Research Article

Intelconn Smart Connection System to Improve Battery Energy Storage Reliability

[1,*] **Sutisna Abdul Rahman**, [2] **Raedy Fathurozzi**

[1,2] Department of Electrical Engineering, Langlangbuana University, Bandung, West Java, Indonesia

* Corresponding Author: sutisna.abdulrahman@unla.ac.id

Abstract: Degradation in battery cells is an unavoidable phenomenon, especially in battery modules connected in parallel. Inconsistencies in current distribution and temperature rise can accelerate degradation and pose potential safety issues. Therefore, evaluation and mitigation strategies are needed to reduce the impact of degradation on each battery cell. This research develops an extended single-particle model with Pade's approach and Taylor expansion to simplify the conventional electrochemical mechanism. Based on this approach, a multidomain electrochemical mechanism simulation model for battery modules connected in parallel is developed. The model was used to analyze the effect of cell degradation on battery module voltage, internal current distribution, and temperature rise under various charging and discharging conditions. The evaluation was conducted using the parameter sensitivity analysis method to assess the contribution of each parameter to the degradation of the parallel-connected battery cells. The results of this study are expected to help in identifying battery cells that degrade faster and developing optimal strategies in battery management for longer life and safe use.

Keywords: battery degradation, current distribution, temperature rise, electrochemical model, sensitivity analysis.

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1. Introduction

In recent years, the use of Battery Energy Storage Systems (BESS) has grown rapidly, especially in supporting renewable energy systems such as solar and wind power. BESS serves as an energy storage solution that allows flexibility in power distribution by storing excess energy when production is high and releasing it when demand increases. This makes BESS a critical component in modern electricity systems, both for large-scale (grid-scale) and small-scale (residential and industrial). One of the main challenges in the implementation of BESS is the uneven degradation of battery cells in a battery pack. This degradation occurs due to various factors such as current inconsistency between cells, uneven temperature rise, and repeated charge and discharge cycles. If not properly monitored, this degradation can lead to decreased storage capacity, imbalances in the system, and potential safety risks such as overheating or thermal runaway.

In addition, the battery is still the most expensive component in the BESS system, mainly because most of the battery cells used are still imported products. Therefore, the efficiency and lifetime of the battery must be optimized so that the BESS system can work economically and sustainably. One way to improve efficiency is to implement a real-time battery cell condition monitoring system that can detect changes in key parameters such as voltage, current, temperature, and capacity of individual cells in the battery pack.

This research aims to develop a battery cell condition monitoring system in BESS with the Pade approach and first-order Taylor expansion. This method is used to improve the accuracy in predicting battery condition, so as to mitigate degradation early and optimize current distribution between cells. With a more sophisticated monitoring system, it is expected that the BESS system can have a longer service life, more stable performance, and higher security in renewable energy applications and backup power supply systems.

With this research, it is hoped that the proposed solution can be an innovative step in improving the efficiency, reliability, and sustainability of battery-based energy storage systems. Based on the background that has been described, there are several main problems in the use of Battery Energy Storage System (BESS), especially in the aspects of monitoring the condition of battery cells and optimizing battery degradation. The problem formulations in this research are as follows:

1. How to design a system that can improve the reliability of BESS?
2. How to design a monitoring system to detect and analyze cell performance inconsistencies in BESS?
3. What methods can be used to analyze and identify degradation in Battery BESS?

This problem formulation will be the basis of research to design and develop a more accurate and effective battery monitoring system, in order to increase the efficiency and lifespan of battery-based energy storage systems. This research aims to develop a degradation monitoring and analysis system for the Battery Energy Storage System (BESS) to improve its reliability and efficiency. The main objectives of this research are:

1. Designing a system that can improve the reliability of BESS, so that the energy storage system is more stable and safe in the long term.
2. Develop a real-time monitoring system to detect and analyze the inconsistency of battery cell performance in the battery pack.
3. Analyze effective methods for identifying battery cell degradation and its impact on BESS capacity and performance.
4. Optimizing current distribution and charge/discharge cycles to extend battery life and improve energy storage system efficiency.

With this research, it is hoped that the proposed solutions can help improve the efficiency, reliability, and sustainability of battery-based energy storage systems, especially in supporting renewable energy and modern electricity systems.

2. Literature Review

2.1 *State of Charging (SOC)*

Research with the title "NMC Lithium ION Battery Management with Distributed Monitoring Topology". It is a previous research that the author did on how a system controls all operations between the battery and the required load. A battery management system is an electronic system intended to regulate, monitor, and prevent conditions that can cause damage to the battery. Given Fan Zhang's previous research on hybrid balancing design and testing, which involves active balancing for each module and passive balancing for each cell. Balancing accuracy, SOC accuracy, and balancing speed tests were used. Results showed that the battery balancing system worked but was very slow; it took twelve hours and forty-four minutes to balance a battery with a voltage difference of 0.9V. On the other hand, the battery supervision system can accurately predict the remaining voltage when the battery is charged and discharged [1]. One active balancing method is pack-to-cell, which channels all the charge from each cell to the pack and then back to each cell to perform active balancing. In this method, the cell with the highest SOC (State of Charging) value is transferred to the cell with the lowest SOC, while keeping the cell with the lowest SOC in mind [2].

The active cell balancing technique transfers cells with higher SOC to lower SOC to increase efficiency. While this is very effective as cells with higher SOC receive more energy, it also increases the complexity of the balancing circuit. Currently, active cell balancing components consist of transducers, DC-DC connectors, and relays. Five separate groups comprise the balanced active method, namely cell to cell, cell to pack, cell to cell, and cell to pack [4]. Jun Xu discusses the optimization of the system management battery from the interference problem in 2016. These disturbances cause the battery to not work fully. Consequently, the battery management system (BMS) should anticipate various types of interference. In other words, the BMS should detect battery faults as soon as they occur. The simulations conducted show that this method can process the fault values and minimize them. This is demonstrated by using the Current Disturbance Estimation method. The BMS system must be fast and accurate in providing response signals and has demonstrated a level of accuracy in responding to battery faults [5].

2.2 *Battery Energy Storage System (BESS)*

Understanding how battery energy storage systems work is essential for anyone who wants to delve into the industry. A Battery Energy Storage System (BESS) is essentially a large-capacity battery that stores energy for later use. This technology ensures a steady supply of electricity when the main energy source is not available. BESS is an important solution for utilities, businesses, and households as it can cope with fluctuations in energy supply due to weather, power outages, or geopolitical factors [6,7].

In recent years, BESS has rapidly evolved from an enabling technology to a key component in modern energy strategies, especially in its integration with renewable energy sources such as solar and wind power. Although abundant, solar and wind energy are not available all the time. By connecting BESS to photovoltaic (PV) systems or wind turbines, the energy generated can be stored and used when needed. This ensures a steady supply of power and overcomes the intermittent nature of renewable energy while improving overall system reliability [8,9,10].

In simple terms, BESS works by storing electrical energy obtained from the grid, power plants, or renewable energy sources such as solar panels and wind turbines. This energy is then re-released when power grid operators (Distributor System Operators - DSOs) need additional power. However, these systems are more than just energy storage batteries. When combined with advanced software, BESS becomes a smart energy management platform. With artificial intelligence (AI), machine learning, and data-driven analytics technologies, it can optimize energy consumption, match supply to demand, and improve the efficiency of energy use. BESS plays an important role in accelerating the transition to clean energy. By supporting the utilization of renewable energy, it helps reduce carbon emissions and lower energy costs for businesses and households, making it a sustainable solution for the future.

2.3 Battery Management System (BMS)

A Battery Management System (BMS) is an electronic system used to monitor, protect, and optimize the performance of rechargeable batteries. The BMS plays a role in estimating the stored energy, balancing the cells, as well as regulating the battery conditions to suit the surrounding environment. In addition, the BMS also serves as a link between the battery and the user device, enabling safer, more efficient, and reliable operation. Batteries are at high risk of safety issues if not managed properly. Overcharging can lead to an increase in battery temperature which could potentially cause a fire or explosion. Conversely, over-discharge can permanently reduce the battery's capacity due to irreversible chemical reactions [11,12,13].

Moreover, to prevent these risks, the BMS is equipped with a safety monitoring and control system that detects abnormal conditions, such as overvoltage, overtemperature, or overcurrent. In the event of an anomaly, the BMS will alert the user and perform predetermined corrective procedures. In addition, the system also plays a role in improving energy efficiency by optimizing power consumption and adjusting operations according to energy demand [14].

A well-designed BMS should include several key functions, namely:

1. Data Acquisition - Collects information on battery voltage, current, and temperature.
2. Safety Protection - Prevents dangerous conditions such as overcharging, over-discharge, or overheating.
3. Battery Status Prediction and Estimation - Calculates the State of Charge (SOC) and State of Health (SOH) to determine the capacity and health of the battery.
4. Charge and Discharge Control - Regulates charge and discharge current to maintain efficiency and extend battery life.

5. Cell Balancing - Maintains voltage balance between cells in a battery pack for longer battery life.
6. Thermal Management - Monitors and controls temperature to prevent overheating.
7. Status Reporting and Authentication - Transmits battery condition information to the user via an external interface.
8. Communication with Battery Components - Integrates data from various sensors and coordinates system operations.
9. Extending Battery Life - Optimizes battery usage for longer life and efficiency.

Errors in battery operation, such as use at low voltage or over-discharge, may cause chemical reactions that produce harmful gases and increase the risk of fire. Similarly, overcharging can drastically increase the temperature, potentially damaging the battery or causing an explosion. Moreover, to solve this problem, a BMS was designed with a combination of sensors, controllers, communication devices, and software-based algorithms [21,22,23]. The system enables the calculation of the maximum charge current limit (CCL) and maximum discharge current limit (DCL). In addition, the BMS is also capable of calculating the total energy that has been used as well as the length of operating time since the battery was first used [15,16,17]. The BMS is an essential component in modern battery management, especially in applications that require high reliability, such as electric vehicles, energy storage systems, and portable electronic devices. With advanced monitoring, protection, and optimization functions, the BMS not only improves energy efficiency but also ensures the long-term safe use of the battery [18,19,20].

2.4 Battery Cells

Battery cells are basic units of electrical energy storage that work based on electrochemical reactions between the materials that make up the cathode and anode (Linden & Reddy, 2010). In general, battery cells consist of several main components, namely the cathode, anode, electrolyte, separator, and cell packaging (Goodenough & Kim, 2010). The cathode is the electrode where the reduction reaction occurs and serves as a collection point for ions from the electrolyte. The anode, as opposed to the cathode, is the electrode where oxidation reactions occur and serves to release ions into the electrolyte (Tarascon & Armand, 2001). The electrolyte itself acts as an ion-conducting medium that allows electricity to flow in battery cells (Bruce et al., 2008).

In operation, battery cells are packaged in various forms, such as cylindrical, prismatic, and pouch. Cylindrical and prismatic battery cells usually have metal or hard plastic packaging, while pouch cells use flexible materials to increase energy density (Nitta et al., 2015). Battery cells have an important role in various applications, ranging from electronic devices to electric vehicles. Along with technological developments, various types of battery cells have been developed, including lithium-ion (Li-ion), nickel-metal hydride (NiMH), and sodium-ion-based batteries that aim to improve the efficiency and sustainability of energy use (Armand & Tarascon, 2008).

2.5 Current Sensor

A current sensor is a device used to detect and measure electric current in a circuit, and then convert it into a signal that can be analyzed or used for system control (Mohankumar, 2015). These sensors serve to improve the safety, efficiency, and performance of electrical systems, including electric vehicle applications, power systems, and electronic devices (Chen et al., 2017). In general, current sensors can be categorized into two main types, namely direct current sensors and non-contact current sensors (Yamazaki & Iwafune, 2013). Direct contact sensors work by inserting a measurement element into an electrical circuit, while contactless sensors use the principle of electromagnetic induction or the Hall effect to detect current without the need to be directly connected to a conductor (Pallas-Areny & Webster, 2001).

Some commonly used types of current sensors include:

1. Shunt Resistor Sensor - Measures the voltage drop across a resistor with a small resistance value to determine the electric current flowing (Zhang et al., 2019).
2. Hall Effect Sensor - Utilizes the Hall effect to detect the magnetic field generated by an electric current and convert it into a voltage signal (Ramsden, 2006).
3. Current Transformer (CT) - Uses the principle of inductive transformation to measure current in high-voltage systems, commonly used in the electric power industry (Ahmed, 2018).
4. Rogowski Coil - A ferromagnetic core-less coil-based sensor used to measure high alternating current with high precision and without saturation (Tumanski, 2007).

Current sensors have an important role in various applications, such as battery system monitoring, protection of electronic devices, and optimization of electric power systems and electric vehicles. The development of current sensor technology continues to improve accuracy, efficiency, and reliability in various application fields (Chen et al., 2020).

2.6 Cell Balancing

Cell balancing is the process of balancing the voltage or capacity between cells in a battery pack to ensure that all cells work optimally and have a longer service life (Plett, 2015). In battery systems consisting of many cells arranged in series or parallel, small differences in cell characteristics, such as storage capacity, internal resistance, and charging efficiency, can cause imbalances during charge and discharge cycles (Chen et al., 2020). These imbalances can cause some cells to fully charge faster or drain faster than others, which can ultimately accelerate cell degradation, reduce the overall capacity of the battery, and increase the risk of system failure (Hussain et al., 2021). Therefore, cell balancing is an important feature in Battery Management Systems (BMS) to improve the efficiency and reliability of energy storage systems (Zhang et al., 2019).

There are two main methods for implementing cell balancing, e.g., Passive and Active Balancing. Passive Balancing: This method works by removing excess energy from cells with higher capacity in the form of heat using shunt resistors (Ramsden, 2006). Passive balancing is simpler and cheaper but has a disadvantage in efficiency because some energy is wasted as heat (Nitta et al., 2015). Active Balancing: In contrast to passive balancing, this method transfers excess energy from cells with higher capacity to cells with lower capacity using DC-DC converters or inductive and capacitive methods (Arora et al., 2018). Active balancing is more efficient because it does not waste energy, but it is more complex and expensive than passive balancing.

2.7 Battery Protection

Battery protection is a protection system designed to ensure the safety, reliability, and longevity of batteries by preventing operating conditions that can damage or degrade battery performance (Linden & Reddy, 2010). This protection is very important in energy storage systems, including electric vehicle batteries and electronic devices, because batteries are vulnerable to various extreme conditions such as overcharge, over-discharge, overcurrent, overheating, and short circuit (Chen et al., 2017). Battery protection systems are usually integrated into a Battery Management System (BMS) that functions to monitor, control, and optimize battery performance to prevent the risk of system failure (Plett, 2015). The main functions of battery protection include:

2.7.1 Protection against Overcharge

Overcharge occurs when a battery is charged beyond its maximum voltage limit, which can lead to excessive chemical reactions, increased temperature, and the risk of fire or explosion (Arora et al., 2018). Overcharge protection is performed by limiting the maximum voltage of charging and cutting off the current if the voltage exceeds the threshold.

2.7.2 Protection against Over-discharge

Overdischarge occurs when a battery is discharged to too low a voltage, which can cause electrolyte degradation and permanently reduce battery capacity (Hussain et al., 2020). This protection works by disconnecting the load if the battery voltage drops below a safe limit.

2.7.3 Protection against Overcurrent

Overcurrent can occur due to excessive load or short circuit, which risks damaging the battery cells and causing excessive heating. Protection is done by using a fuse or circuit breaker to stop the flow of electricity when the current exceeds the safe limit (Zhang et al., 2019).

2.7.4 Protection against Overheating

High temperatures can accelerate chemical reactions inside the battery, potentially causing thermal runaway, fire, or even explosion (Goodenough & Kim, 2010). This protection is implemented with a temperature sensor that will disable the battery if the temperature exceeds a safe threshold.

2.7.5 Protection against Short Circuit

Short circuits can occur due to insulation failure or physical damage to the battery, which can result in very high currents in a short period of time and increase the risk of fire. This protection is done by using a safety circuit that automatically cuts off the current when a short circuit occurs (Lukic et al., 2010).

Battery protection plays an important role in maintaining the safety and reliability of energy storage systems, especially in electric vehicle applications and renewable power systems. With the development of technology, battery protection systems are continuously improved with the integration of smart sensors and artificial intelligence to improve prediction and response to abnormal conditions (Chen et al., 2020).

3. Method

Figure 1 is the overall Flowchart System, while Figure 2 is the specific IntelConn Block Diagram built in this research.

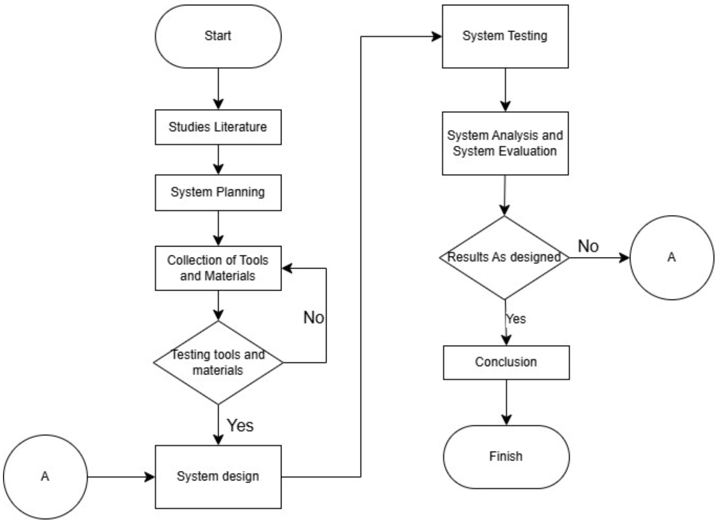


Figure 1. Flowchart system

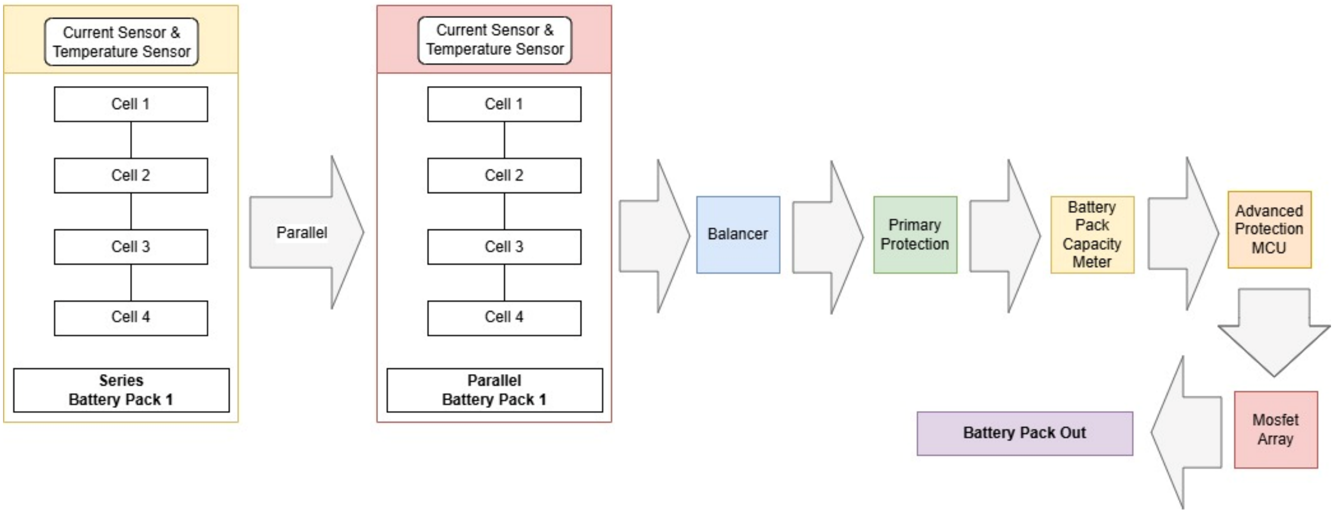


Figure 2. *IntelConn* Block Diagram

Figure 2 is the system planning architecture to examine how this system architecture runs in this study. The explanation of Figure 2, is as follows:

- *Parallel Battery Pack 1*
  Consists of battery cells connected in series, then connected in parallel with Battery Pack 2 to increase energy storage capacity.
- *Parallel Battery Pack 2*
  Shows battery cells connected in series to increase system voltage.
- *Balancer*
  Serves to balance the voltage between battery cells during the charging process, so that all cells can be charged optimally and prevent power imbalance.
- *Ultimate Protection*
  Protects each battery cell from harmful conditions such as overcharge and over-discharge, which can accelerate cell degradation and reduce battery life.
- *Battery Pack Capacity Measurement*
  Measures the total capacity of the battery pack as well as other important parameters, such as current, voltage, and actual power used in the system.
- *Current Sensor & Temperature Sensor*
  Measures the power in and out of the battery pack for performance monitoring. Measures battery temperature to prevent overheating and maintain system stability.
- *Protection MCU*
  Serves as the main controller of the protection system on the battery pack.
  Protections provided include:
  - Overcharge Protection
  - Over-discharge Cut-off Protection
  - Temperature Protection
  - Overcurrent Protection

In addition, this MCU also manages communication protocols such as WiFi, Bluetooth Low Energy (BLE), RS485, and CAN Bus, enabling remote monitoring and control.

- *MOSFET Array*
  Serves as a breaker and connector for the output power from the battery pack. The status of the MOSFET Array is controlled by the Protection MCU to ensure the safety and efficiency of power distribution according to the operational conditions of the system. In detail, Figure 3 shows *Intelconn* BESS topologists.

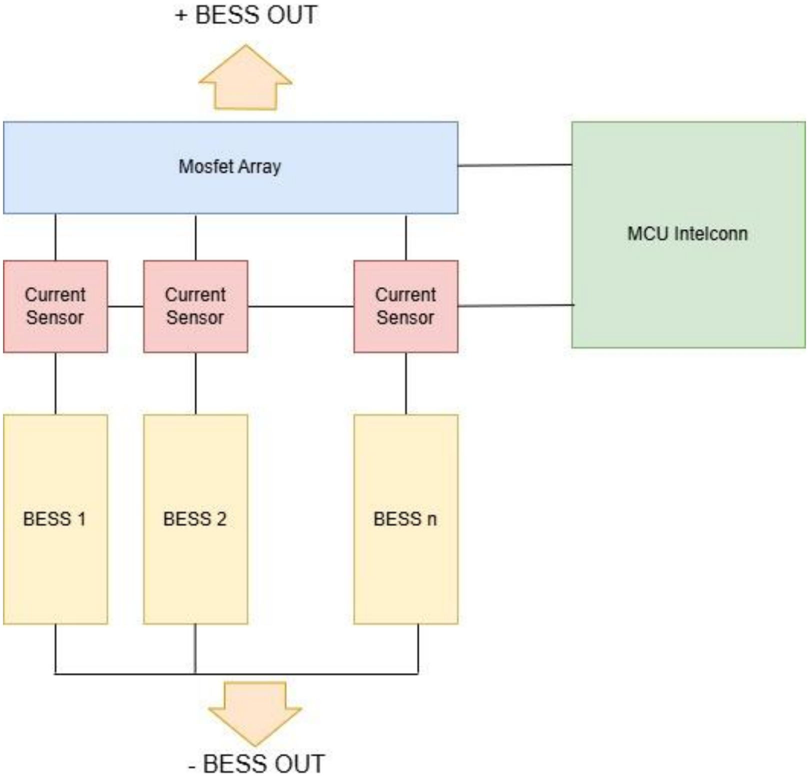


Figure 3. *Intelconn* BESS topologists

4. Result and Discussion

4.1 Simulated test with the same battery voltage value

A simulated test with the same battery voltage value is shown in Figure 4. In this test, we used the wiring configuration as below. By simulating the voltage conditions of battery 1 and battery 2 have the same voltage value. Figure 4 is a Wiring Testing, While Figures 5 and 6 are the result of reading the value of voltage information on battery BMS 1 and 2.

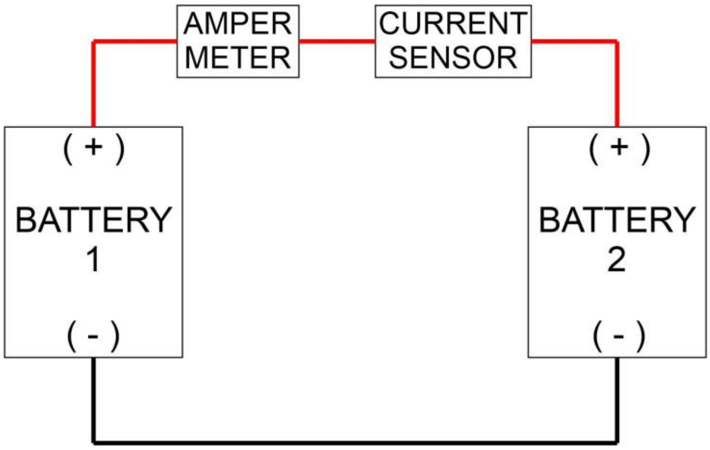


Figure 4. Wiring Testing

D01808012C95

98%

voltage 26.4V
current 0.0A
remaining capacity 29.4Ah
Chg MOS ● Dischg MOS ● Balance ○

Maximum volt	Minimum volt	Average volt	voltage difference	Cycles	Power KW
3,332v	3,152v	3,325v	0,180v	0	0,000kw

Figure 5. Battery 1 Voltage Information

D01808012AB2

95.5%

voltage 26.6V
current 0.0A
remaining capacity 28.6Ah
Chg MOS ● Dischg MOS ● Balance ○

Maximum volt	Minimum volt	Average volt	voltage difference	Cycles	Power KW
3,329v	3,322v	3,325v	0,007v	0	0,000kw

Figure 6. Battery 2 Voltage Information

Based on the results of reading the voltage value listed on the BMS application, there is a slight difference in voltage value but it is still within the tolerance threshold. We take measurements again using a multimeter in Figure 7.

Figure 7. Battery voltage measurement 1

Figure 8. Battery voltage measurement 2

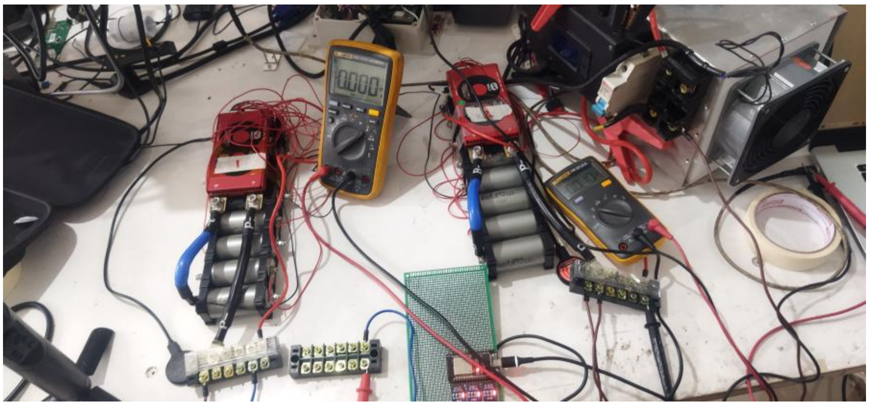


Figure 9. *Intelconn* Testing

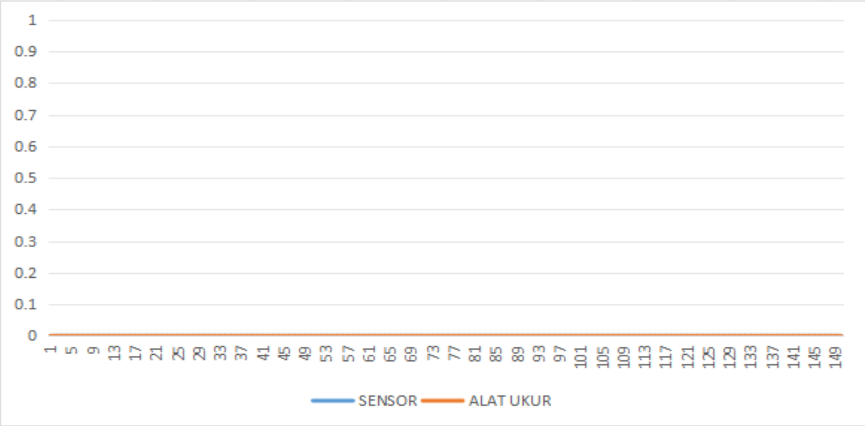


Figure 10. Battery Condition Testing Chart Same Voltage

4.2 *Test simulation with different battery voltage values*

In this test we used the wiring configuration as below. By simulating the voltage conditions of battery 1 and battery 2 have different voltage values. The specific output can be seen in Figure 11.

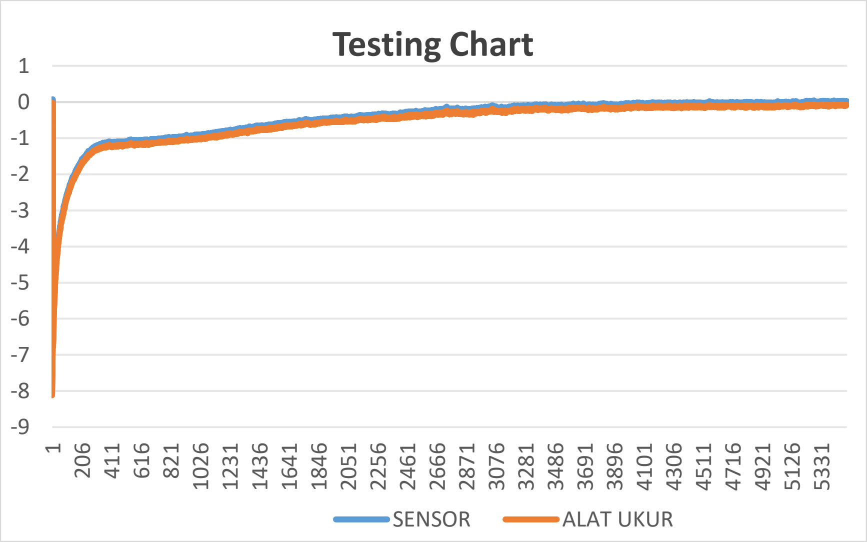


Figure 11. Battery Condition Testing Chart Different Voltage

Figure 10 is the datalog of the capture results in the Intelconn test with the same battery energy storage simulation. Testing is carried out using a current sensor and multimeter measuring instrument to ensure the suitability of the measurement data in this test. In Figure 10, the current reading shows 0 A, this indicates that the battery pack cell is in a stable condition, because there is no current flowing between battery A and battery B. Moreover, the current graph in Figure 11 shows the flow from battery 1 to battery 2, this shows the inconsistency in battery storage can be known early. So that you can find out the condition of the battery that has been degraded. In the graph above it is also seen that the battery charges towards the left so that the value becomes minus which means that the battery charges other batteries.

4.3 BESS Current Testing with Parallel Configuration

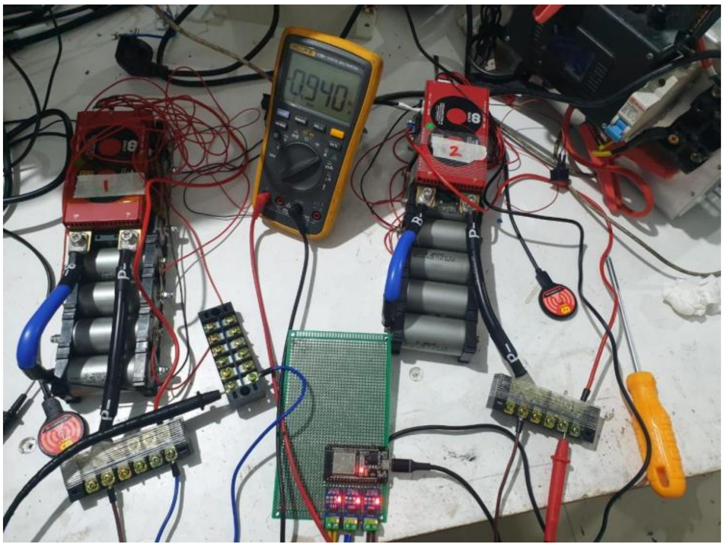
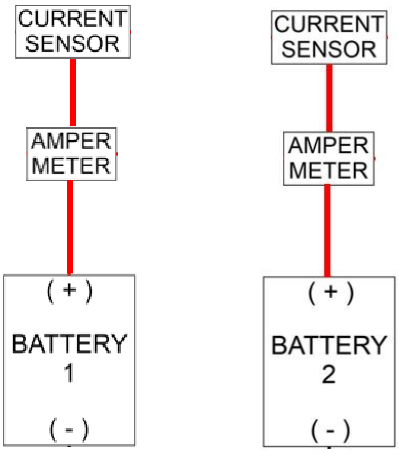


Figure 12. BESS Current Testing with Parallel Configuration

Furthermore, the current graph in Figures 11 and 12 shows the flow from battery 1 to battery 2, this shows the inconsistency in battery storage can be known early. So that you can find out the condition of the battery that has been degraded. In the graph above it is also seen that the battery charges towards the left so that the value becomes minus which means that the battery charges other batteries. The graph data logger table above is in the attachment sheet. Furthermore, Figure 12 is Intelconn testing with different simulations of the voltage value on the battery energy storage. Testing is done using a current sensor and multimeter measuring instrument to ensure the suitability of the measurement data in this test.

4.4 Simulated testing with two separate battery packs

Furthermore, in this test, we used the wiring configuration in Figure 13. By simulating conditions with battery pack 1 and battery pack 2. This test is carried out to determine the condition of each battery cell in each battery pack.



(a) (b)

Figure 13. (a, b) Wiring Testing Battery Pack 1 & 2

The following is a graph in Figure 14 of the measurement log for 30 minutes at 1 minute intervals for battery pack 1. The test results on battery pack 1 in graphs and tables are attached in the appendix:

1. Data was recorded for 30 minutes, with a gradual increase in voltage as the battery was charged.
2. The current decreases as the voltage increases, following the charging characteristics of the battery.
3. The power value is calculated from the total voltage × current.

The test results on battery pack 2 in graphs and tables are attached in the appendix:

1. Cells do not rise at the same speed → Some cells charge more slowly than others.
2. Increasing voltage difference → At the beginning, the voltage varied around 0.35V, and at the end, it reached 0.22V difference between the highest and lowest cells.
3. Drastically reduced current → From 5.2A at the beginning to 1.5A at the end, as some cells were almost full while others were not yet fully charged.

Potential Problems If Out of Balance:

1. Overcharge in some cells → Higher cells may reach 4.2V before others, causing damage.
2. Undercharge in some cells → Lower cells will not be fully charged, causing reduced battery capacity.
3. Decreased battery performance and lifespan → An unbalanced battery will have a shorter cycle life.

Furthermore, the details of Battery Pack 1 Testing are shown in Figure 14, while the Battery Pack 2 test is shown in Figure 15. In detail, Table 1 shows the overall results of testing Battery 1, and Table 2 shows the overall results of testing Battery 2 from Cell Voltage 1 (v) to Cell Voltage 8.

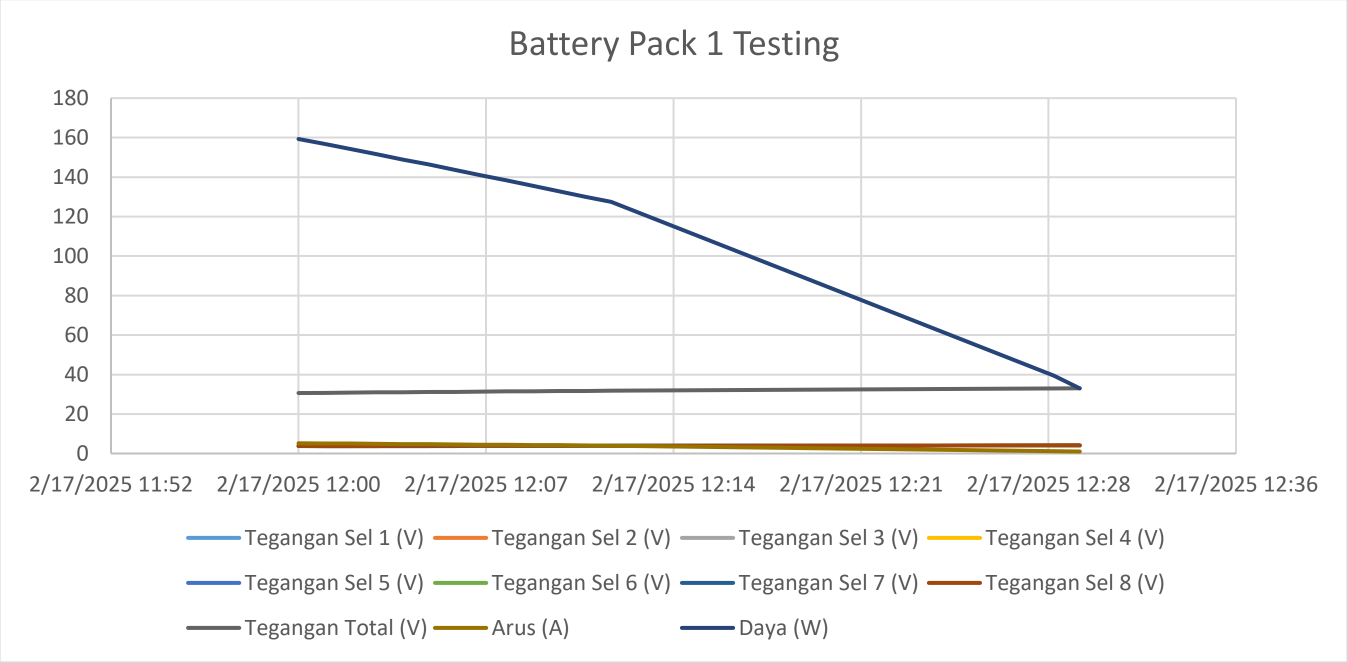


Figure 14. Battery Pack 1 Testing

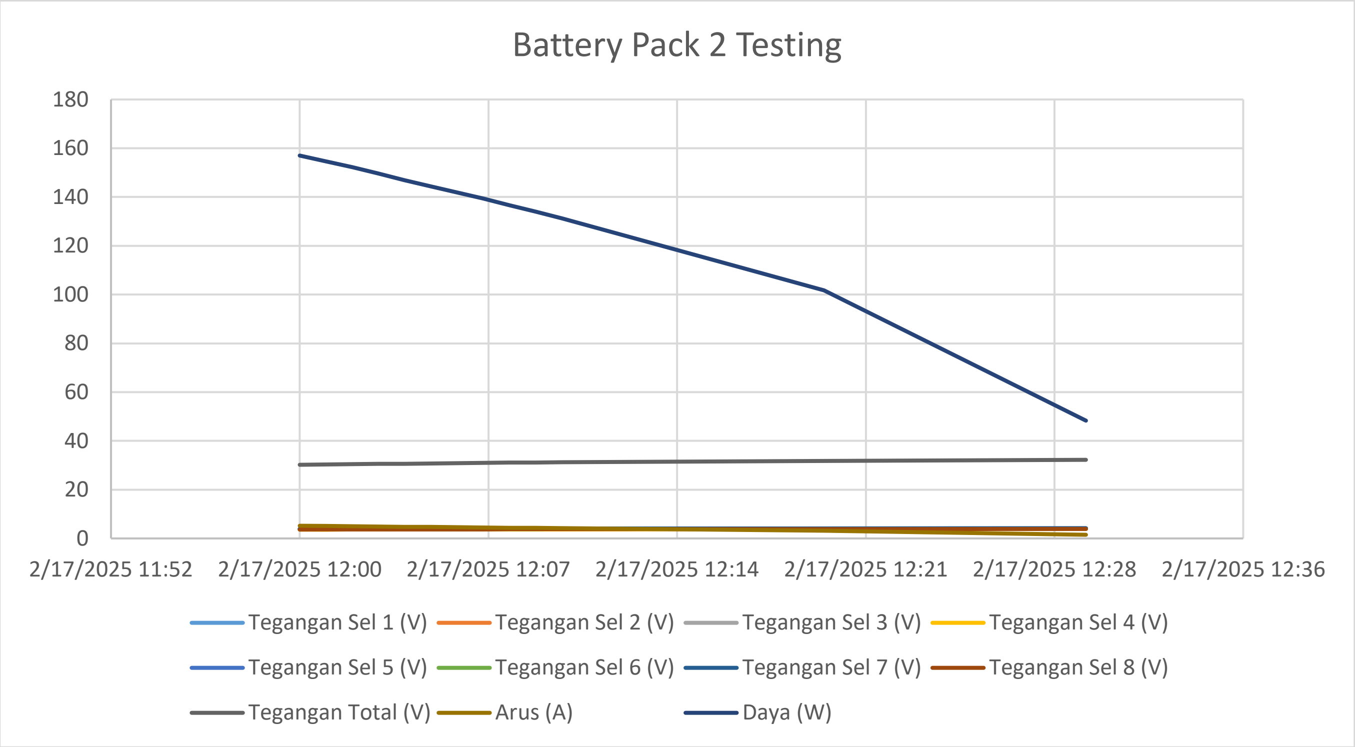


Figure 15. Battery Pack 2 Testing

Table 1. Battery Testing 1

Timestamp	**Voltage Cell 1 (V)**	**Voltage Cell 2 (V)**	**Voltage Cell 3 (V)**	**Voltage Cell 4 (V)**	**Voltage Cell 5 (V)**	**Voltage Cell 6 (V)**	**Voltage Cell 7 (V)**	**Voltage Cell 8 (V)**	**Voltage Total (V)**	**Current (A)**	**Power (W)**
2/17/2025 12:00	3.8	3.82	3.79	3.81	3.83	3.8	3.79	3.82	30.64	5.2	159.3
2/17/2025 12:01	3.81	3.83	3.8	3.82	3.84	3.81	3.8	3.83	30.74	5.1	156.8
2/17/2025 12:02	3.82	3.84	3.81	3.83	3.85	3.82	3.81	3.84	30.84	5	154.2
2/17/2025 12:03	3.83	3.85	3.82	3.84	3.86	3.83	3.82	3.85	30.94	4.9	151.6
2/17/2025 12:04	3.84	3.86	3.83	3.85	3.87	3.84	3.83	3.86	31.04	4.8	148.9
2/17/2025 12:05	3.85	3.87	3.84	3.86	3.88	3.85	3.84	3.87	31.14	4.7	146.4
2/17/2025 12:06	3.86	3.88	3.85	3.87	3.89	3.86	3.85	3.88	31.24	4.6	143.7
2/17/2025 12:07	3.87	3.89	3.86	3.88	3.9	3.87	3.86	3.89	31.34	4.5	141

Timestamp	Voltage Cell 1 (V)	Voltage Cell 2 (V)	Voltage Cell 3 (V)	Voltage Cell 4 (V)	Voltage Cell 5 (V)	Voltage Cell 6 (V)	Voltage Cell 7 (V)	Voltage Cell 8 (V)	Voltage Total (V)	Current (A)	Power (W)
2/17/2025 12:08	3.88	3.9	3.87	3.89	3.91	3.88	3.87	3.9	31.44	4.4	138.3
2/17/2025 12:09	3.89	3.91	3.88	3.9	3.92	3.89	3.88	3.91	31.54	4.3	135.6
2/17/2025 12:10	3.9	3.92	3.89	3.91	3.93	3.9	3.89	3.92	31.64	4.2	132.9
2/17/2025 12:11	3.91	3.93	3.9	3.92	3.94	3.91	3.9	3.93	31.74	4.1	130.1
2/17/2025 12:12	3.92	3.94	3.91	3.93	3.95	3.92	3.91	3.94	31.84	4	127.4
2/17/2025 12:29	4.1	4.12	4.09	4.11	4.13	4.1	4.09	4.12	32.94	1.2	39.5
2/17/2025 12:30	4.11	4.13	4.1	4.12	4.14	4.11	4.1	4.13	33.04	1	33

Table 2. Battery Testing 2

Timestamp	Voltage Cell 1 (V)	Voltage Cell 2 (V)	Voltage Cell 3 (V)	Voltage Cell 4 (V)	Voltage Cell 5 (V)	Voltage Cell 6 (V)	Voltage Cell 7 (V)	Voltage Cell 8 (V)	Voltage Total (V)	Current (A)	Power (W)
2/17/2025 12:00	3.8	3.7	3.85	3.6	3.9	3.75	3.95	3.65	30.2	5.2	157
2/17/2025 12:01	3.82	3.72	3.86	3.61	3.91	3.77	3.96	3.66	30.31	5.1	154.6
2/17/2025 12:02	3.84	3.73	3.88	3.63	3.92	3.79	3.97	3.68	30.44	5	152.2
2/17/2025 12:03	3.86	3.74	3.89	3.64	3.93	3.8	3.98	3.69	30.53	4.9	149.6
2/17/2025 12:04	3.88	3.75	3.9	3.65	3.94	3.81	3.99	3.7	30.62	4.8	146.9
2/17/2025 12:05	3.89	3.76	3.91	3.67	3.95	3.83	4	3.72	30.73	4.7	144.4
2/17/2025 12:06	3.91	3.78	3.93	3.68	3.96	3.84	4.02	3.73	30.85	4.6	141.9
2/17/2025 12:07	3.93	3.79	3.94	3.69	3.98	3.86	4.03	3.75	30.97	4.5	139.4

Timestamp	Voltage Cell 1 (V)	Voltage Cell 2 (V)	Voltage Cell 3 (V)	Voltage Cell 4 (V)	Voltage Cell 5 (V)	Voltage Cell 6 (V)	Voltage Cell 7 (V)	Voltage Cell 8 (V)	Voltage Total (V)	Current (A)	Power (W)
2/17/2025 12:08	3.94	3.8	3.95	3.71	3.99	3.87	4.04	3.76	31.06	4.4	136.7
2/17/2025 12:09	3.96	3.81	3.96	3.72	4	3.88	4.05	3.77	31.15	4.3	134
2/17/2025 12:10	3.98	3.82	3.97	3.73	4.02	3.89	4.07	3.78	31.26	4.2	131.3
2/17/2025 12:20	4.05	3.9	4.03	3.8	4.08	3.96	4.12	3.85	31.79	3.2	101.7
2/17/2025 12:30	4.12	3.95	4.08	3.85	4.14	4.01	4.18	3.9	32.23	1.5	48.3

5. Conclusion

Based on the results of the research that has been done, the following conclusions are obtained:

1. The designed Intelconn has the main feature, namely to monitor early Battey energy storage that has been degraded. Thus reducing the possibility of degradation in other Battery energy storage. This can have an impact on the reliability of Battery energy storage, because if there is one battery connected in parallel in a degraded condition. Then the other battery which was originally in good condition, will also be degraded.
2. Intelconn has been implemented and tested under conditions in accordance with the safe operation of battery energy storage, taking into account variations in voltage and current.
3. Each battery energy storage has different characteristics depending on the type of battery energy storage and the condition of the battery energy storage itself.
4. The test results in Datalog show that the current reading on the measuring instrument and *Intelconn* current sensor have high accuracy. So that it can provide data with accurate batteries that have been degraded.

6. Suggestion

Based on the research that has been done, the following suggestions can be made:

1. This Intelconn is expected to be integrated and communicate with the existing BMS on battery energy storage.
2. Further research is expected to have a more compact, complete, and modern intelconn design. So that it is easier to use.

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