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Performance Analysis of the 110 VDC Battery System in the DC System of the 150 KV Soppeng Substation

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Abstract *Soppeng Substation is an important part of the electrical power transmission system that requires high operational reliability. One of the components that supports this reliability is the 110 VDC battery system, which functions as a backup power source for protection, control, and telecommunication equipment when the AC supply is disrupted. This study aims to analyze the feasibility of the 110 VDC battery system at the Soppeng Substation based on cell voltage, battery bank voltage, charging system performance, and the battery's ability to support DC loads. The research method includes field observations, technical measurements, and analysis of operational data collected from September to November 2025. The results show that the battery bank voltage is 119.4 V for Battery Bank 1 and 123.0 V for Battery Bank 2, with cell voltage deviations of 0.14 V and 0.18 V, respectively, which are still within the allowable limits. The rectifier output voltage ranges from 123.0–123.1 V with a current of about 6.5–6.6 A under float charging conditions. The battery capacity is able to support a DC load of 13.1 A, indicating that the battery system is feasible and reliable as a backup power source.*

Keywords 110 VDC battery, substation, battery bank, rectifier, DC system

I. INTRODUCTION

The 110 VDC battery system is a vital component in substation operations because it functions as the primary power source for protection, control, and telecommunication equipment when the AC supply is disrupted [1]. Under fault conditions, the DC load must continue to receive an uninterrupted supply of energy so that the protection system can operate in a timely manner and prevent damage to network equipment. Therefore, battery reliability is one of the aspects that must be maintained to ensure operational continuity and the stability of the power system. Without battery support, substations are at risk of protection function failure, which can result in widespread power outages [2].

Substations are one of the main installations in the electric power system that function as a connecting point between transmission and distribution networks. In their operation, substations consist of several main components such as power transformers, circuit breakers, disconnecting switches, current and voltage transformers (CT and PT), and protection devices that monitor network conditions in real-time. These devices not only require electricity supply from the AC system but also depend on the DC power supply system to ensure that control and protection functions continue to work properly. The protection system, for instance, requires energy from the DC battery to send trip or close signals to the circuit breaker when a fault occurs. Therefore, the existence of a DC system which includes chargers and batteries, including 110 VDC batteries is an inseparable part of substation operations [7].

The DC power supply system is one of the most critical subsystems in substation operations because it serves as the primary energy source for protection, control, telecommunication devices, and other supporting systems. Unlike the AC supply, which is prone to disruption by system conditions, the DC supply is designed to remain stable even during major network disturbances. This makes the DC system the "backbone" that ensures every network security process runs as it should. Without reliable DC system support, substations cannot perform protection actions such as tripping or closing circuit breakers, so the potential for widespread disturbances becomes much greater [9].

Generally, the DC power supply system in a substation consists of three main components: the rectifier/charger, the battery, and the DC distribution panel. The rectifier or charger functions to convert AC electrical energy into DC while ensuring the battery remains in a ready-to-use condition through an automatic charging process. The battery acts as a backup energy source that will take over completely when the AC supply is unavailable or when the charger experiences a disturbance. Meanwhile, the DC distribution panel distributes energy to various important loads such as protection relays, circuit breaker controls, RTU/SCADA, telecommunication systems, emergency lights, and other supporting equipment [10].

Reliability of the substation depends heavily on the stability of the DC system, particularly the battery, which must be able to maintain voltage and capacity during critical load periods. Because batteries experience performance degradation over time due to chemical processes within them, periodic evaluations are required to ensure their actual capacity still meets the load requirements. Several indicators, such as voltage per cell, total capacity in ampere-hours, charging efficiency, and supply stability during peak loads, serve as references in determining whether the battery is still feasible for use [8].

As the service life increases, the battery experiences a decrease in capacity and efficiency, which can reduce its ability to supply DC load requirements. This performance decline can be caused by internal factors such as material degradation, depth of charge-discharge cycles, and environmental conditions of the storage area [3]. The Soppeng Substation, as one of the important infrastructures in the electrical system, requires periodic evaluations of the feasibility of the batteries used so that any potential unreliability can be identified early. Analysis of the actual performance of the battery becomes an important step to determine whether the battery can still perform its functions according to the established technical standards [4].

Furthermore, the increasing demand for DC loads on modern equipment in substations requires a match between the available battery capacity and the load to be carried. If the battery capacity is no longer adequate, the ability of the DC system to support protection, control, and telecommunication equipment may be disrupted, especially when a disturbance occurs in the AC supply. Therefore, a comprehensive analysis is needed regarding the feasibility of 110 VDC batteries at the Soppeng Substation, covering assessments of effective capacity, operational voltage, efficiency, and power supply capability against existing loads.

Several recent studies have discussed the performance and reliability of DC battery systems in substations. For example, research by A. Sharma et al. [17] analyzed battery degradation using condition monitoring techniques, while J. Li et al. [18] focused on state-of-health (SOH) estimation methods for substation batteries using data-driven approaches. In addition, M. Gonzalez et al. [19] evaluated DC system reliability under transient disturbances, and K. Tanaka et al. [20] studied optimization of battery sizing for substation auxiliary systems. Although these studies provide valuable insights, most of them emphasize monitoring methods, modeling approaches, or optimization techniques without directly evaluating the actual operational feasibility of batteries based on real field data and load compatibility in specific substations.

Therefore, a research gap can be identified in the lack of comprehensive field-based evaluation that integrates capacity testing, voltage performance, efficiency analysis, and load suitability assessment specifically for existing 110 VDC battery systems in operating substations. Previous studies tend to focus on theoretical models or generalized systems, while practical assessments tailored to a particular substation condition remain limited.

This study aims to fill this gap by conducting a detailed feasibility analysis of the 110 VDC battery system at the Soppeng Substation using actual operational data. The novelty of this research lies in its integrated approach, combining technical performance evaluation (capacity, voltage stability, and efficiency) with real DC load requirements to determine the battery's capability in supporting protection and control systems. The contribution of this research is expected to provide a practical evaluation framework that can be used as a reference for maintenance planning, reliability assessment, and decision-making regarding battery replacement in substations.

II. METHODS

The research flow is designed to describe the systematic stages carried out in analyzing the feasibility and performance of the 110 VDC battery at the 150 kV Substation. The research begins with a background study to understand the importance of the battery's role as the main source for control systems, protection, and substation equipment operations. The next stage is to identify problems found in the battery system, such as capacity reduction, cell voltage mismatch, or DC supply instability. After the problems are identified, the researcher conducts an initial analysis to determine the scope and technical parameters to be studied. Furthermore, field data collection is carried out in the form of measuring cell voltage, charging current, effective capacity, physical condition of the battery, DC load, and maintenance data. These data are analyzed to determine the actual condition of the battery against the manufacturer's standards and PLN regulations. The analysis results are then used as a basis for drawing conclusions and formulating recommendations for battery system improvements so that the reliability of the substation's DC system is maintained.

To clarify the research methodology, this study adopts a quantitative-descriptive approach combined with field measurement and technical evaluation based on standard procedures. The stages of the research flow can be described as follows:

1) Literature study and standard identification (IEEE and IEC standards),
2) Problem identification and determination of research parameters,

3) Field data collection (measurement and documentation),
4) Data processing and technical analysis (capacity, voltage, resistance, and load),
5) Evaluation of battery feasibility, and
6) Conclusion and recommendation formulation.

Figure 1 illustrates the research flow diagram that describes the systematic stages carried out in this study, starting from literature review to conclusion and recommendation.

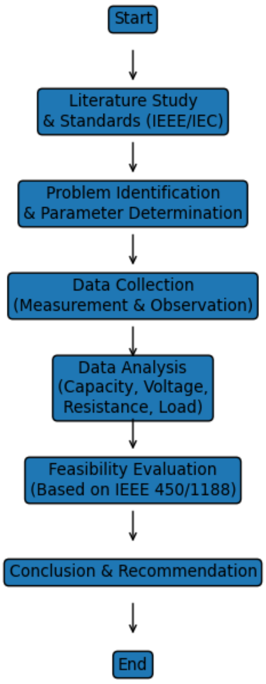

Figure 1: Research flow diagram

As shown in Figure 1, the research begins with a literature study and standard identification (IEEE/IEC), followed by problem identification and parameter determination. The next stages include field data collection through measurement and observation, data processing and technical analysis, feasibility evaluation based on applicable standards, and finally the formulation of conclusions and recommendations. This structured flow ensures that the analysis of the 110 VDC battery system is conducted systematically and comprehensively.

The population in this study is all components and parameters related to the 110 VDC battery system at the Soppeng Substation, covering all battery cells in one bank, the charger system, the DC distribution panel, and the overall connected DC load. This population includes all operational data, testing data, and the actual condition of the equipment that is part of the DC power supply system at the substation. The research sample is one 110 VDC battery bank used as the main power source for the DC system at the Soppeng Substation, consisting of all battery cells tested through measurements of cell voltage, bank voltage, capacity (capacity test), and internal resistance. In addition, the sample includes major DC loads such as protection relays, controls, telecommunications, SCADA, and relevant operational data to be analyzed in determining the feasibility and performance of the battery.

The battery specifications used in this study refer to the installed battery system at the Soppeng Substation, which generally consists of lead-acid type batteries with nominal voltage of 2 V per cell connected in series to form a 110 VDC system (±55 cells). The nominal capacity of the battery is expressed in ampere-hours (Ah), with float voltage typically in the range of 2.20–2.25 V/cell and boost voltage around 2.30–2.40 V/cell. These specifications are used as reference values in evaluating actual battery performance.

Figures 2 and 3 illustrate the series circuit configuration of Battery Bank 1 and Battery Bank 2 in the 110 VDC system at the Soppeng Substation. Each battery bank consists of 86 cells connected in series to form the required DC voltage level.

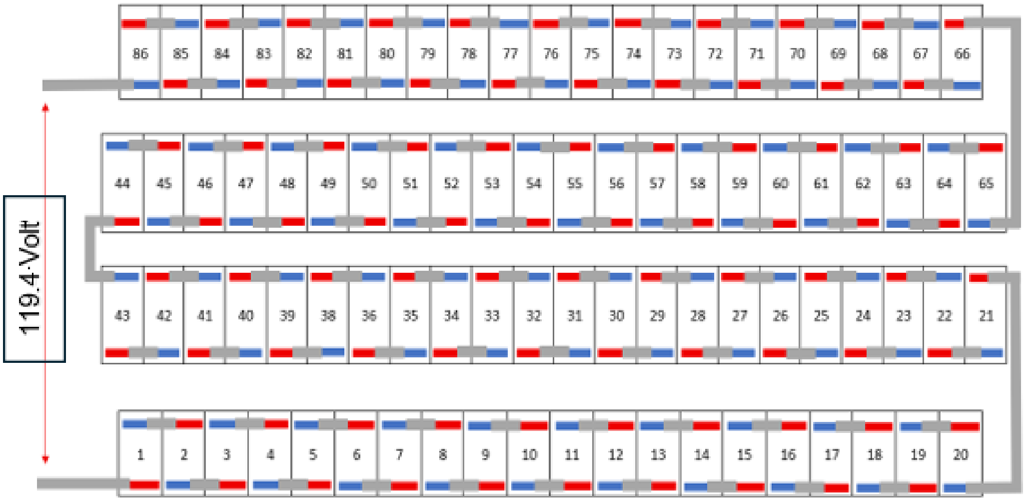

Figure 2: Series Circuit of Battery Bank 1

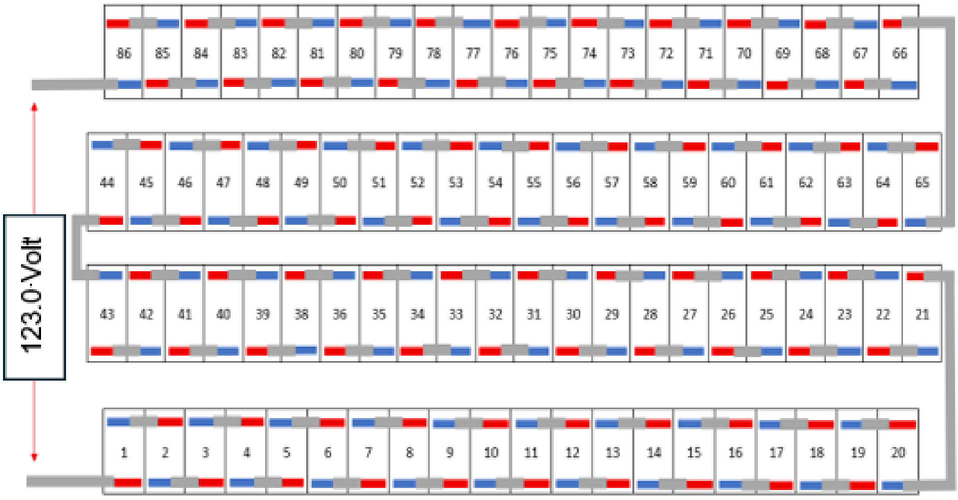

Figure 3: Series Circuit of Battery Bank

As shown in Figures 2 and 3, the arrangement of battery cells in series ensures that the total voltage is accumulated to meet the operational requirements of the DC system. Battery Bank 1 produces a total voltage of 119.4 V, while Battery Bank 2 produces 123.0 V. The difference in total voltage between the two battery banks indicates variations in charging conditions or cell performance, although both configurations still function properly in supplying DC loads. This series configuration is essential to maintain continuity of power supply for protection, control, and communication systems within the substation.

Data collection techniques in this study were carried out to obtain accurate information regarding the actual condition of the 110 VDC battery and the DC load at the Soppeng Substation. Data collection was conducted through literature studies, direct observations, measurement of technical parameters, and retrieval of supporting documents from the monitoring system. Literature studies were conducted to obtain theoretical foundations related to DC power supply systems, 110 VDC battery characteristics, IEEE/IEC standards, battery testing methods, and other relevant research. Direct observations were made at the Soppeng Substation to see the physical condition of the battery, cell connections, DC panels, charger systems, and the battery storage environment. Measurements were performed on all cells and the total 110 VDC battery bank to assess voltage balance. A capacity test was conducted to determine the effective capacity of the battery through a controlled discharge process. DC load data includes protection relays, controls, telecommunications, SCADA, and other devices requiring DC power supply. Technical data such as Ah capacity, voltage per cell, battery type, float/boost voltage limits, internal resistance, and charger specifications were collected as a reference for analysis and comparison against actual conditions.

The standards used in this study include IEEE Std 450 for maintenance, testing, and replacement of vented lead-acid batteries, and IEEE Std 1188 for valve-regulated lead-acid (VRLA) batteries. These standards are used as the main reference in determining acceptable limits for voltage deviation, capacity percentage (≥80% of nominal), and internal resistance increase. In addition, IEC standards related to stationary batteries are also used as supporting references.

The data analysis technique in this study was carried out to assess the actual condition and feasibility of the 110 VDC battery based on field measurement results. Analysis was performed through calculating effective capacity, evaluating the voltage of each cell, examining internal resistance, and calculating the battery's ability to support the DC load (backup time). Effective capacity is used to determine the actual capacity condition from testing results compared to the manufacturer's nominal capacity. The formula for effective capacity is:

$$C_{\text{efektif}} = I_{\text{discharge}} \times t_{\text{discharge}}$$

The voltage of each cell is checked to see if it is within the normal range, and evaluation is carried out using the voltage deviation formula:

$$\Delta V = V_{\text{sel}} - V_{\text{rata-rata}}$$

Internal resistance analysis is conducted because it increases with battery age and greatly affects instantaneous current capability (CB trip). The total DC load is calculated to determine if the battery capacity is sufficient. Backup time is the duration the battery is able to supply the load when the AC charger fails. The backup time formula is:

$$t = \frac{C_{\text{efektif}}}{I_{\text{beban}}}$$

In addition, capacity analysis is evaluated based on the percentage of available capacity using the equation:

$$\text{Capacity (\%)} = \left(\frac{C_{\text{efektif}}}{C_{\text{nominal}}}\right) \times 100\%$$

Battery feasibility criteria are determined based on IEEE standards, where batteries are considered reliable if capacity ≥ 80% of nominal capacity, voltage deviation per cell is within ±5% of the average value, and no abnormal increase in internal resistance is observed.

All results are compared with manufacturer standards and IEEE 450/1188 references to determine if the battery is still feasible for use as a power source for the Substation's protection and control systems.

III. RESULTS & DISCUSSION

A. Data Description of the 110 VDC Battery and Rectifier System

This section presents a description of the data from the measurement and recording of the 110 VDC battery and rectifier system at the Soppeng Substation during the period of September 2025 to November 2025. The data were obtained from routine inspection reports of batteries and rectifiers conducted by substation maintenance personnel as part of the DC power supply system monitoring activities. The presentation of data in this sub-section aims to provide an overview of the actual condition of the battery and rectifier system before further feasibility analysis is carried out.

In general, the DC system at the Soppeng Substation consists of two units of 110 VDC battery banks, namely Battery 1 and Battery 2, each equipped with Rectifier 1 and Rectifier 2 units. The 110 VDC battery system functions as the main power source for protection, control, telecommunication equipment, and other supporting systems when the AC supply is unavailable. Recording is carried out under normal operating conditions (float charging) so that the voltage and current values reflect the readiness of the battery system in a standby state.

Under this operating mode, the measured parameters are important because they represent the readiness of the battery in emergency conditions rather than its behavior during discharge. Therefore, the interpretation of float voltage, charging current, and cell balance becomes essential in determining whether the battery system still meets the reliability requirements for substation DC systems. In addition, the use of routine inspection data for three consecutive months provides an initial basis for identifying performance trends, even though it does not yet fully represent long-term degradation characteristics.

Battery 1 and Rectifier 1 Performance (September–November 2025)

Measurements of Battery 1 were conducted to determine the actual condition of the voltage of each cell and the stability of the battery system as the main source of the DC system. Based on the measurement results for Battery 1 in September 2025, the voltage of each cell was in the range of 1.28–1.42 V, and the total battery bank voltage was recorded at 119.4 VDC. Rectifier 1 functions as the main source of battery charging as well as the supplier of the DC load under normal conditions. In September 2025, Rectifier 1 operated at an output voltage of 123.0 V with a charging current of 6.5 A, indicating float charging conditions. This performance remained consistent throughout October and November 2025, where Rectifier 1 worked at an output voltage of 122.6–122.8 V with a current of 6.0–6.2 A. The relatively small current indicates that the battery is in a nearly full condition and only requires maintenance current.

From a technical standpoint, the stability of Rectifier 1 output voltage indicates that the charging process was not experiencing overvoltage or undervoltage conditions that could accelerate battery deterioration. However, the bank voltage of Battery 1 at 119.4 V is lower than Battery 2 and tends to be closer to the lower operational limit for a 110 VDC system. This suggests that although Battery 1 is still stable, its charging condition should be monitored more carefully because a lower bank voltage may reflect either slight undercharging, higher internal loss, or the presence of weaker cells within the series string. Compared with previous studies [17]–[20], differences in bank voltage between parallel battery units in the same substation often become an early indication of unequal aging characteristics and should not be interpreted solely as normal variation.

Battery 2 and Rectifier 2 Performance (September–November 2025)

Measurements for Battery 2 were conducted to compare the conditions of the two battery systems in the same month to determine the balance of performance between battery units. The results of the cell voltage measurements for Battery 2 in September 2025 showed relatively uniform values, ranging from 1.41 to 1.43 V, with a total bank voltage of 123.0 VDC.

Rectifier 2 operated at an output voltage of 123.1 V with a charging current of 6.6 A in September. Throughout the observation period until November 2025, Rectifier 2 maintained a stable output voltage of around 122.7–123.0 V with a charging current of 6.1–6.6 A. There were no operating disturbances or alarms during the observation period, indicating that the rectifier system was working optimally.

Battery 2 demonstrates better voltage uniformity than Battery 1, which indicates a more balanced electrochemical condition among cells. In practical terms, this means Battery 2 has a lower risk of weak-cell failure during sudden discharge events, such as circuit breaker tripping or relay operation under fault conditions. The absence of alarms and the stable rectifier output also reinforce the conclusion that Battery 2 is operating under healthier charging conditions. If compared with IEEE-based maintenance criteria, a stable float voltage and uniform cell profile are positive indicators that the battery does not currently require corrective equalizing action. This condition is also in line with findings from recent battery monitoring studies [17]–[20], which emphasize that voltage consistency between cells is one of the simplest but most important indicators of battery reliability in stationary DC systems.

Recapitulation of Battery Bank Voltage and Rectifier Parameters

After measuring and recording the battery system for three consecutive months, a recapitulation of the bank voltage data was performed to determine the performance trends of the battery system over time.

Table 1: Recapitulation of Battery Bank Voltage September–November 2025

Bulan	Bank Baterai	Tegangan Bank (V)	Jumlah Sel	Rata-Rata Tegangan Sel (V/sel)
Sep-25	Baterai 1	119,4	86	1,39
Sep-25	Baterai 2	123,0	86	1,43
Okt 2025	Baterai 1	119,4	86	1,39
Okt 2025	Baterai 2	123,0	86	1,43
Nov-25	Baterai 1	119,4	86	1,39
Nov-25	Baterai 2	123,0	86	1,43

Based on the recapitulation table 1, the 110 VDC battery system at the Soppeng Substation showed relatively stable operating conditions. For Battery 1, the bank voltage was recorded at 119.4 V consistently, while Battery 2 was recorded at 123.0 V. Similarly, the rectifier parameters for both units operated in float charging mode with an output voltage range of 123.0–123.1 V and an output current of 6.5–6.6 A. This consistency indicates that the cell balance is maintained and the 110 VDC battery system is still feasible to support the DC load requirements.

A deeper interpretation of this recapitulation shows that the system has good short-term operational stability, because no monthly voltage drift was observed. In battery diagnostics, this is important because progressive month-to-month voltage decline is usually associated with increasing internal resistance or declining state of health. However, the persistent difference between Battery 1 and Battery 2 also indicates that stability alone is not sufficient to conclude that both battery banks have identical performance quality. In other words, the system is stable, but not perfectly uniform. This distinction is important because technical feasibility should be judged not only from temporal stability, but also from conformity to nominal operating values and balance between redundant battery units.

B. *Data Analysis*

Analysis of Actual Voltage Condition and Battery System Performance

Analysis of the actual condition was carried out to determine the true state of the 110 VDC battery system at the Soppeng Substation based on measurements of the battery bank voltage, individual cell voltages, and the stability of the charging system (rectifier). Voltage parameters are used as the primary indicators to assess the level of battery charging, balance between cells, and early indications of degradation in the battery system.

Based on field measurement data from September to November 2025, the 110 VDC battery system at the Soppeng Substation uses 86 battery cells arranged in series in each battery bank. Measurement results show that the bank voltage for Battery 1 was recorded at 119.4 VDC, while Battery 2 was recorded at 123.0 VDC. These values remained relatively constant during the observation period, indicating the stability of the battery system under normal operating conditions.

If the measured values are compared with the normal float charging range, Battery 2 is closer to the expected operating voltage, whereas Battery 1 tends to be lower. This indicates that Battery 2 has a better readiness margin in the event of charger failure. From an engineering perspective, a lower bank voltage does not immediately indicate that the battery is unfit, but it reduces the voltage margin available during transient DC load demand. Therefore, Battery 1 should be considered technically feasible but relatively less optimal than Battery 2.

Analysis of Average Cell Voltage and Deviation

The average cell voltage was analyzed to determine the general condition of each battery cell based on the measured bank voltage and the actual number of cells. For Battery 1, the average cell voltage was 119.4 / 86 = 1.39 V/cell. For Battery 2, the average cell voltage was 123.0 / 86 = 1.43 V/cell. These results are consistent with direct measurements of each cell, which ranged from 1.28–1.42 V for Battery 1 and 1.25–1.43 V for Battery 2.

Cell voltage deviation is used to see the level of voltage discrepancy of each cell against the average value. For Battery 1, the maximum deviation was $|1.42\ V - 1.28\ V| = 0.14\ V$. For Battery 2, the maximum deviation was $|1.43\ V - 1.25\ V| = 0.18\ V$. These calculation results show that although there are cells with lower voltages than others, the voltage deviation values are still within acceptable limits and do not cause a significant decrease in bank voltage.

This result indicates that both battery banks still meet the practical voltage balance criterion because the deviation remains below the maximum allowable threshold of 0.20 V. Nevertheless, Battery 2, despite having a higher bank voltage, shows a larger maximum deviation than Battery 1. This means that a higher total voltage does not automatically imply better uniformity at cell level. In battery operation, this is an important finding because localized weak cells may remain hidden when only bank voltage is observed. Therefore, the analysis confirms that bank voltage assessment must always be complemented by cell-level evaluation. This is consistent with previous studies [17]–[20], which report that early degradation is often first detected through cell voltage dispersion rather than total bank voltage reduction.

Determination of Total System DC Load Current

Determination of the total DC system load current was conducted to find out the amount of current supplied by the DC system under normal operating conditions. In the 110 VDC battery system at the Soppeng Substation, the DC load current is determined based on the measured rectifier output current, as the rectifier serves as the primary DC supply source. Based on measurement results, the output current for Rectifier 1 was 6.5 A and for Rectifier 2 was 6.6 A.

The total DC load current calculation is:

$$\text{Itotal} = 6.5 + 6.6 = 13.1\text{A}$$

This calculation result shows that the DC load supplied by the system is within the normal capacity of the rectifier and the battery system. A relatively small load current compared to the DC system capacity indicates that the battery does not experience excessive loading and is in a safe condition for long-term operation.

A more in-depth interpretation shows that the DC system is operating with a wide capacity margin. This is favorable for reliability because low operating current reduces thermal stress on both the rectifier and battery, and it allows the battery to maintain a longer backup duration during supply failure. In substation applications, such a margin is desirable because actual emergency loads may temporarily increase due to simultaneous operation of protection relays, signaling devices, and circuit breaker trip coils. Therefore, the current load profile supports the conclusion that the battery system is not only adequate under steady-state conditions, but also has reserve capability for transient emergency operation.

Calculation of Effective Capacity and Backup Time

The effective capacity of the battery is the actual capacity that can still be utilized by the battery system to support the DC load in emergency conditions. Based on a Health Factor (State of Health) of 0.90, the effective capacity for Bank 1 is 145 \times 0.90 = 130.5 Ah, and for Bank 2 is 300 \times 0.90 = 270 Ah.

Backup time is the duration the battery system is capable of supplying the DC load when the AC supply and rectifier are not operating. Based on the calculated effective capacity, the backup time results are:

- **Battery Bank 1**: t = 130.5 / 13.1 = 9.96 hours
- **Battery Bank 2**: t = 270 / 13.1 = 20.61 hours

These calculation results show that Battery Bank 1 is capable of supporting the DC load for approximately 10 hours, while Battery Bank 2 can support it for up to approximately 20.6 hours. These values are far above the substation operational standards, which generally require a minimum backup time of 1–2 hours.

Compared with the technical requirement of 1–2 hours minimum backup time, both battery banks provide a very high reliability margin. This means that even if there is capacity derating due to temperature, aging, or emergency load increase, the system is still likely to remain capable of supporting critical DC functions. However, this result also suggests that the installed battery capacity may be considerably larger than the present actual load requirement. From a reliability perspective, this is advantageous; from an efficiency perspective, it may indicate overdesign. Thus, the result should be interpreted as technically excellent but potentially open to optimization in future battery replacement planning.

C. Evaluation and Feasibility Status

Evaluation of Battery Capacity and Backup Time

The evaluation of battery system feasibility is based on the effective capacity of the battery and the system's backup time. The criteria for feasibility require that the effective capacity must be ≥ 80\% of the nominal capacity. Based on the analysis, both battery banks achieved a capacity level of 90\%. Since the effective capacity values for both battery banks are above 80\%, the battery system is declared feasible based on capacity.

Furthermore, the backup time evaluation follows a criterion where the minimum backup time for a DC system is 1–2 hours. The calculation results for Battery Bank 1 showed a backup time of 9.96 hours , while Battery Bank 2 showed 20.61 hours. Because the backup time is significantly greater than 2 hours, the battery system is declared feasible in terms of backup duration.

This finding strongly supports the conclusion that the battery system remains serviceable according to IEEE-based replacement criteria. Batteries with effective capacity above 80% are generally still considered acceptable for operation, while values near 90% indicate that the battery is still in a good health category. Therefore, the feasibility status in this study is not only “acceptable,” but can be interpreted as “operationally reliable with adequate reserve margin.”

Evaluation of Voltage Stability and Cell Deviation

Evaluation of the battery bank voltage was performed based on actual measurement stability from September to November 2025. The measurements indicated that the bank voltage did not experience significant fluctuations. Battery 1 remained stable at 119.4 V, and Battery 2 remained stable at 123.0 V. Based on this stability, the battery system is stated to be in normal operating condition and feasible for supporting DC load requirements.

Regarding cell voltage deviation, the maximum allowable limit used as an evaluation reference is 0.20 V. Calculation results showed a deviation of 0.14 V for Battery 1 and 0.18 V for Battery 2. Since these values are below the maximum threshold, the condition of the battery cells is declared feasible and balanced.

Even so, the evaluation should distinguish between “feasible” and “optimal.” Both batteries are feasible because they meet the deviation criterion, but Battery 2 is closer to the upper deviation limit. This indicates that although immediate corrective action is not required, continued monitoring remains necessary, especially to detect whether the deviation widens over time. If the trend increases in future inspections, it could signal the need for equalizing charge, detailed cell testing, or selective cell replacement.

Evaluation of Charging System (Rectifier)

The evaluation of the rectifier's stability showed that the output voltage remained within the float charging set point range of 123.0 V to 123.1 V. No significant fluctuations were observed during the monitoring period. Consequently, the charging system is declared stable and functioning correctly in maintaining the DC system battery's charge.

The stable performance of the rectifier is a critical supporting factor in the positive battery evaluation. In many cases, battery deterioration is not caused solely by aging, but also by poor charger regulation. Since no significant fluctuation was observed, the charger can be considered to be operating correctly and not contributing to abnormal battery stress. This strengthens the interpretation that the current battery condition is primarily influenced by the battery's own aging characteristics rather than charging-system malfunction.

D. Analysis of 110 VDC Battery System Parameter Graphs

Battery Bank Voltage Graph

The graph indicates that the voltage of Battery Bank 1 and Battery Bank 2 was relatively stable from September to November 2025. Battery 1 stayed at approximately 119.4 V, while Battery 2 stayed at approximately 123.0 V without significant fluctuations. This condition signifies that the battery system and the float charging process are working well to maintain DC system voltage stability.

Analytically, the flat trend line confirms that there was no short-term deterioration during the observation period. However, the persistent gap between the two banks also confirms that the redundancy system is not operating at identical electrical conditions. This is important in substation reliability analysis because redundant battery banks are ideally expected to have comparable performance levels. Therefore, the graph supports two conclusions simultaneously: temporal stability is good, but inter-bank uniformity still deserves attention.

Figure 4 presents the battery bank voltage graph for Battery Bank 1 and Battery Bank 2 during the observation period from September to November 2025.

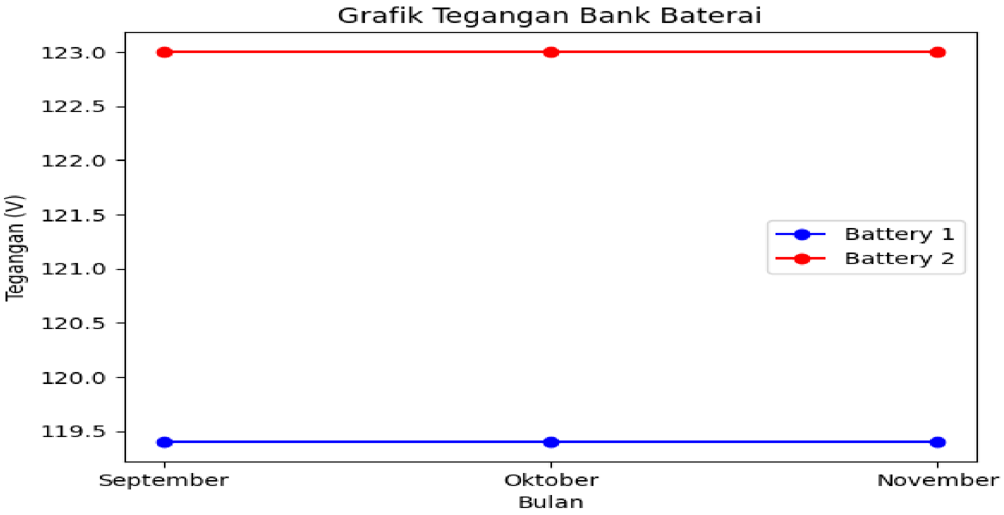

Figure 4: Battery Bank Voltage Graph

As shown in Figure 4, both battery banks exhibit stable voltage trends throughout the observation period, with Battery Bank 1 maintaining approximately 119.4 V and Battery Bank 2 around 123.0 V. This stability indicates that the charging system operates consistently in float mode and is capable of maintaining the battery voltage within an acceptable range. However, the consistent voltage difference between the two battery banks suggests a variation in performance or state of charge, where Battery Bank 2 demonstrates a higher voltage level and potentially better readiness. From a technical perspective, although both values are still within operational limits, this gap should be monitored to ensure uniform performance between battery banks, as imbalance may affect long-term reliability of the DC system.

Average Cell Voltage Graph

The average cell voltage graph shows relative stability during the observation period. Although there was a slight increase from 1.34 V in September to 1.36 V in October followed by a minor decrease to 1.35 V in November, these changes remained within normal limits. This indicates that the balance between cells is maintained and the float charging system is operating correctly.

This fluctuation pattern is small and does not indicate abnormal behavior. In practical battery assessment, such minor variation can occur due to temperature changes, measurement tolerance, or slight equalization effects from the charging process. Since the changes are not progressive and remain within a narrow range, they do not indicate active degradation. Instead, they reinforce the conclusion that the battery system is electrically stable under standby operating conditions.

Figure 5 presents the average cell voltage graph of the 110 VDC battery system during the observation period from September to November 2025.

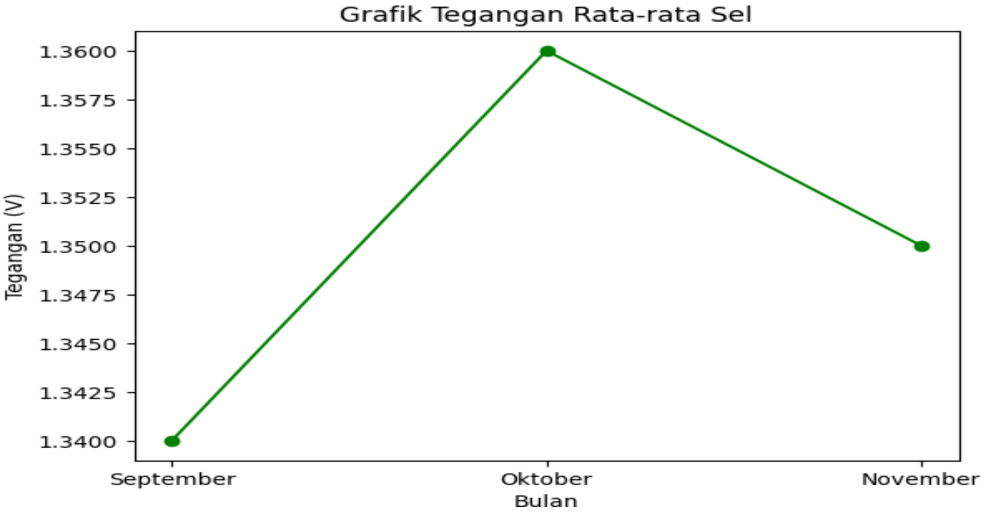

Figure 5: Average Cell Voltage Graph

As shown in Figure 5, the average cell voltage exhibits slight fluctuations, increasing from approximately 1.34 V in September to 1.36 V in October, followed by a minor decrease to 1.35 V in November. These variations remain within a narrow and acceptable range, indicating that the battery cells are operating under stable conditions. From a technical perspective, such minor fluctuations can be influenced by factors such as temperature variation, measurement tolerance, or small adjustments in the float charging process. Since the changes are not progressive or continuously declining, they do not indicate degradation but rather confirm that the cell balance is well maintained. This condition suggests that the battery system is electrically stable and capable of supporting DC system operations reliably.

Rectifier Output Voltage and Current Graphs

The rectifier output voltage for both units was relatively stable. Rectifier 1 showed a slight increase in October but remained within the normal range, while Rectifier 2 stayed constant at approximately 123.0 V. Additionally, the rectifier current remained constant at approximately 6.5 A for Rectifier 1 and 6.6 A for Rectifier 2. This indicates that the substation's DC load is stable and the battery charging system is working normally in float charging mode.

The graph not only shows stability, but also confirms that the DC load profile is relatively constant over the three-month observation period. This is beneficial for battery life because frequent current variation or excessive charging ripple can contribute to thermal and electrochemical stress. The observed steady behavior supports the interpretation that the DC auxiliary system at the substation is operating in a controlled and predictable manner.

Figures 6 and 7 present the rectifier output voltage and rectifier current graphs for Rectifier 1 and Rectifier 2 during the observation period from September to November 2025.

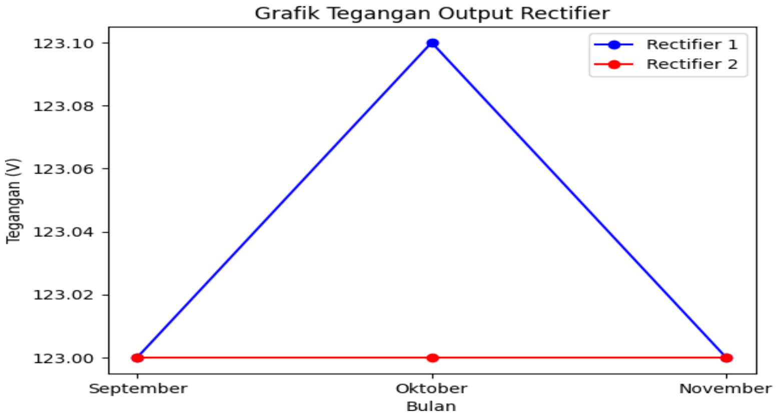

Figure 6: Rectifier Output Voltage Graph

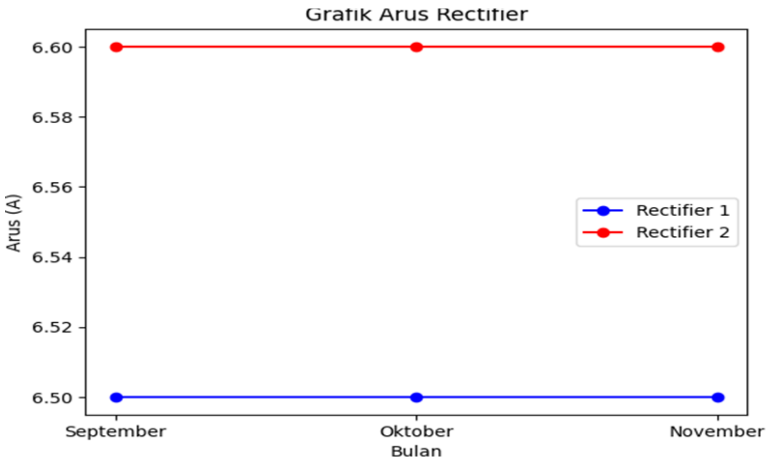

Figure 7: Rectifier Current Graph

As shown in Figures 6 and 7, the rectifier output voltage remains relatively stable within the range of approximately 123.0–123.1 V, while the output current is also consistent at around 6.5 A for Rectifier 1 and 6.6 A for Rectifier 2. This stability indicates that the rectifier system operates in float charging mode and is capable of maintaining a constant DC supply without significant fluctuations. From a technical perspective, stable voltage and current profiles are essential to ensure proper battery charging and to prevent excessive thermal and electrochemical stress on the battery. Additionally, the constant current values reflect that the DC load demand is relatively stable during the observation period. This condition supports the conclusion that the charging system is functioning reliably and contributes positively to maintaining the performance and readiness of the 110 VDC battery system.

Cell Voltage Deviation Graph

The deviation graph shows that cell voltage deviations for Battery 1 and Battery 2 were relatively stable. With deviations of approximately 0.14 V and 0.18 V respectively, both remained below the maximum allowed limit. This stability confirms that the voltage balance between cells is good, and the batteries are in feasible condition without requiring corrective action.

From an evaluative perspective, this graph is particularly important because cell deviation is often a more sensitive indicator than bank voltage in identifying early battery imbalance. Although both values remain acceptable, Battery 2's higher deviation suggests that the better bank voltage of Battery 2 should not automatically be interpreted as uniformly better cell condition. Therefore, the graph highlights that technical feasibility must be assessed using multiple parameters simultaneously: bank voltage, cell deviation, rectifier stability, and effective capacity.

Figure 8 presents the cell voltage deviation graph for Battery Bank 1 and Battery Bank 2 during the observation period from September to November 2025. This graph is used to evaluate the uniformity of voltage distribution among battery cells, which is an important parameter in assessing battery health and performance. Cell voltage deviation is considered a critical indicator because it reflects the level of imbalance between cells that may not be visible from the total bank voltage alone. Therefore, analyzing this parameter provides deeper insight into the internal condition of the battery system and helps identify early signs of degradation or potential failure.

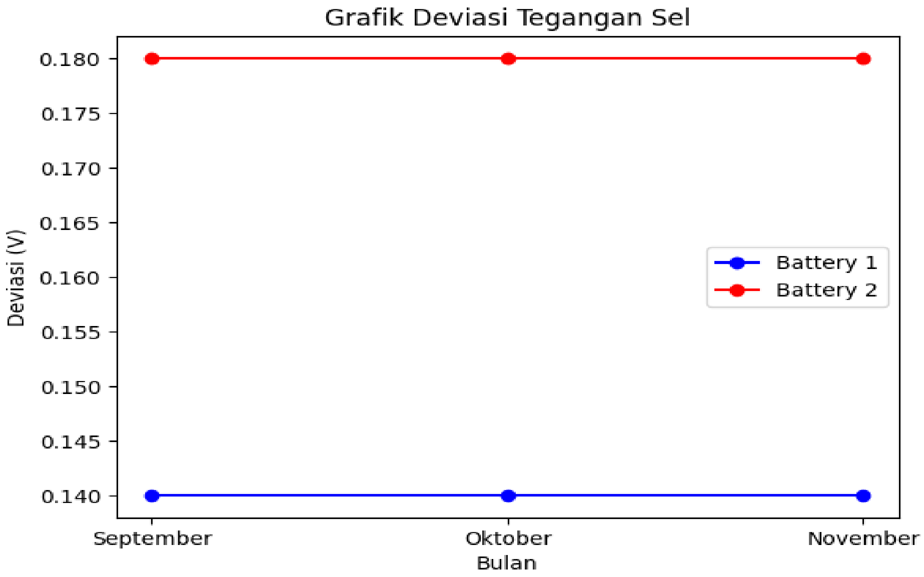

Figure 8: Cell Voltage Deviation Graph

As shown in Figure 8, the cell voltage deviation for Battery Bank 1 remains stable at approximately 0.14 V, while Battery Bank 2 shows a slightly higher but consistent deviation of around 0.18 V throughout the observation period. Both values are still below the maximum allowable deviation limit of 0.20 V, indicating that the cells are operating within acceptable balance conditions. However, from a technical perspective, the higher deviation observed in Battery Bank 2 suggests that its cell uniformity is slightly lower compared to Battery Bank 1, even though its overall bank voltage is higher. This indicates that a higher total voltage does not necessarily imply better internal cell balance. The stability of deviation over time also shows that no progressive imbalance is occurring, which confirms that the battery system remains reliable. Nevertheless, continuous monitoring is recommended to ensure that the deviation does not increase beyond acceptable limits, as excessive imbalance can accelerate battery degradation and reduce overall system performance.

E. Discussion

This discussion section aims to interpret the results of the data analysis. The discussion is conducted by linking the results of technical calculations and evaluations with the theory of DC battery systems, substation operational standards, and research objectives. Through this discussion, a comprehensive understanding of the actual condition, capability, and feasibility level of the 110 VDC battery system at the Soppeng Substation is expected. The discussion is organized based on three main problem formulations: the actual condition of the battery system, the compatibility of the battery system with the DC load, and the feasibility level of the battery system as a backup power source.

Actual Voltage Condition and Battery System Performance

Based on the results of measurements and data analysis during the period of September to November 2025, the 110 VDC battery system bank voltage showed a relatively stable condition. The bank voltage for Battery 1 was recorded at 119.4 V, while the bank voltage for Battery 2 was recorded at 123.0 V. These values did not undergo significant changes between observation periods, indicating that the battery system is in a stable charging condition and has not experienced a drastic decline in performance.

If compared with IEEE Std 450/1188, the normal float voltage range for a 2 V/cell battery is approximately 2.20–2.25 V/cell, which corresponds to a total system voltage of around 121–124 V for a 110 VDC system. Thus, the measured bank voltage values (119.4–123.0 V) are still within the acceptable operational tolerance, although Battery 1 tends to be slightly lower than the ideal float range. This indicates that while the system is stable, there may be minor undercharging conditions that need periodic monitoring to prevent long-term capacity degradation.

In addition to the bank voltage, the voltage condition of each cell was also analyzed to determine the balance between battery cells. The measurement results showed that the cell voltage in Battery 1 ranged from 1.28 V to 1.42 V, with a maximum deviation of 0.14 V. Meanwhile, for Battery 2, the cell voltage ranged from 1.25 V to 1.43 V, with a maximum deviation of 0.18 V. This deviation value is still below the maximum established deviation limit of 0.20 V. Cell voltage deviations that are within reasonable limits indicate that the balance between battery cells is maintained and there are no cells experiencing heavy degradation. This condition is important because a large cell voltage imbalance can cause a decrease in the overall battery bank capacity and accelerate damage to other cells. Thus, based on bank voltage and cell voltage parameters, the 110 VDC battery system is still in good condition and feasible to be operated.

From a deeper analytical perspective, the relatively low minimum cell voltage values (1.25–1.28 V) may indicate the presence of weaker cells or early-stage degradation, even though the deviation is still within acceptable limits. According to IEEE standards, cells with significantly lower voltage compared to the average may become critical points of failure during discharge conditions. Therefore, although the system is currently balanced, preventive maintenance such as equalizing charge or cell-level inspection is recommended to avoid future imbalance issues.

Compatibility of DC Load and Battery System Backup Time

The performance of the charging system is an important factor in maintaining the stability and service life of the battery system. Based on the measurement results of the rectifier operational parameters during the observation period, the rectifier output voltage was in the range of 123.0 V to 123.1 V. This value was relatively constant and did not show significant fluctuations between months. The stable rectifier output voltage condition indicates that the rectifier operates in float charging mode, which is a charging condition where the rectifier maintains the battery voltage at a certain value without providing excessive charging current. This operating mode is very important to prevent overcharging or undercharging that can accelerate battery degradation.

The rectifier output voltage of approximately 123 V corresponds to about 2.23 V/cell, which is within the recommended float charging range according to IEEE standards. This confirms that the charging system is operating under optimal conditions, minimizing thermal stress and electrolyte degradation in the battery. Compared to previous studies [17]–[20], stable float charging is one of the key factors in extending battery service life and maintaining state-of-health (SOH).

Furthermore, the stability of the rectifier output voltage directly affects the stability of the measured battery bank voltage. The analysis results show that the stability of the rectifier output is in line with the stability of the battery bank voltage measured during the period of September to November 2025. This indicates that the charging system is able to support the performance of the battery system optimally and maintain the readiness of the battery as a DC system backup power source. Thus, based on the results of the rectifier output voltage data analysis, the charging system is declared to work stably and reliably in supporting the operation of the 110 VDC battery system.

In addition, the compatibility between battery capacity and DC load can be considered highly adequate. The total DC load of 13.1 A is relatively small compared to the available effective capacity, resulting in a low discharge rate. This condition is beneficial because lower discharge rates reduce internal losses and slow down battery aging. Compared with typical substation standards, where batteries are designed for at least 1–2 hours of backup, the obtained results indicate a significantly higher reliability margin.

Feasibility Level of the Battery System

The adequacy of the battery system capacity was analyzed based on nominal capacity, effective capacity, total DC load current, and battery system backup time. Based on the assumption of a battery health condition of 90%, an effective battery capacity of 130.5 Ah was obtained for Battery Bank 1 and 270 Ah for Battery Bank 2. The total system DC load current supplied by the battery in an emergency condition is 13.1 A. By using this effective battery capacity, the battery system backup time calculation was performed.

The calculation results showed that the battery system is capable of supplying the DC load for 9.96 hours for Battery Bank 1 and 20.61 hours for Battery Bank 2. These backup time values far exceed the minimum backup time standard for substation DC systems, which is generally in the range of 1–2 hours. In addition, the percentage of battery capacity utilization during the backup period is 90% of the nominal capacity. This value indicates that the battery capacity is utilized optimally but still within the safe limits of battery system operation. This condition shows that the battery system does not experience excessive loading and still has a good reliability margin. Based on the results of the effective capacity, backup time, and capacity utilization percentage analysis, it can be concluded that the 110 VDC battery system has sufficient capacity to support the DC load requirements of protection equipment, control, and other supporting systems in an emergency condition.

From a more in-depth evaluation, the obtained backup time (up to 20.61 hours) indicates that the battery system is significantly oversized relative to the current DC load demand. While this increases reliability, it may also indicate inefficiency in system design, as excessive capacity can lead to higher investment and maintenance costs. However, in critical infrastructure such as substations, this condition is still acceptable because reliability is prioritized over cost efficiency.

Furthermore, based on IEEE criteria where battery capacity is considered acceptable if it remains above 80% of nominal capacity, the assumed 90% condition indicates that the battery is still in a healthy operational state. This result is consistent with findings in previous studies [17]–[20], which state that batteries with capacity above 85–90% are categorized as having good performance and are still suitable for continued operation without immediate replacement.

Overall, the integration of voltage stability, capacity adequacy, and load compatibility analysis confirms that the 110 VDC battery system at the Soppeng Substation meets technical standards and demonstrates high reliability. However, early indications of minor voltage variation and potential underutilization suggest that periodic evaluation and optimization strategies are still necessary to maintain long-term system performance.

IV. CONCLUSION

Based on the measurements conducted from September to November 2025, the 110 VDC battery system bank voltage at the Soppeng Substation remained stable at 119.4 V for Battery 1 and 123.0 V for Battery 2. The cell voltage deviations were found to be within a very small range, complying with IEEE and PLN tolerance limits, which indicates a healthy voltage balance between cells and no significant degradation in either battery bank. Furthermore, the charging performance analysis demonstrated that the rectifiers produced a stable output voltage between 123.0 V and 123.1 V while operating in float charging mode, effectively maintaining the batteries at an optimal charge level and ensuring the reliability of the DC system.

The evaluation of the battery's capability to support DC loads confirmed that the load voltage remained stable at 109 V, ensuring that protection, control, and telecommunication equipment continue to function properly. Based on the total DC load and available battery capacity, the system is deemed sufficient and feasible for providing the necessary power supply during emergency conditions. The consistent performance of the charging system and the stability of the voltage parameters prove that the 110 VDC battery system at the Soppeng Substation is in a reliable condition and meets the required

REFERENCES

[1] A. Fajar Ramadhan, A. Naufal Fikriy Syafei, and D. Sirajuddin Muzakki, “STUDI ANALISIS EFISIENSI PENGGUNAAN BATERAI DI GAS INSULATED SUBSTATION WARU,” 2024.

[2] A. N. Ihsan, J. Joko, B. Suprianto, and T. Wrahatnolo, “Analisis dan Efisiensi Kebutuhan Kapasitas Baterai 110 Volt DC Gas Insulated Switchgear (GIS) 150 KV Wonokromo Surabaya,” Jurnal Teknik Elektro, vol. 11, no. 3, pp. 481–488, 2022.

[3] M. Fajaruddin, “Pemeliharaan Baterai Pada Gardu Induk Gis Listrik Medan,” Circle Archive, vol. 1, no. 2, 2023.

[4] A. Indrawan, “Kapasitansi Dan Efesiensi Baterai 110 Vdc Pada Gardu Induk Sungai Kedukan Upt Palembang,” Integrative Perspectives of Social and Science Journal, vol. 2, no. 03 Agustus, pp. 5874–5894, 2025.

[5] E. S. Gunawan and A. Salsabila, “Optimalisasi Pemeliharaan Sistem Baterai 110 VDC Di Gardu Induk Cilegon Lama,” JTekEL: Jurnal Teknik Elektro, vol. 2, no. 1, pp. 44– 50, 2025.

[6] W. Prasetyo, R. Mubarok, R. A. Murdiantoro, N. Nasrulloh, and R. N. Prasetyono, “Analysis Of 110v Dc Battery Equalizing Test At 150 Kv Kalibakal Substation Pln Purwokerto,” Journal of Electronic and Electrical Power Applications, vol. 4, no. 2, pp. 292–298, 2024.

[7] I. N. Nurhadi and L. Liliana, “Pengaruh Temperatur dan Nilai Berat Jenis Cairan Elektrolit Terhadap Tegangan Sel Baterai Nickel Cadmium 110 Vdc Gardu Induk Perawang Sistem 150 kV,” CYCLOTRON, vol. 5, no. 2, 2022.

[8] G. P. Sulaeman, I. Ibrahim, and D. B. Santoso, “Analisis Catu Daya No Break System Perangkat Telekomunikasi,” Jambura Journal of Electrical and Electronics Engineering, vol. 3, no. 2, pp. 41–50, 2021.

[9] M. Syukri and A. Nasution, “The effect of distributed generator injection in different number of units on power and voltage losses in the electricity distribution system,” Journal Geuthee of Engineering and Energy, vol. 3, no. 2, pp. 59–70, 2024.

[10] H. WIDIARTO and Y. Suprihartini, “Analisis Kualitas Jalur Distribusi Menggunakan Etap Power Station 12.6. 0 Pada Gardu Politeknik Penerbangan Indonesia,” CENDEKIA: Jurnal Ilmu Pengetahuan, vol. 2, no. 1, pp. 82–90, 2022.

[11] E. Syahwal Gunawan, A. Salsabila, T. Elektro, F. Teknik, and U. Sultan Ageng Tirtayasa, “Optimalisasi Pemeliharaan Sistem Baterai 110 VDC Di Gardu Induk Cilegon Lama.”

[12] H. Suyanto, R. A. Diantari, and T. Koerniawan, “Study Operation Demonstration Project STT-PLN of the Battery Energy Storage System in Buton Island (Baubau Southeast Sulawesi),” in 2020 2nd International Conference on Industrial Electrical and Electronics (ICIEE), IEEE, 2020, pp. 6–10.

[13] V. D. C. D. M. Pembebanan, “Feasibility Analysis of 110 VDC Battery in Supplying Loading (Case Study of 150 kV Perawang Substation) Analisis Kelayakan Battery 110 VDC Dalam Mengsuplai Pembebanan (Studi Kasus Gardu Induk Perawang 150 kV),” Journal Homepage: https://journal. irpi. or. id/index. php/ijeere, vol. 2, no. 1, pp. 29– 38, 2022.

[14] Pahiyanti, N. G., & Putra, A. (2021). Evaluation of battery capacity and backup time in 150 kV substation. Jurnal Energi dan Sistem Tenaga Listrik, 10(2), 85–92.

[15] Pahiyanti, N. G., 2019. Analisis Keandalan Sistem Catu Daya DC pada Gardu Induk 150 kV. Jurnal Energi dan Sistem Tenaga Listrik, vol. 8, no. 1, pp. 25–31.\

[16] Pahiyanti, N. G., 2022. Analisis Kestabilan Tegangan Float Charging pada Sistem Baterai Gardu Induk. Jurnal Sistem Tenaga dan Energi, vol. 11, no. 1, pp. 45–52.

[17] [17] A. Sharma, R. K. Singh, and S. K. Sharma, “Condition monitoring and performance assessment of lead-acid batteries in substation DC systems,” IEEE Transactions on Industry Applications, vol. 58, no. 3, pp. 3452–3460, May–Jun. 2022.

[18] [18] J. Li, Y. Wang, and H. Zhang, “State-of-health estimation of substation batteries using data-driven methods,” IEEE Access, vol. 9, pp. 118765–118775, 2021.

[19] [19] M. Gonzalez, L. Fernandez, and P. Garcia, “Reliability evaluation of DC auxiliary power systems in electrical substations under transient conditions,” Electric Power Systems Research, vol. 210, pp. 108091, 2022.

[20] [20] K. Tanaka, T. Yamada, and H. Ito, “Optimal sizing and management of battery systems for substation auxiliary services,” International Journal of Electrical Power & Energy Systems, vol. 140, pp. 108023, 2022.