International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-5; May, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.115.7

Effect of Charging Current Variation on Internal Resistance in Lithium-Ion Batteries

Keshawa Udiatma, S.T.[1], Trias Andromeda, S.T., M.T., Ph.D.[2], Dr. Iwan Setiawan, S.T., M.T.[3]

[1]Department of Electrical Engineering, Diponegoro University, Indonesia
Email: keshawaudiatmaa@gmail.com
[2]Department of Electrical Engineering, Diponegoro University, Indonesia
Email : triasandromeda@lecturer.undip.ac.id
[3]Department of Electrical Engineering, Diponegoro University, Indonesia
Email : iwansetiawan@lecturer.undip.ac.id

Received: 09 Apr 2024,

Receive in revised form: 11 May 2024,

Accepted: 22 May 2024,

Available online: 31 May 2024

***Keywords*— Current, Internal Resistance, Charging, State of Health, Lithium-Ion.**

***Abstract*— Internal resistance of a battery is affected by the amount of charging current and how many charge cycles are carried out. The value of internal resistance is also related to the State of Health (SoH) of the battery. The smaller value of internal resistance indicates a higher SoH of the battery. This paper presents a comparison of internal resistance due to variation of charging current. The current values are 500 mA, 1000 mA, and 3000 mA. Lithium-ion 18650 batteries which have capacity 1200 mAh are charged by these current values. Three batteries are used using three scenarios, namely the 500 mA for scenario 1 using the Liitokala-Lii500 charger, 1000 mA for scenario 2 using the Liitokala-Lii500 charger, and the 3000 mA for scenario 3 using the XL4016 constant current (CC) constant voltage (CV) charger. Every battery is charged 20 times. Internal resistance of each battery is measured using YAOREA YR1030 module during experimental work. The data experiments indicate that variation of current of 500 mA for scenario 1, internal resistance is increased by 1 mΩ. Scenario 2, 1000 mA, internal resistance will extend by 1.4 mΩ. Scenario 3 which uses 3000 mA, gives the highest internal resistance alteration by 2.1 mΩ. It can be concluded that the greater values of charging current will affect a higher value of internal resistance.*

I. INTRODUCTION

Recently, batteries are widely used for electrical energy storage. Batteries can be easily applied to existing electronic devices and convenience to users.

Batteries have many types depending on the use to be used, but batteries also have an age where the battery is still suitable for use or not, battery life is usually called State of Health (SoH). SoH has many parameters to determine whether the battery has good performance or has decreased performance including the value of internal resistance, internal resistance is one of the parameters that shows the ability of the battery to conduct electric current. The lower the value of the internal resistance, the better the battery's ability to flow current. The higher the internal resistance value also affects the decrease in battery performance to flow current, the energy lost due to the large value of the internal resistance will be converted into heat, which makes the battery heat faster and battery performance will decrease. Lithium-ion 18650 batteries were used in research because they have several advantages, namely fast charging, long battery life, and higher power density.

But in addition to the advantages of lithium-ion batteries, lithium-ion batteries also have some disadvantages, namely temperatures that can increase quickly, prone to overcharge which can damage the battery, prone to explode if too hot. The selection of the 18650 battery is based on the experience of researchers that the 18650 battery has better battery life for performing charge and discharge cycles with large quantities, and also has a more diverse reference module measurement circuit than other types of batteries. The author chose to use the constant current constant voltage charger method because this method is considered the safest method for batteries because it combines 2 charging methods that can avoid overcharge if the battery remains installed in the module when the condition is fully charged.

II. RESEARCH METHODS

The research method will be divided into two parts, namely theoretical basis and research flow.

2.1 Theoretical Basis

2.1.1 Lithium-Ion Battery

The batteries used in this research are *lithium-ion* 18650 type batteries. This type of battery falls into the category of rechargeable batteries. *Lithium-Ion* batteries are widely used in electronic devices that require high power and have a long lifespan. The name "18650" refers to the physical dimensions of the battery, which are 18 *mm* in diameter and 65 *mm* in height, with "0" indicating high tolerance. For example, these batteries have a longer lifespan when used in electronic circuits equipped with protection [1].

These batteries have a standard operating voltage of 3.7 *V* and a maximum operating voltage of 4.2 *V* when fully charged. When the voltage is between 2.8 *V* and 3 *V*, it indicates that the battery is empty. The maximum capacity of these batteries is known to reach 3600 *mAh*, which means the battery can provide an electrical current of 3600 *mA* for one hour of use [1].

The basic component of these batteries is *lithium-ion*, which can be combined with other chemicals such as *cobalt*, *manganese*, and so on. The advantage of this material is its large storage capacity and it does not have detrimental memory effects after several charging and discharging cycles. However, these batteries are susceptible to the risk of fire under certain conditions [1].

2.1.2 Internal Resistance

Internal resistance is a crucial parameter for assessing the health condition of a battery. Generally, the lower the internal resistance, the better the battery is at delivering current to electronic devices. Conversely, if the internal resistance increases, the battery will struggle to deliver current to electronic devices and may cause excessive heat in the battery [2]. This determines whether the battery can still be used and provides an indication of its lifespan.

Measuring the internal resistance of a battery can be done by using a circuit where the batteries are connected in a closed loop, with the load directly connected to the battery.

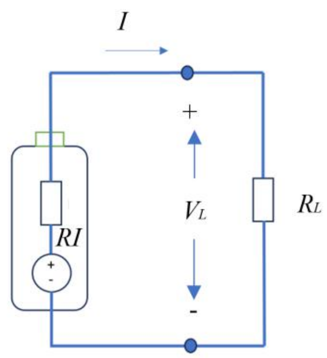

Fig. 1: Internal resistance tester circuit

In Fig. 1, we can add an *RL* load to calculate the magnitude of the internal resistance (*RI*) of the battery. First, we will use *Ohm*'s law to find the value of the current (*I*) flowing from the battery to the *RL* load, and the calculation can be seen in the following equation (2.1) :

$$I = VL \ / \ RL \qquad (2.1)$$

After determining the magnitude of the current (*I*) flowing from the battery to the load, the next step is to calculate the voltage drop across the internal resistance. The principle used to calculate the voltage drop is using *Kirchoff*'s law, which states that the voltage drop across both resistors, *RI* and *RL*, must be equal to the ideal battery voltage. This voltage drop will be symbolized by *VI*. Where *Voc* is the voltage reading when the circuit is open, measured manually using a multimeter. Thus, the calculation to determine the value of *VI* or the voltage drop can be seen in the following equation (2.2) :

$$VDROP = VOC - VL \qquad (2.2)$$

After determining the value of the voltage drop that occurs across the internal resistance, the next step is to find the value of the internal resistance (*RI*) using *Ohm*'s law. This can be calculated using equation (2.3) as follows :

$$RI = VDROP \ / \ I \qquad (2.3)$$

After the calculation above, the value of its internal resistance can be determined. This value determines whether the battery is still usable or not, as a higher internal resistance leads to poorer battery performance.

The increase in internal resistance value in the battery is typically influenced by the charging and discharging cycles, age, and battery temperature.

2.1.3 Buck Converter XL4016 CCCV

The charger module used in this study is the XL4016 Buck Converter Constant Current Constant Voltage (CCCV) module. This module has the main function of converting the DC value of a system to be smaller than its input voltage, or in other words, reducing the input voltage [3]. The XL4016 module has two loops or multilevel feedback, the inner loop, which controls current, and the outer loop, which controls output voltage. The XL4016 module is depicted in Fig. 2. below.

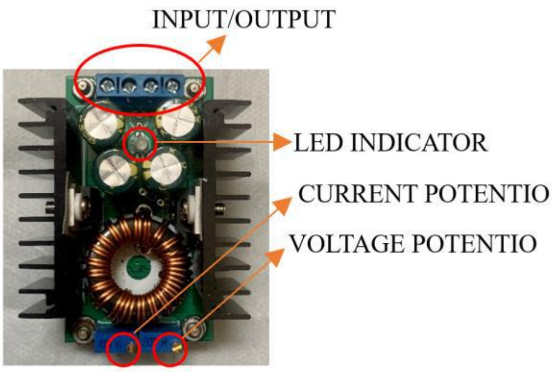

Fig. 2: Buck converter XL4016 module

The XL4016 module has two components potentiometer that functions to adjust the output voltage and another potentiometer that functions as a current limiter generated by the buck converter. The working principle of the XL4016 module is as follows,

a. Outer Loop (CV mode)

If the load connected to the module is a resistive load, with a resistance value large enough approaching infinity, then the resulting voltage at the control block will be relatively small, and this control value will become the current reference value. The module will activate constant voltage mode, meaning the output voltage will track this reference.

b. Inner Loop (CC mode)

If the load connected to the module is a resistive load, with a resistance value very small approaching zero, then the result from the voltage feedback control will produce a relatively large control signal (approaching infinity). However, because the control signal passes through the current saturation block or limiter, what is passed to the inner loop is the flowing current, which does not exceed the current limit set on the current potentiometer. The module will activate constant current mode.

In conclusion, constant voltage (CV) mode will be active when the current value is below the current limit, while constant current (CC) mode will be active when the current reaches the current limit, indicating that the battery charging mode has reached a full or charged condition.

2.2 Research Flow

The research procedure begins with determining the type of battery to be used, namely the *lithium-ion* 18650 battery with a capacity of 1200 *mAh*. Subsequently, the internal resistance value of the battery is measured using the YAOREA YR1030+ Internal Resistance Tester before the charging process. Ensure that the battery is in a discharged state before conducting the internal resistance measurement. The results of the internal resistance measurement of the battery can be seen in Fig. 3. below.

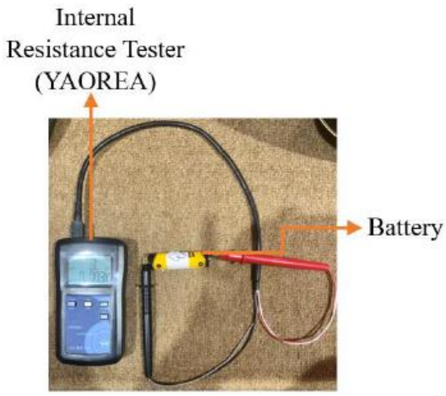

Fig. 3: Measuring battery internal resistance

After obtaining the initial values of internal resistance and battery voltage before the charging process, the next step is to install the battery for scenarios 1 and 2, which involve current variations of 500 *mA* and 1000 *mA*, using the Liitokala-Lii500 charger module. This can be seen in Fig. 4. below.

In scenario 1, with a charging current variation of 500 *mA*, the battery takes approximately 2 hours and 5 minutes to reach full charge. Meanwhile, in scenario 2, with a charging current variation of 1000 *mA*, the battery requires about 1 hour and 10 minutes to reach full charge. After the battery is fully charged, the internal resistance and voltage values are measured again to gather data post-charging.

The next step is to assemble the battery charger circuit for scenario 3 by connecting a 19*V* power supply to the XL4016 charger module to reduce the voltage to 4.2 *V*, and adjusting the desired output current variation to 3000 *mA*. This can be seen in Fig. 5.

Fig. 4: Battery charging for scenario 1 and scenario 2

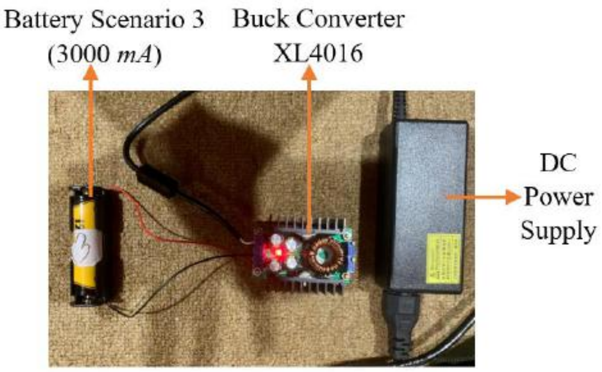

Fig. 5: Battery charging for scenario 3

During the charging phase of scenario 3 with a current variation of 3000 *mA*, the battery requires approximately 35 minutes to reach full charge. However, the time needed for the battery to charge from empty to full is considered too long. This is due to the charging current supplied by the XL4016 module to the *lithium-ion* battery not reaching precisely 3000 *mA*. This is because the *lithium-ion* battery used in this study does not have a *C-Rate* specification that allows such a high current to flow.

The ideal time required to charge a 1200 *mAh* battery should only take 24 minutes if the charging current flowing from the XL4016 module reaches 3000 *mA*. When charging the battery load, the LED on the XL4016 module will be colored red, which means that the module by continuously flowing charging current, this condition can be referred to as constant current mode. Then the LED will be blue when the battery is fully charged which means that current is no longer flowing from the module to the battery, but the voltage value remains constant to keep the battery in full condition, which means the module is in constant voltage mode. Once the battery is fully charged it then takes measurements of the internal resistance value and voltage back to collect data after the charging process.

The next stage is to assemble the discharging module using the Zhiyu ZB2L3 module which is supplied with a DC voltage supply of 5 *V*, the Zhiyu ZB2L3 module has a discharge current setting value of 1 *A*. The installation scheme of the discharge module can be seen in Fig. 6.

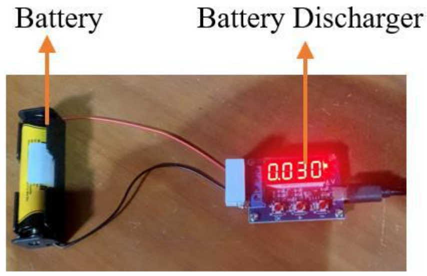

Fig. 6: Battery discharging system

In this stage, the battery is installed in the Zhiyu ZB2L3 module to undergo the discharging process with a minimum discharge voltage limit of 3*V*. This value is chosen because it is considered safe to discharge the battery without damaging it. The discharging process takes approximately 1 hour and 25 minutes, and it is considered complete when the LED screen flashes continuously, indicating that the battery capacity value has been reached.

After all stages are completed, the process continues with the final measurement of internal resistance values for all three batteries using the YAOREA YR1030+ Internal Resistance Tester module. This process is repeated until the internal resistance and battery voltage values are obtained after the discharging process. The measurement process is repeated 20 times, representing 20 charging and discharging cycles.

The final stage of this research is the creation of a trend graph comparing the internal resistance values of the batteries when new with the internal resistance values after undergoing 20 charging and discharging cycles.

III. RESULTS

The process of measuring the internal resistance value of the batteries is conducted over 20 charging and discharging cycles. These measurements are taken after the batteries undergo the charging process as well as after they undergo the discharging process. The results of these measurements are recorded in graphs that show the increase in internal resistance values across the three current variation scenarios. These graphs can be seen in Fig. 7., Fig. 8., and Fig. 9.

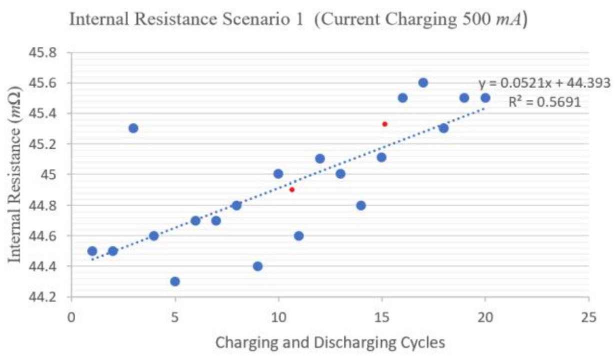

Fig. 7: Internal resistance graph of scenario 1 (500 mA)

In Fig. 7., it can be observed that the data for the internal resistance value in the charging current variation scenario of 500 mA has an initial value of 44.5 mΩ. This value increases to 45.5 mΩ, indicating that the battery experiences an increase in internal resistance of 1 mΩ after undergoing 20 charging and discharging cycles.

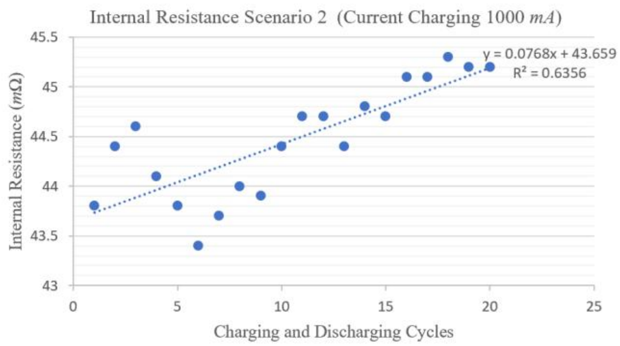

Fig. 8: Internal resistance graph of scenario 2 (1000 mA)

In Fig. 8. it can be seen that the data of the internal resistance value in the scenario of a charging current variation of 1000 *mA*, has an initial value of 43.8 *mΩ* whose data increases to a value of 45.2 *mΩ*, which means that the battery experiences an increase in the value of internal resistance by 1.4 *mΩ* after 20 charge and discharge cycles.

In Fig. 9., it is evident that the data for the internal resistance value in the charging current variation scenario of 3000 *mA* has an initial value of 41.5 *m*Ω. This value increases to 43.6 *m*Ω, indicating that the battery experiences an increase in internal resistance of 2.1 *m*Ω after undergoing 20 charging and discharging cycles.

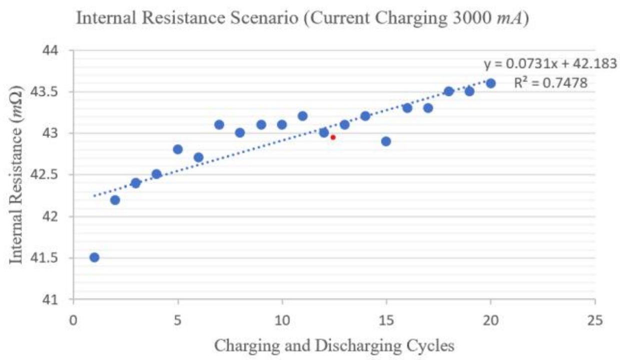

Fig. 9: Internal resistance graph of scenario 3 (3000 mA)

IV. CONCLUSION

From the data obtained in this study, it can be concluded that the larger the charging current variation, the greater the increase in internal resistance in the battery. In the case of scenario 1, with a current variation of 500 *mA*, there is a lower increase in internal resistance, only 1 *m*Ω. Meanwhile, in scenario 2, with a current variation of 1000 *mA*, there is an increase in internal resistance of 1.4 *m*Ω, and in scenario 3, with a current variation of 3000 *mA*, there is the highest increase in internal resistance, which is 2.1 *m*Ω. The larger the value of the charging current variation, the greater the impact on the State of Health (SoH) of the battery, as the internal resistance value will increase more rapidly compared to the charging process using small currents.

One advantage of using larger current variations is shorter charging times. For example, in scenario 3 with a charging current variation of 3000 *mA*, only 35 minutes are needed, which is much faster than scenario 1, where a charging current variation of 500 *mA* requires about 2 hours and 5 minutes.

REFERENCES

[1] 6 Jenis Baterai Mobil Listrik dan Karakteristiknya. Retrieved Augustus 8 , 2023, from https://nissan.co.id/new-press/artikel/6-jenis-baterai-mobil-listrik-dan-karakteristiknya/

[2] Measuring Internal Resistance of Batteries. Retrieved December 18, 2023, from https://learn.sparkfun.com/tutorials/measuring-internal-resistance-of-batteries/internal-resistance

[3] Metode Pengisian Baterai Asam Timbal. Retrieved Augustus 9, 2023, from https://henduino.github.io/library/ototronik/leadacid-charger/

[4] Putra, R., Rusdinar, & Kurniawan. (2015). Desain dan Implementasi Sistem monitoring dan Manajemen Baterai

Mobil Listrik. Bandung: Fakultas Teknik Elektro, Universitas Telkom.

[5] Farizy, A., Asfani, & Soedibjo. (2016). Desain Sistem Monitoring State of Charge Baterai Pada Pengisian Station Mobil Listrik Berbasis Fuzzy Logic Dengan Mempertimbangkan Temperature. Surabaya: Jurusan Teknik Elektro, Fakultas Teknologi Industri, Institut Teknologi Sepuluh November.

[6] Susanti, R., Rumiasih, Carlos, & Firmansyah. (2019). Analisa Penentuan Kapasitas Baterai dan Pengisiannya Pada Mobil Listrik. Palembang: Politeknik Negeri Sriwijaya.

[7] Suwanto. (2016). Rancang Bangun Sistem Pengisian Baterai Berbasis Smart Pengisian Dengan Metode Pengisian Arus Konstan. Surabaya: Program Magister Bidang Keahlian Instrumentasi, Fakultas Matematika dan Ilmu Pengetahuan Alam, Institut Teknologi Sepuluh November.

[8] Fan, Y., Yijie, L., & Renjing, S. (2023). A Module-Level Pengisian Optimization Method of Lithium-Ion Battery Considering Temperature Gradient Effect of Liquid Cooling and Pengisian Time. China: Dallan University of Technology.

[9] Arunagirinathan, S. (2023). Analysis of a Li-Ion Battery State of Charge by Artificial Neural Network. Department of Electrical and Electronics Engineering, Government College of Technology, India.

[10] Fioritti, Sacarpelli, Pellegrino, Lutzemberger, Micolano, & Samalone. (2023). Battery Lifetime of Electric Vehicles by Novel Rainflow-Counting Algorithm With Temperature and C-Rate Dynamics: Effect of Fast Charging, User Habits, Vehicle-To-Grid, and Climate Zones. University of Pisa, Italy.

[11] Zhicheng, Zhang, Sun, & Liu. (2022). The Electric-Thermal Coupling Simulation and State Estimation of Lithium-Ion Battery. Hebei University of Technology, China.

[12] Xianfei, Zhang, Wang, Zhang, Zhiqiang, Zhu, Zhao, Liu, & Jiang. (2022). Transient Thermal Analysis of The Thermal Management of High-Power Fast Charging Module Using Phase Change Material. Zhongyuan University of Technology, China.

[13] Al-Saadi, Olmos, Saez-de-Ibarra, Mierlo, & Berecibar. (2022). Fast Charging Impact on Lithium-Ion Batteries' Lifetime and Cost-Effective Battery Sizing in Heavy-Duty Electric Vehicle Applications. Vrij Universiteit Brussel, Belgium.

[14] Jiang, Berliner, Lai, Asinger, Zhao, Herring, Bazant, & Braatz. (2021). Fast Charging Design for Lithium-Ion Batteries via Bayesian Optimization. Department of Automation, Tsinghua University, Beijing, China.

[15] Makeen, Ghali, & Memon. (2022). A Review of Various Fast Charging Power and Thermal Protocols for Electric Vehicles Represented by Lithium-Ion Battery Systems. Electrical Engineering Department, Faculty of Engineering, The British University of Egypt, Egypt.

[16] Irianto, Yanaratri, & Rahmatullah. (2021). Desain dan Simulasi Battery Charger Metode CCCV (Constant Current-Constant Voltage) dengan Kontrol Logika Fuzzy Menggunakan MATLAB. Politeknik Elektronika Negeri Surabaya, Surabaya.

[17] Ramadhan, Putra, Salam, Parizi, Anugrah, & Warmi. (2022). Perancangan Model Wireless Fast Charging Menggunakan Constant Current Dan Constant Voltage Pada Kendaraan Listrik. Program Studi Teknik Elektro, Institut Teknologi Padang, Padang.

[18] Bakhtiar, & Tadjuddin. (2021). Pengaruh Battery Management System (BMS) Pada Pengisian Baterai Lithium Sistem PLTS. Teknik Elektro, Politeknik Negeri Ujung Pandang, Makassar.

[19] Anshori, Siswojo, & Hasanah. (2020). Teknik Fast Charging Baterai Lithium-Ion Menggunakan Logika Fuzzy. Universitas Brawijaya, Surabaya.

[20] Nugraha, Ersha, Sunarno, Qudsi, Frediansyah, & Prabowo. (2021). Desain Baterai Charger Kendaraan Listrik dengan Metode Constant Current dan Constant Voltage. Politeknik Elektronika Negeri Surabaya, Surabaya.

[21] Yaqin, Pratiwi, & Maison. (2019). Rancang Bangun Charge Controller Panel Surya Dengan Menggunakan Sistem Fast Charging. Fakultas Teknik Elektro, Universitas Jambi, Jambi.

[22] Tarigan, Setiawan, & Edi. (2022). Rancang Bangun Voltmeter Ekonomis Berbasis Android Dengan Kalibrasi Open Circuit Voltage Menggunakan Metode Moving Average Untuk Aplikasi Sistem Monitoring Baterai Pada Kendaraan Elektrik. Teknik Otomotif, Mesin Otomotif, Politeknik Astra, Cikarang.

[23] Firmansah, Prastiyo, & Alimi. (2022). Rancangan Bangun Indikator Baterai Untuk Baterai Pesawat Tanpa Awak Menggunakan Sensor INA260 Secara Nirkabel. Teknik Dirgantara, STTKD, Yogyakarta

[24] Mamahit, Ticoh, Memah, & Angmalisang. (2022). Studi Sistem Pengisian Cepat Baterai Kendaraan Listrik Berbasis Papan Pengendali OpenEVSE. Pendidikan Teknik Elektro, Fakultas Teknik, Universitas Negeri Manado, Manado.