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Performance Analysis of a 220 V DC Lead-Acid Battery Using the Dummy Load (Torkel 840) Method in The Electrical System of a Steam Power Plant 2x 100 MW

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Abstract— Battery performance can be affected by operational disturbances such as overcharging and deep discharging, which may lead to voltage instability, temperature rise, and accelerated degradation. This study analyzes the effect of discharge current on the voltage and temperature characteristics of a lead-acid battery in a 220 V DC LAA system using a dummy load method. The experimental test was conducted using a Torkel 840 battery discharge tester with a constant discharge current of 25 A for a duration of 10 hours. Parameters including total battery voltage, average cell voltage, battery temperature, and electrolyte specific gravity were measured periodically during the discharge process. The minimum allowable battery voltage was determined based on manufacturer specifications to ensure safe operation. The results indicate that the battery voltage decreased gradually and remained above the minimum allowable limit of 187.2 V, demonstrating stable voltage performance under constant load conditions. Battery temperature increased moderately from 22.36 °C to 25.93 °C and remained within the recommended operating range. The electrolyte specific gravity showed a consistent decrease corresponding to normal electrochemical behaviour. These results confirm that the tested lead-acid battery is suitable for reliable operation as a DC backup power source in power plant applications.

Keywords: *Lead-acid battery, Discharge current, Dummy load test, DC system, and Battery temperature.*

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1. Introduction

Batteries are a key component of energy storage systems because they convert chemical energy into electrical energy. In industrial applications, they play a crucial role as emergency power supplies and energy storage devices, particularly in areas requiring high reliability, such as power plants. With the increasing demand for renewable energies and efficient energy storage systems, research into battery performance is gaining in importance [1]. Batteries can be divided into two main categories: primary batteries and secondary batteries. Primary batteries are designed for single use and cannot be recharged, while secondary batteries, such as lead-acid batteries, are rechargeable and reusable [2]. Secondary batteries are widely used in various fields, including electric vehicles, renewable energy storage systems, and as emergency power supplies in electrical systems [3].

Battery performance can be maintained by avoiding common disturbances such as overcharging and deep discharging, as these can impair reliability [4]. These two main problems can reduce the battery's lifespan and performance [5]. Overcharging occurs when the battery is charged beyond its maximum capacity. This leads to a temperature increase, gas formation, and can even cause a fire [6]. Deep discharge, on the other hand, occurs when the battery is used until the voltage drops below the minimum safe limit and the output current increases sharply [7]. Testing battery performance is crucial for ensuring operational safety and efficiency. A common method for evaluating battery performance is dummy load testing. In this test, the battery is subjected to a defined load under real-world conditions to

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measure its capacity and efficiency [8].

Lead-acid batteries are among the most widely used battery types worldwide, particularly in industrial and automotive applications. They are characterized by their ability to deliver high power in a short time and are relatively inexpensive [9]. According to a study by Andrea C. et al. [10], lead-acid batteries exhibit good cycle stability and reliability under various conditions, although their energy density is lower compared to lithium-ion batteries. This makes them a good choice for high-power applications, such as motor vehicles and emergency power systems.

Battery testing is a crucial step in ensuring their proper and safe operation. Various test methods have been developed, including capacity tests, lifetime tests, and charging current tests. According to a study by Shahid et al. [11], proper testing can identify potential problems before the battery is used in critical applications. Carefully conducted tests not only improve battery reliability but can also extend its lifespan. One of popular method in battery testing is the dummy load method, particularly for lead-acid batteries.

This method uses a resistor or other component that draws current from the battery during the test. This allows for the simulation of real-world conditions to which the battery is exposed in everyday use. Studies by Zeyad [12], show that using a dummy load improves test accuracy and provides more realistic battery performance data. This is particularly important because a poorly tested battery can cause serious performance and safety issues. Several studies have investigated the effectiveness of the dummy load method in testing lead-acid batteries. Zhao [13], demonstrated in one study that using a dummy load not only improves test accuracy but also facilitates the diagnosis of problems that may occur during charge and discharge cycles. These results suggest that the dummy load method is a very useful tool in battery testing and could find wider application in industry to optimize testing processes and ensure product quality.

However, most existing studies focus on laboratory-scale battery testing or lithium-based batteries. Limited research has been reported on field-based dummy load testing of lead-acid batteries in 220 V DC LAA systems used in steam power plants. Unlike previous studies that predominantly focus on laboratory-scale testing or lithium-based batteries, this study provides a field-based performance evaluation of a 220 V DC lead-acid battery system installed in an operating 2×100 MW steam power plant. The results offer practical insights for maintenance decision-making and operational reliability assessment of industrial DC protection and control systems. Therefore, this study aims to evaluate the discharge performance and operational reliability of a 220 V DC lead-acid battery system in an operating 2×100 MW steam power plant using a dummy load testing method.

2. Method

This experiment is designed to verify the performance of lead-acid batteries using the dummy load method. The batteries to be tested are selected based on relevant specifications such as type (e.g., conventional lead-acid batteries) and capacity. The subject of this investigation is a lead-acid battery in a 220 V DC battery system, which serves as the power source for the DC system. The batteries are connected in series to generate a nominal voltage of 220 V DC.

The test is conducted in two phases: a discharge test and a charge test. The equipment and materials used in this study are as follows:

a. LAA 220 V DC System
   This system serves as a power source for the lead-acid battery circuit under test and simultaneously as a DC power supply for protection and control devices [9].

b. Torkel 840
   Used as a battery discharge tester or dummy load to supply a constant load current to the battery

during the discharge process.

c. Ampere Clamp
Used to measure the current flowing from the battery to the Torkel 840 to ensure that the load current value meets the test parameters.

d. Thermogun
Used to measure the surface temperature of the battery during the testing process without contact.

e. Hydrometer
Used to measure the density of the battery electrolyte and thus assess the state of charge and health of the battery.

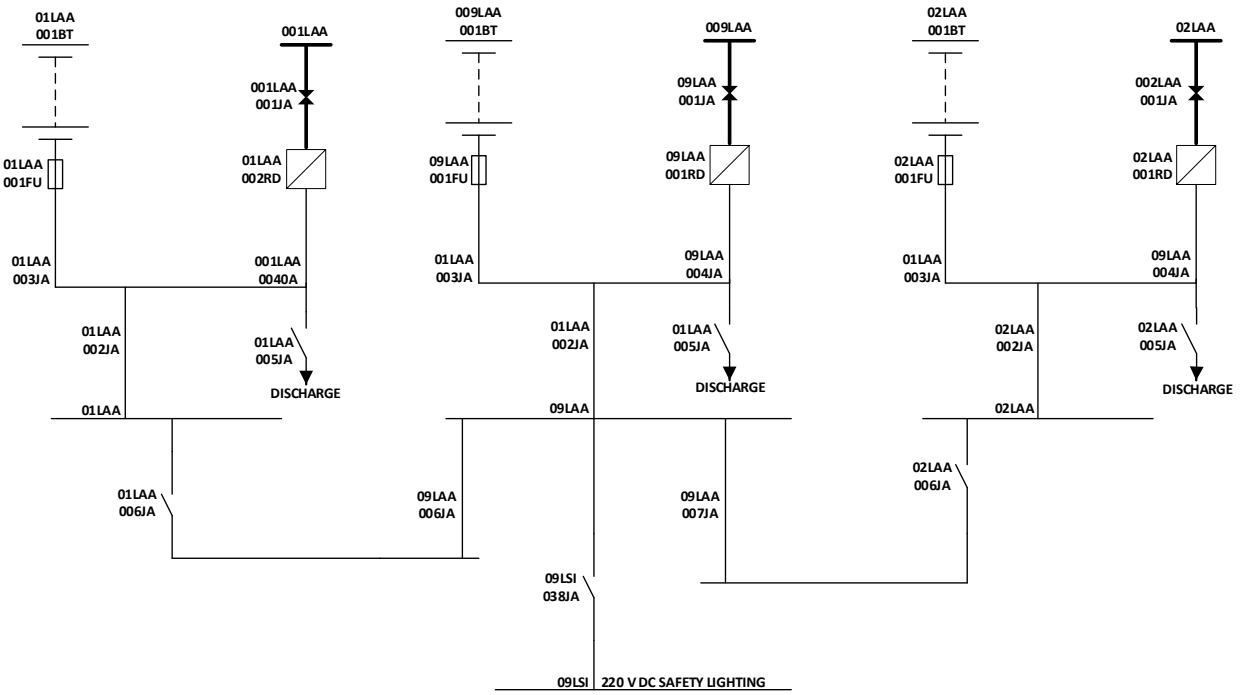


Figure 1. LAA 220 V DC system configuration

The configuration of the 220 V DC LAA system used in this study is shown in Figure 1. The system consists of a battery connected in series a DC distribution panel, a circuit breaker, and a discharge path used during the tests. Under normal operation, the battery is charged. For the tests, the system was disconnected from charging, and the battery was connected to the Torkel 840 via the discharge path. This configuration ensures that the test is performed using only battery power and without any influence from the charger.

2.1 Procedure of Dummy Load Testing Using Torkel 840

The dummy load test on the lead-acid battery of the 220 V DC LAA system was conducted using a Torkel 840 battery discharge tester. This test was performed to evaluate the voltage and temperature characteristics of the battery during the discharge process under constant current conditions. The testing procedure was carried out systematically to ensure operational safety and data accuracy. Prior to the discharge test, initial measurements were performed while the battery system was in the *on-charging* condition. The measured parameters included the cell voltage, electrolyte specific gravity, and total battery voltage of the 220 V DC LAA system.

Subsequently, the load was transferred from the 01 LAA bus to the 09 LAA bus by activating the corresponding circuit breaker, while the charger circuit breaker was deactivated. After the load transfer process, the battery circuit breaker was opened to prepare the system for the discharge test. Once the system was in the *off-charging* condition, the cell voltage and total battery voltage were re-measured to confirm the initial condition prior to testing. The charger input connection was then disconnected from the battery terminals to ensure that the discharge process relied solely on the battery energy.

The Torkel 840 was connected to the battery terminals according to the configuration shown in Figure 2. The device was supplied with 220 V AC power, and the main power switch was activated. The test cables were connected to the battery terminals with correct polarity. After the Torkel 840 was powered on, the test parameters were configured according to the battery specifications. The minimum allowable battery voltage was determined based on the minimum cell voltage multiplied by the total number of battery cells, as expressed in Equation (1):

$$V_{min} = 1.8 \times 104 = 187.2 \text{ V} \quad (1)$$

The discharge current was determined based on the battery capacity and the test duration. With a battery capacity of 250 Ah and a discharge duration of 10 hours, the applied discharge current was set to 25 A. The selected discharge current of 25 A corresponds to a C/10 discharge rate, which is commonly recommended for capacity and performance testing of lead-acid batteries to minimize thermal stress and ensure representative operational behavior. After all test parameters were properly configured, the circuit breaker was closed and the discharge test was initiated by pressing the start button on the Torkel 840.

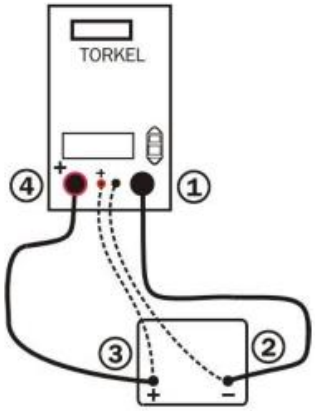


Figure 2. Configuration of Torkel 840 Connection to the Lead-Acid Battery

3. Result and Discussion

3.1 Total Battery Voltage Characteristics

The variation of total battery voltage during the dummy load test is presented in Figure 3, while the summarized numerical data are provided in Table 1. Prior to discharge, the battery voltage was measured at 227.2 V, indicating a fully charged condition for the 220 V DC system. As the discharge progressed under a constant current of 25 A, the battery voltage decreased gradually. After 10 hours of discharge, the voltage reached 198.8 V, which remained above the minimum allowable voltage of 187.2 V. This result indicates that the battery was capable of supplying the required load while maintaining voltage stability within safe operational limits. This voltage trend is consistent with the findings reported in previous studies on lead-acid battery discharge behavior under constant current conditions, where a gradual voltage decrease is observed while remaining within acceptable operating limits [2][10].

Compared to similar field and laboratory discharge tests reported in the literature [2], [9], and [10], the tested 220 V DC lead-acid battery demonstrates comparable voltage stability under constant current discharge conditions. In previous studies, lead-acid batteries discharged at C/10 rates typically maintain cell voltages above 1.90 V throughout most of the discharge period. In this study, the average cell voltage remained at 1.94 V at the end of the 10-hour discharge test, indicating consistent electrochemical performance. Furthermore, the observed gradual voltage declined and absence of sudden voltage drops suggest healthy internal resistance characteristics, which are in agreement with the discharge behavior reported in industrial DC auxiliary battery systems used in power plant applications.

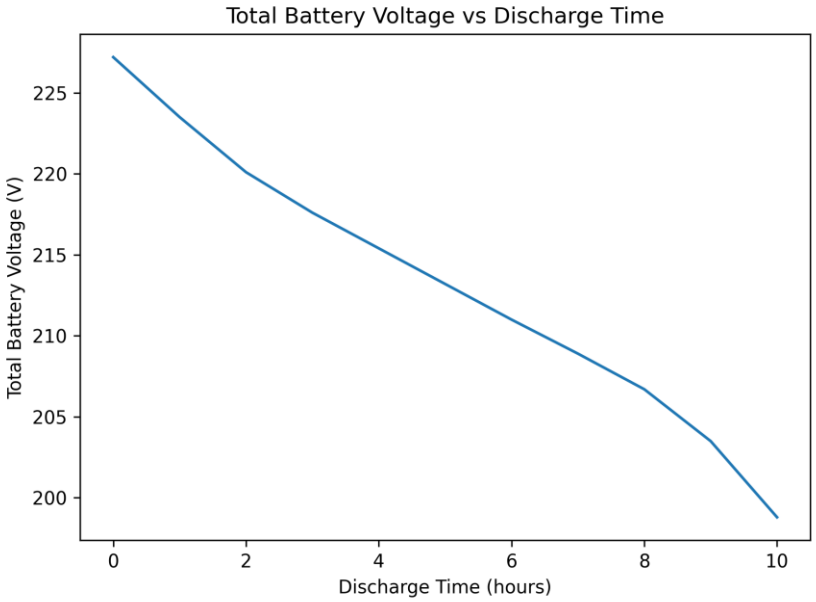


Figure 3. Total Battery Voltage vs Discharge Time

Table 1. Summary of Battery Parameters During Dummy Load Test

Discharge Time (h)	Total Voltage (V)	Average Cell Voltage (V)	Battery Temperature (°C)	Specific Gravity (kg/L)	Discharge Time (h)
0	227.2	2.18	22.36	1.25	0
2	220.1	2.12	25.07	1.24	2
4	215.4	2.07	25.60	1.22	4
6	211.0	2.03	25.80	1.20	6
8	206.7	1.99	25.90	1.17	8
10	198.8	1.94	25.93	1.15	10

According to IEEE Std 450 and IEC 60896 [14][15], a lead-acid battery is considered acceptable if the final discharge voltage remains above 1.80 V per cell under rated discharge conditions. In this study, the minimum measured total battery voltage was 198.8 V, corresponding to an average cell voltage of 1.94 V, which exceeds the minimum standard requirement. This indicates that the battery system satisfies international operational criteria for DC auxiliary systems in power plant applications.

$$\text{Voltage drop rate} = \frac{227.2V - 198.8\,V}{10\,h} = 2.84 \text{ V/h} \quad (2)$$

In addition to the observed voltage trend, the average voltage degradation rate was calculated to provide a quantitative assessment of discharge stability. Based on the measured initial and final voltages,

the voltage drop rate was approximately 2.84 V/h. This relatively low and uniform degradation rate indicates a stable discharge behavior and suggests the absence of abnormal internal resistance increase within the battery cells during the test period.

$$V_{avg} = \frac{227.2V + 198.8\,V}{2} = 213\ \text{V} \quad (3)$$

$$E = V_{avg} \times I \times t \quad (4)$$
$$= 213 \times 25 \times 10 = 53{,}250\ \text{Wh} = 53{,}25\ \text{kWh}$$

Based on the average discharge voltage and constant current condition, the energy delivered by the battery during the 10-hour discharge test was estimated. Using an average voltage of approximately 213 V, a discharge current of 25 A, and a discharge duration of 10 h, the total delivered energy was estimated at around 53.25 kWh. Although this estimation is simplified, it provides a quantitative indication of the battery's energy delivery capability under actual operating conditions. This estimation does not account for inverter losses or dynamic voltage variations and is intended as a practical approximation for field-based assessment.

3.2 Battery Temperature Behavior

The battery temperature variation during the discharge process is illustrated in Figure 4. At the beginning of the test, the average battery temperature was 22.36 °C. A gradual temperature increase was observed after 10 hours of discharge, reaching a maximum value of 25.93 °C at the end of the test. The temperature rises of approximately 3.6 °C is attributed to internal resistance losses and electrochemical reactions during the discharge process. However, the observed temperature increase remained well within the recommended operating range for lead-acid batteries, indicating that the applied discharge current did not cause excessive thermal stress. This temperature rise is lower than the typical temperature increase of 5–10 °C reported in similar lead-acid battery discharge tests under comparable current levels [2], indicating favorable thermal behavior during field operation.

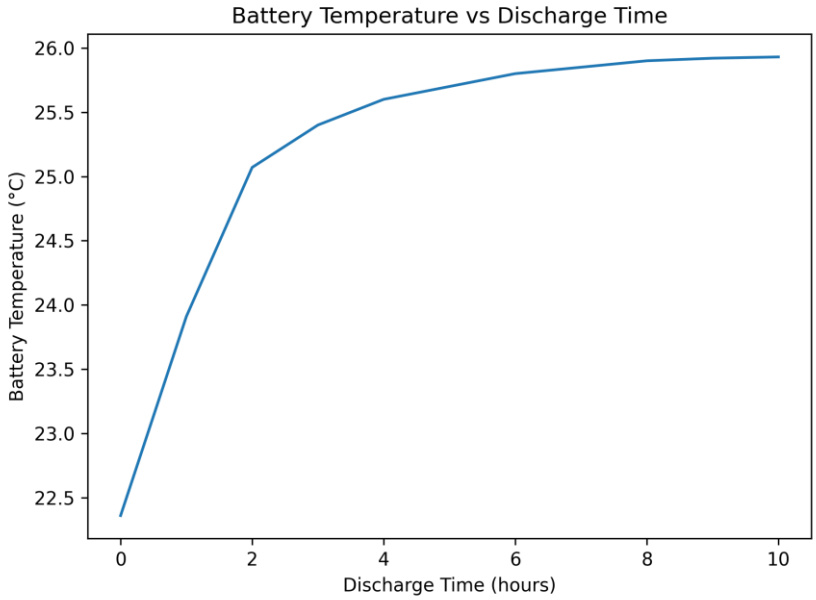


Figure 4. Battery Temperature vs Discharge Time

3.3 Electrochemical Performance Evaluation

The decrease in electrolyte specific gravity during the discharge process, as shown in Table 1, followed a consistent downward trend from 1.25 kg/L to 1.15 kg/L. This behavior is consistent with the expected electrochemical characteristics of lead-acid batteries, where sulfuric acid concentration decreases as discharge progresses. The consistent voltage reduction, moderate temperature increase, and stable specific gravity behavior collectively indicate that the battery system was in good condition and suitable for its application as a DC backup power source.

4. Conclusion

The experimental results demonstrate that the application of a constant discharge current of 25 A resulted in a gradual and stable decrease in both total battery voltage and average cell voltage throughout the 10-hour discharge period. At the end of the discharge test, the total battery voltage remained above the minimum allowable limit of 187.2 V, indicating that the battery was able to supply the required load while maintaining voltage stability within safe operating limits. The observed voltage reduction was relatively uniform, suggesting good cell balance and the absence of significant degradation during the test.

The battery temperature exhibited a moderate increase during the discharge process, rising from 22.36 °C to 25.93 °C. This temperature rise is attributed to internal resistance losses and electrochemical reactions during discharge; however, the temperature remained within the recommended operating range for lead-acid batteries. Additionally, the decrease in electrolyte specific gravity followed the expected electrochemical behavior, further confirming normal battery performance. This study was limited to a constant discharge current of 25 A (C/10). Future work should investigate the impact of higher discharge currents (e.g., C/5 or C/3) to evaluate voltage stability, thermal stress, and potential degradation effects under more demanding operating conditions. Overall, the results indicate that the tested lead-acid battery system is in good condition and remains suitable for use as a DC backup power source in power plant applications.

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