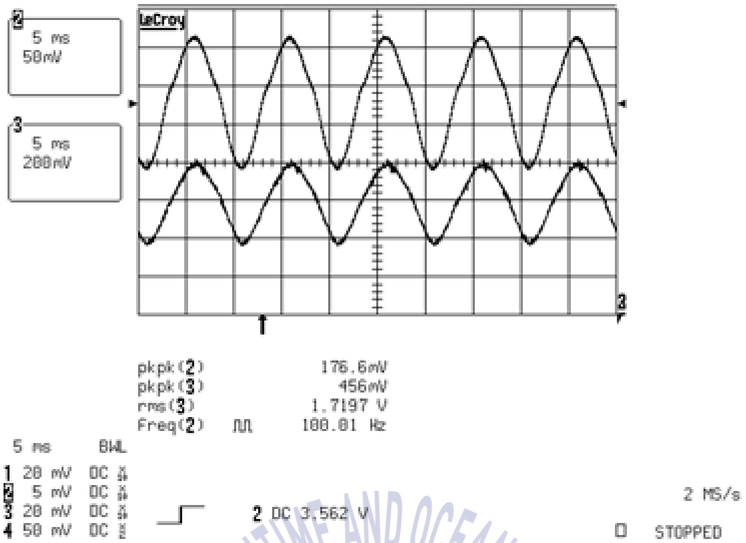


Fig. 25 100Hz alternating current flows through the battery

Fig. 26 shows the experimental results of varying the frequency from 1kHz to 1Hz. The X axis is the resistance component R, and the Y axis is the reactance component X plotted. At 1kHz, the impedance is low, the phase angle is small, and the lower the frequency, the larger the impedance becomes, and the larger the phase angle, the larger the reactance X becomes. After about 50 Hz, the impedance is similar but the phase angle is small, so the region where the reactance X is small can be confirmed.

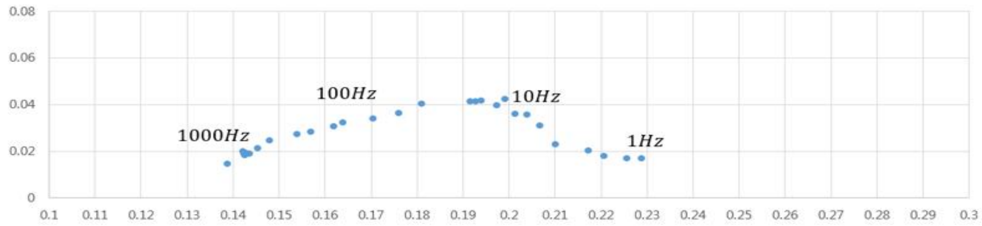


Fig. 26 EIS results of battery

3.5 Impedance according to battery condition

Fig. 27 Shows the change in impedance when the frequency is changed from 5 kHz to 50 mHz. The left side is the new battery and the right side is the battery that has undergone rapid charge and discharge. Batteries that have been charged and discharged compared to new batteries are larger than R_1 and R_2, and bug impedance is observed from a relatively high frequency.

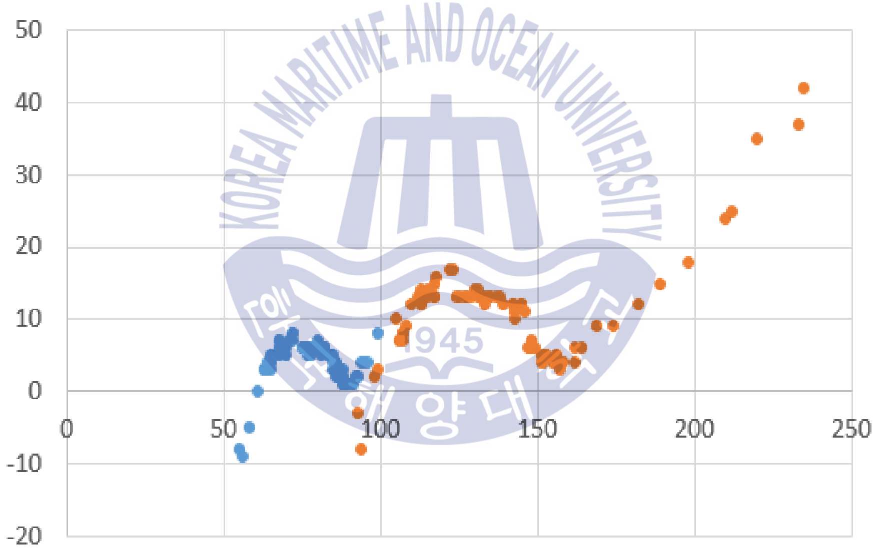


Fig. 27 Impedance change according to lifetime (1)

Fig. 28 Shows the change in impedance when the frequency is changed from 5 kHz to 50 mHz. The right side of the new battery is a battery that is continuously overcharged during the charge / discharge test. As the battery is charged and discharged, R_1 and R_2 are increased, but overcharging progresses and the bug impedance is different from the normal battery. As the frequency decreases, the reactance value increases sharply.

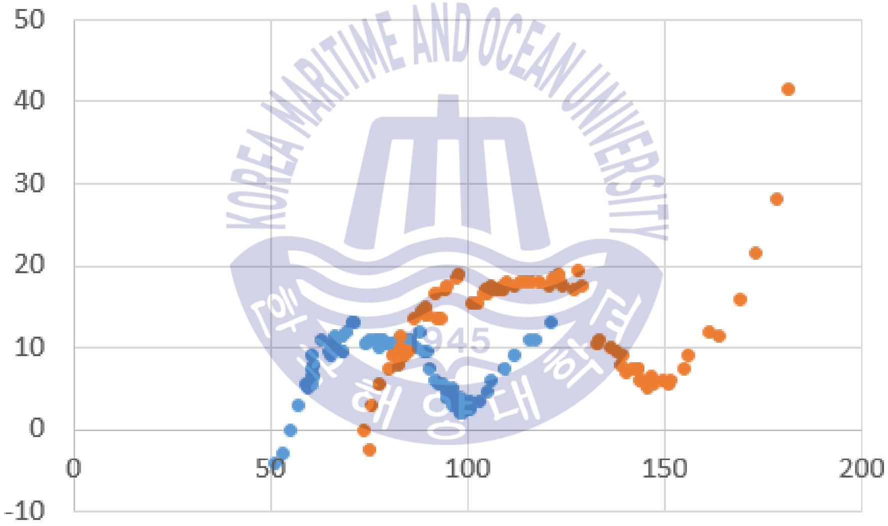


Fig. 28 Impedance change according to lifetime (2)

Fig. 29 is the impedance of a battery which can be used less than half of its original capacity by using a lot of battery. A battery with a relatively low impedance has a capacity of less than 40%, and a battery with a high impedance has a capacity of less than 5%. Both batteries have a semicircle to measure R_1 and R_2, but they are small enough to be meaningless compared to the bug impedance. In both batteries, the reactance value X rises sharply as the frequency and the bug impedance decrease. In dead batteries, the reactance value X increases and the resistance value R decreases. Additional research is needed.

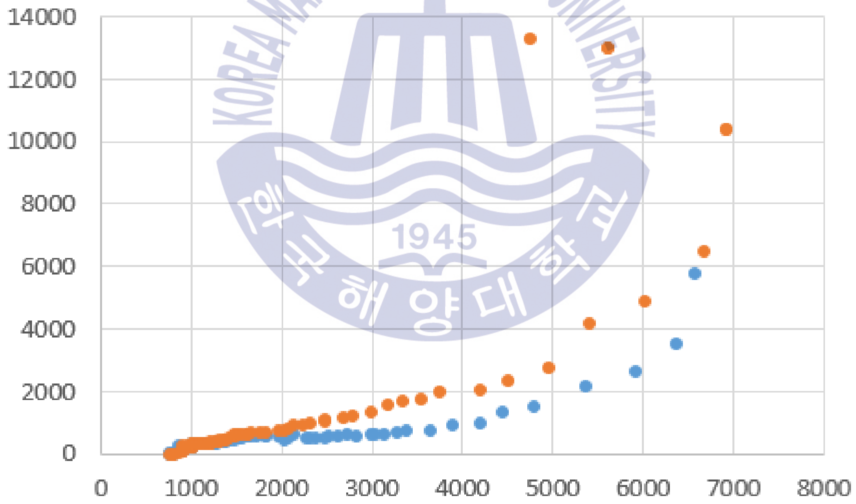


Fig. 29 Impedance of battery with very low initial capacity

Fig. 30 is a battery that has been left on for too long with the BMS installed and has been continuously discharged. Impedance measurements were performed by charging the battery. The change in the impedance of this plot is due to a sudden rise in the reactance value X in the middle of the semicircle and the bug impedance is observed in the middle. However, usually the battery is observed at frequencies where and bug impedance is the slowest, but other types of impedance changes in this battery were observed at slower frequencies.

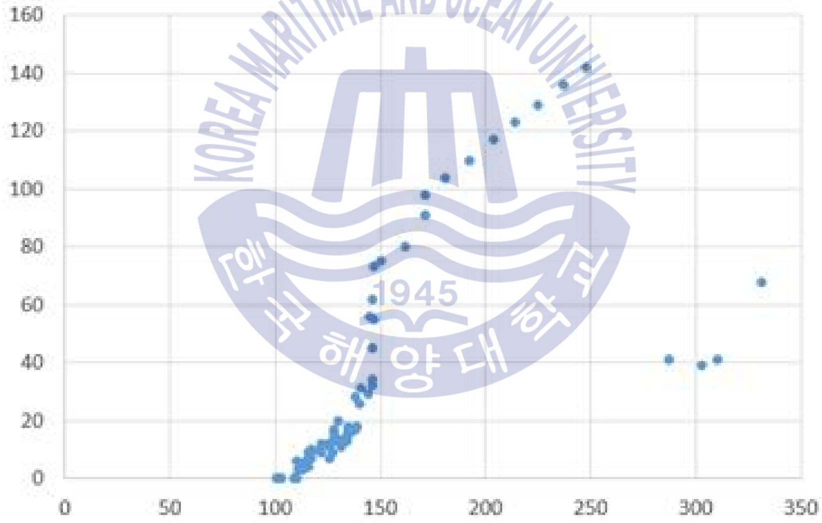


Fig. 30 Batteries made by continuous overdischarge by BMS

4. Conclusion

In this paper, we measured the impedance of a battery using Electrochemical Impedance Spectroscopy and estimated the state of the battery using it.

In order to check the applicability of the proposed development system, we measured the impedance for a lithium polymer battery.

The results of this study are summarized as follows.

1) The alternating current and alternating voltage of the battery are measured by inducing an alternating current to the battery. In the case of AC voltage, the peak value of the voltage is low and the circuit for amplifying it is constructed and measured.

2) It is possible to estimate the state of the battery and to check the impedance information to judge whether the battery can be used in the future.

3) The EIS equipment proposed in this paper has a disadvantage that the equipment cost of the battery is increased. However, there is a great advantage in not only being able to check the state and information of available batteries in an emergency, but also to prevent accidents caused by the battery. In addition, it is expected to be applicable to various fields such as checking the overall condition of a battery room divided in

a large land / marine plant and checking initial defective battery in a battery production factory.

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감사의 글

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