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Systematic reconditioning maintenance kit for gel-type lead-acid batteries in a photovoltaic (PV) system in Bacolor, Pampanga

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ABSTRACT

Lead-acid batteries remain indispensable in energy storage systems due to their affordability and reliability, particularly for off-grid photovoltaic (PV) applications. However, the identified unused gel-type lead-acid batteries within the PV system at Don Honorio Ventura State University (DHVSU) face challenges with operations by the reason of degradation over extended periods without maintenance.

This paper developed a methodical process of reconditioning maintenance kit to track and recover the usefulness of unused batteries. Sixteen (16) unused gel type lead-acid batteries were checked to determine State-of-Charge (SoC), capacity and internal resistance. The reconditioning process extended to cleaning and desulfation by way of controlled, slow recharging which achieved periodic load testing of the batteries within the 368-watt aquarium to put the batteries through a high-load environment.

To make sure that it works, a series of minimal load testing was also performed, with two 15-watt LED bulbs and a 12-watt electric fan. The findings indicate that although a number of batteries were in useable condition upon applying the reconditioning kit, others were irreversibly damaged due to the long period of neglect and low maintenance of the batteries. A maintenance kit was created to highlight the tools and procedures required in a systematic, feasible and safe methodology of managing batteries in photovoltaic (PV) systems. This undertaking facilitates sustainability in the use of energy as it minimizes the waste of energy and optimizes the life cycle of the available energy.

Keywords: Battery Diagnostics; Battery Management; Capacity Testing; Controlled Charging; Desulfation; Energy Storage; Gel-Type Lead-Acid Battery; Load Testing; Maintenance Kit; Photovoltaic System; Reconditioning; State-of-Charge Monitoring.

1. Introduction

Lead-acid batteries are crucial parts in energy storage, particularly for off-grid and backup power applications, due to their affordability, reliability, and effective use in renewable energy systems [1]. The Philippines has slowly made progress to adapt to the shift towards renewable energy solutions, as if they supply a continuous and stable power supply, especially in rural and isolated areas that cannot be reached by distribution power companies [2]. One of the batteries that are used in photovoltaic (PV) systems is gel-type lead-acid batteries due to their reliable capability when it comes to deep cycles [3].

It can also be highlighted that with proper care, checkups, and reconditioning of the batteries, they can last in more extended periods, thus outperforming under-maintained batteries. It can also be noted that with the aforementioned proper care for the batteries, once they are maintained adequately, the produced waste from discarding them will reduce, thereby there will be a decrease in premature replacements and other costs that come with changing batteries [4]. Nonetheless, it is unfortunate that in real life, having preparations to maintain or check on batteries is hard to implement, given the lack of knowledge and the types of equipment to care for the batteries as consumers [5]. As a consequence of the batteries being disposed of rashly without properly inspecting their status, it leads to an increase in problems in both environmental and financial terms, especially for the end-users [6]. The rapid manufacturing and utilization of electric vehicles further shows the need for sustainable battery management, including proper maintenance and safe disposal practices of the batteries that have served their entire life span without causing hazards [7].

Battery energy storage systems or BESS, are vital in renewable applications, where among the available options of their batteries, gel-type lead-acid batteries are preferred. These types of batteries are likely to be chosen based on their reliable performance in different applications, particularly in the renewable energy field. These gel-type lead-acid batteries are also good at handling deep discharge cycles and have lower maintenance demands compared to other battery options. These batteries are widely used in off-grid photovoltaic (PV) systems for their robust and enclosed design that saves the battery and the handler from getting inflicted with possible hazards [8]. However, if they are left unchecked or lack the maintenance they need, the batteries will suffer from degradation over time, such as sulfation, capacity loss, and increased internal resistance, which impair their performance and reduce overall system efficiency [9].

Through programs like the National Renewable Energy Program (NREP) and the Philippine Energy Plan (PEP), the Philippines continuously seeks to strengthen its renewable energy sector to help achieve the country's aspirations in its national sustainability [10],[11]. Don Honorio Ventura State University (DHVSU), a state higher education institution in Pampanga, is implementing the use of PV systems on the campus to contribute to the goal. However, sixteen gel-type lead-acid batteries, which are essential elements of the university's solar energy infrastructure, have been discovered unused for a period exceeding six years. These batteries displayed an apparent decline in their performance as a result of the lack of systematic monitoring and maintenance, further limiting their usability and compromising the PV system's efficiency.

Monitoring the status of the batteries closely and regularly is a must for preserving the life of the batteries and their performance, whether they are stored away or applied in a system. Parameters that are crucial in close maintenance and diagnosing a battery are its voltage, capacity, and internal resistance to check the state they are in, good or bad [12]. Without these data-dependent assessments, batteries are prone to being discarded prematurely, that results in higher replacement costs whilst also adding to the piling environmental waste [13].

This study addresses the gap by designing and implementing a Systematic Reconditioning Maintenance Kit that integrates both reconditioning procedures and monitoring protocols. The kit makes it more accessible to diagnose, maintain, and recover unused gel-type lead-acid batteries, to monitor their state for possible usage.

The study highlights the importance of monitoring the batteries consistently along with the addition of the reconditioning procedures in improving the sustainability and reliability of the batteries that are used in the PV system. Waste can be reduced while also maximizing the batteries' lives by periodically monitoring the batteries' condition from multiple trials of diagnostics and recovery. Desulfation through slow charging is a reconditioning process that can help degraded batteries restore their life. Regular checkups on the batteries' voltage, internal resistance, and State-of-Charge (SoC) also help monitor, maintain, and slow the batteries' wear and tear over time.

1.1. Study Objectives

The specific objectives of this study are:

1) Conduct diagnostic tests to monitor the state of charge, internal resistance, and capacity of unused gel-type lead-acid batteries before and after reconditioning;

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2) Identify and assemble the necessary tools for implementing long-term battery maintenance and reconditioning;

3) Develop and apply a structured reconditioning process that includes cleaning and desulfation through slow recharging, along with a user-friendly instructional guide;

4) Evaluate battery performance under both high-load and low-load test conditions;

5) Assess the overall usability and recovery of the batteries after systematic reconditioning.

2. Methods

In this research study, an experimental research design method was used to recondition unused gel type lead-acid batteries that were part of the photovoltaic (PV) system of Don Honorio Ventura State University. The experiment in the study involves the diagnosis of the condition of the batteries, targeted desulfation by slow charging, close monitoring of the behaviors of the batteries under different loads - high and low, and the final observations.

2.1. Conceptual Framework

This research has a conceptual framework that is systematic in its process. It starts with the pre-testing of the unused gel-type lead-acid batteries. The unused batteries were collected in six years and stored in the storage rooms of the fabrication laboratory and a photovoltaic system. Desulfation and controlled slow charging is a reconditioning technique, and the identification and application of the necessary tools concerning this step are essential in the subsequent processes.

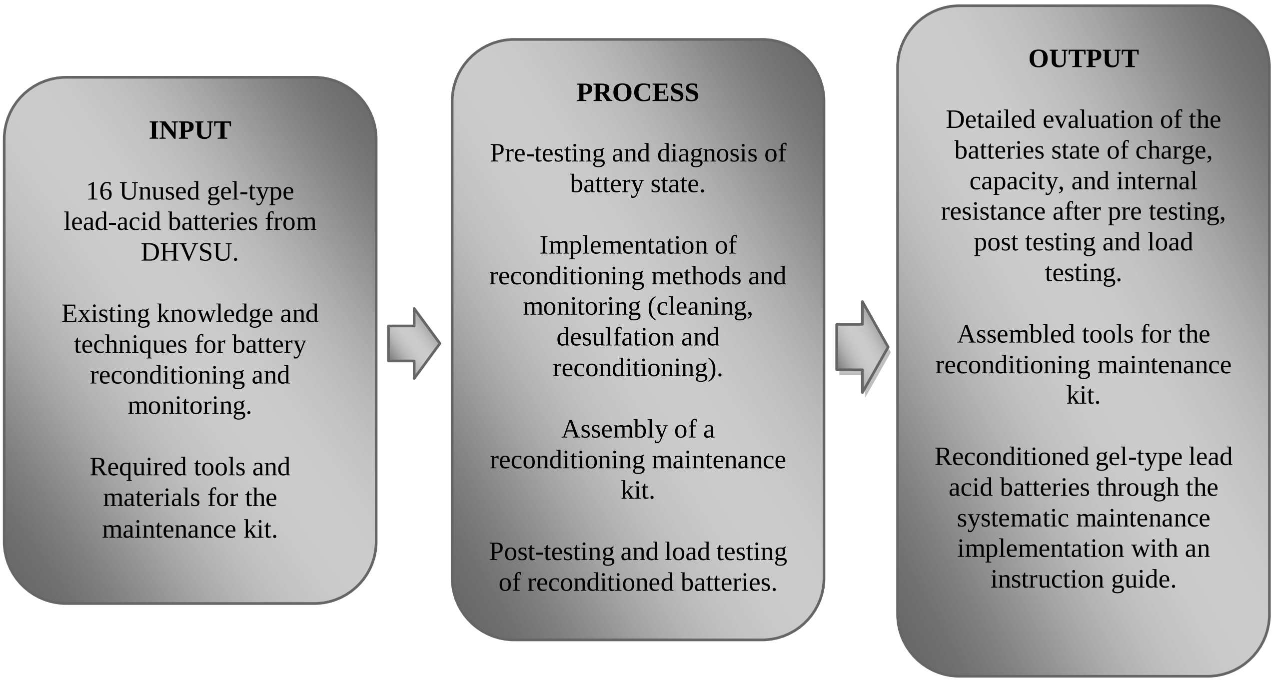

Figure 1. Conceptual Framework

The reconditioning process of each and every battery has a number of steps. The first step that has been taken in the process was the diagnostic assessment, which, diagnosed the state that the batteries were in. This could involve the use of reconditioning methods such as cleaning of the surface, desulfation and gradual recharging depending on the analysis and battery condition evaluation [14]. At the final step the reconditioned batteries were also tested on how well they performed in various load operations and this enabled appropriate equipment to be added in the proposed maintenance kit [15].

The conceptual structure of this study, which outlines the flow from input acquisition, through process stages, to final output, is illustrated in Figure 1. This framework ensures that each stage of battery assessment and reconditioning is systematically approached, emphasizing the integration of diagnostics, maintenance methods, and evaluation protocols to achieve a reliable maintenance kit.

2.2. Battery Selection and Pre-testing

The choice of the batteries was dependent on their availability as well as the time they were not in use, and the batteries indicated that they were the best to be reconditioned. Three parameters, namely State-of-Charge (SoC), internal resistance, capacity were measured in pre-testing phase. A State-of-Charge (SoC) measurement was made by performing an Open-Circuit Voltage (OCV) test whereby 12.85 V was adopted as the full charge value of the 12 V battery [16].

$$State\ Of\ Charge(SOC) = \frac{Current\ Capacity}{Maximum\ Capacity} \text{ x } 100 \quad (1)$$

Internal resistance was measured using a battery analyzer or conductance tester. Batteries with higher internal resistance were flagged as having potential sulfation or internal corrosion [17].

$$Internal\ Resistance(R_{int}) = \frac{V_{no\ load} - V_{load}}{I_{load}} \quad (2)$$

Due to the extremely low voltage of some units below 7.5 V, direct capacity testing was not possible. In these cases, capacity was estimated using self-discharge rates based on the storage duration. Referring to CSB Battery data, lead-acid batteries typically lose 3-5% of their capacity per month under proper storage conditions. The estimated remaining capacity was calculated using the formula:

Remaining Capacity (%) = 100% – (self-discharge rate × number of months stored) (3)

Battery performance classifications were determined based on measured state-of-charge (SoC), voltage, internal resistance, and capacity range. Batteries with over 80% of their rated capacity and a voltage above 12.5 V were categorized as being in good condition. In comparison, those with less than 50% capacity and a voltage below 12.0 V were considered to be in poor condition.

Table 1. Criteria for Each Battery Condition Note: Adapted from Battery University (n.d.) and Battery Council International (2019) [18],[19]

Parameter	Good Condition	Fair Condition	Poor Condition
State-of-Charge (SoC)	100% to 75%	100% to 75%	<50%
Voltage	12.8V to 12.5V	12.4V to 12.0V	Below 12.0V
Capacity	≥ 80% of rated capacity	50%-79% of rated capacity	<50% of rated capacity
Internal Resistance	3-10 mΩ (optimal range)	11-15 mΩ (slightly elevated range)	>15 mΩ (high resistance; potential damage)

2.3. Reconditioning Procedure

The reconditioning procedure involved a combination of cleaning and desulfation through slow recharging. The cleaning was done to ensure safety and electrical conductivity, which included carefully inspecting the batteries for any physical damage, then cleaning the terminals where corrosion may reside mostly. Corrosion was removed using a wire brush, and the components were checked properly and thoroughly dried before undergoing slow recharging.

A smart battery charger that was capable of gel-type lead-acid battery charging was used, and this was specifically designed to operate at low current. To get clear data in the assessment, an open-circuit voltage (OCV) test was done once again before charging the batteries. The charging itself was done within 12 to 48hrs depending upon the extent of the sulfation present in each battery. Certain chargers had a desulfation setting which uses controlled electrical pulses to help destroy the sulfation buildup at the batteries. The voltage level, temperature, and any overheating indicator were closely monitored during the process to ensure safety of equipment, people and the testing site including the functioning of the battery itself. The recheck of the batteries after desulfation was undertaken to determine the potential improvements of the batteries in the internal resistance, capacity, and the voltage. It was with this post-assessment that the researchers could confirm whether the battery could be deemed as good in terms of operations, as well as, the tools that had to be part of the output kit.

2.4. Load Testing and Performance Evaluation

To evaluate the operational performance of the reconditioned batteries, a series of load-testing procedures was conducted using controlled setups and photovoltaic (PV) system connections. A high-load test scenario was performed using a 368-watt PV-powered system operating at 24V, with Batteries 3 to 6 designed to replicate real-world energy-intensive applications such as aquarium pumps, ventilation equipment, and larger household appliances. This system was directly connected to selected reconditioned batteries to assess their performance under sustained, higher power demands. Also, for low-load conditions, each battery (specifically Batteries 3 to 8) was connected to a system comprising two 15-watt LED bulbs and one 12-watt electric fan, powered through a 12V, 300W inverter, simulating typical small DC loads commonly found in off-grid, backup, or photovoltaic (PV) storage systems. The selection of a 3-hour (180 minutes) operational runtime for both test conditions was based on the recommended discharge test duration guidelines outlined in IEEE 1188-2020, which permit operational and performance testing from 1 to 8 hours, depending on battery capacity, condition, and testing objectives. Specifically, shorter durations between 1 to 3 hours are recommended for operational verification tests, while longer durations are reserved for full-capacity evaluations [20].

Table 2. Criteria for Battery's Condition with Load, Note: Adapted from IEEE (2005) and NFPA (2022) [21],[22]

Load Support Duration (mins)	Status	Remarks
< 0.05	Fail	Insufficient Backup
0.05 - < 3.00	Marginal Pass	Needs Maintenance/Review
≥ 3.00	Pass	Battery in Good Condition

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The standards used to evaluate the performance of the batteries under load testing conditions are summarized in Table 2. This table presents the classification system used to interpret the batteries' runtime during the tests, including the thresholds that define a fail, marginal pass, or acceptable performance, which served as a basis for post-test analysis.

2.5. Materials and Equipment

The equipment and tools that were required during the research were as follows: a battery tester to perform OCV and load tests, a multimeter to check the voltage level, a smart charger to perform recharging in a controlled manner, and standard cleaning tools such as brushes and a clean cloth. The use of insulated gloves and safety goggles was a major way of ensuring safety during all the handling processes. Each of the tools chosen to make up the kit was graded on how they performed in the reconditioning process and how easily they could be used in the field in routine repair in the future [23].

2.6. Ethical Consideration

Ethical standards were adhered to and understood in all research activities presented. University authorities and personnel involved were given prior consent. The research was conducted without a human or animal subject; however, intense safety measures were used. All data was documented in an open manner, and there was no alteration or distortion of the results.

3. Results and Discussion

This is the section that portrays the data derived after a number of diagnostic and performance tests are carried out on the gel-type lead-acid batteries, both before and after the process of reconditioning. Each battery was tested through a total of three (3) trials of each diagnostic and performance test during each testing phase, in order to assure that the test results were accurate, consistent, and reliable. Their key performance indicators, which describe the operational condition of the unused batteries systematically measured by the diagnostic evaluation which includes their open-circuit voltage (OCV), state-of-charge (SoC), internal resistance, and also their capacity retention. Continuous load testing was also done by carrying out three trial runs under various loads to determine the capability of the batteries to provide constant power output under working conditions. With these consecutive and closely observed tests, the efficiency of the reconditioning maintenance kit and procedures was confirmed.

3.1. Pre-Test Diagnostic Results of Gel-Type Lead-Acid Batteries

The pre-test diagnostic assessment conducted on the 16 gel-type lead-acid batteries, as summarized in Table 3, indicates that the majority of the units were in severely degraded condition before any maintenance procedures. Most of the batteries recorded notably low open circuit voltage (OCV) values, with several falling beneath the critical 6-volt threshold, signifying deep discharge states and potential internal cell deterioration. Correspondingly, state of charge (SoC) measurements reflected this trend, with more than half of the batteries registering SoC levels below 40 percent, including Battery 16, which displayed a value under 1 percent. These results suggest prolonged periods of undercharging, natural self-discharge, or the presence of advanced sulfation [23],[24].

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Table 3. Pre-Test Diagnostic Results of Gel-type Lead-Acid Batteries

Battery #	OCV (V)	SoC (%)	Int. Res. (mohms)	Capacity	Remarks
1	0.95	7.42	35.22	17.54	Poor Condition
2	2.93	22.8	30.46	15.37	Poor Condition
3	8.28	26.4	25.69	34.36	Poor Condition
4	8.9	69.26	24.69	20.16	Poor Condition
5	11.83	92.09	13.23	100.6	Fair Condition
6	10.6	82.52	11.02	90.46	Fair Condition
7	11.9	92.61	12.66	100.01	Fair Condition
8	11.71	91.13	11.43	90.79	Fair Condition
9	10.91	84.9	42.72	84.12	Poor Condition
10	6.68	52.01	19.43	49.38	Poor Condition
11	4.81	37.41	26.67	35.78	Poor Condition
12	3.89	30.25	31.44	28.92	Poor Condition
13	2.75	21.37	38.26	19.67	Poor Condition
14	1.11	8.65	45.7	7.37	Poor Condition
15	0.1	0.78	52.49	0.15	Poor Condition
16	0.08	0.62	55.99	0.1	Poor Condition

Internal resistance values varied across the samples, with many batteries exhibiting elevated resistance levels, indicating deterioration of internal structures and impaired ionic conductivity [25]. Capacity testing supported these results, showing that only a few batteries, namely Batteries 5, 6, and 7, maintained their rated or near-rated capacities. Other batteries exhibited reduced capacity values, with some values approaching zero. Along with these diagnostic findings, it confirms that the overall condition and usability of the battery set were severely compromised. Thirteen out of the sixteen batteries were found to be in poor condition, most likely due to factors such as aging, inadequate maintenance, and improper storage practices [26],[27].

3.2. Post-Test Diagnostic Result of Gel-Type Lead-Acid Batteries

After completing the reconditioning procedures, the post-test diagnostic results presented in Table 4 displayed varying levels of functional recovery among the tested gel-type lead-acid batteries. General improvements were observed in both open-circuit voltage (OCV) and state of charge (SoC), with several batteries recording notable voltage increases, indicating effective restoration of surface charge along with partial reactivation of electrochemical activity. Batteries 14, 15, and 16, which previously exhibited critically low SoC values below 9 percent, improved to over 60 percent following reconditioning.

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Table 4. Post-Test Diagnostic Result of Gel-Type Lead-Acid Batteries

Battery #	OCV (V)	SoC (%)	Int. Res. (mohms)	Capacity	Remarks
1	6.58	47.81	30.21	19.58	Poor Condition
2	5.22	40.60	27.00	27.84	Poor Condition
3	12.17	94.68	18.28	41.13	Fair-Poor Condition
4	12.52	94.76	20.80	23.92	Fair-Poor Condition
5	12.26	95.42	20.35	98.21	Good Condition
6	12.16	94.66	13.41	98.54	Good Condition
7	10.45	92.22	11.89	99.66	Fair Condition
8	12.03	93.59	12.20	97.35	Good Condition
9	11.79	91.73	41.82	63.65	Poor Condition
10	11.01	85.68	28.68	56.86	Poor Condition
11	10.41	83.01	44.80	58.40	Poor Condition
12	9.88	76.91	47.00	53.69	Poor Condition
13	8.71	67.81	49.08	44.73	Poor Condition
14	8.34	64.93	50.37	41.45	Poor Condition
15	8.08	62.88	22.92	39.24	Poor Condition
16	7.92	61.63	35.46	59.04	Poor Condition

Additionally, batteries such as 3 through 8 achieved SoC readings above 90 percent, suggesting that the applied slow charging and desulfation processes were at least partially effective in counteracting deep discharge conditions [28]. Some of the batteries' capacity show great improvement in different samples. For instance, Battery 16 increased its capacity from 0.10 ampere-hours to 59.04 ampere-hours, signifying a transition from near-total failure to a usable energy storage level.

However, internal resistance remained a major limiting factor. While modest reductions were noted in certain units, other batteries, such as Battery 14, exhibited a rise in internal resistance from 13.23 milliohms to 20.35 milliohms, indicating the persistence of structural issues, including sulfation or grid corrosion, despite reconditioning efforts [29]. Out of the 16 batteries assessed, only four units, specifically Batteries 5, 6, 7, and 8, reached performance levels near the acceptable threshold for good operational condition, marked by high SoC, substantial capacity, and internal resistance values within or close to standard limits.

The remaining batteries remained in poor condition classifications. These outcomes suggest that although the reconditioning processes were able to partially enhance several electrical properties, they were insufficient to completely restore the internal structure and sustained energy storage performance of most heavily deteriorated batteries [29],[30].

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3.3. Observed Battery Condition during Load Testing

Case 1: High Load Testing (368-Watt Aquarium Setup)

In this scenario, the batteries were subjected to a high-load environment designed to simulate real-world applications such as aquarium pumps and other energy-intensive appliances. Batteries 3 and 4, despite having undergone reconditioning, delivered extremely poor performance. Each sustained the load for only 0.05 minutes, approximately two to three seconds. This result classifies them under the "Marginal Pass" category and indicates their inability to retain deep-cycle energy storage capacity after reconditioning. The short runtime highlights the limited energy delivery potential of severely degraded batteries, even when SoC levels appear normal [32].

On the other hand, Batteries 5 and 6 demonstrated good performance under the 368-watt load for the full 3-hour test duration. Their ability to sustain this high load suggests reliable deep-cycle capabilities and effective reconditioning outcomes. These batteries were therefore categorized as being in good condition, with stable internal resistance and sufficient residual capacity. Additionally, Batteries 7 and 8 were excluded from higher-load testing due to the system constraints where the setup operates in pairs, and Battery 7 exhibited an early voltage drop to 9V, which is below the safe operating threshold of 12V, suggesting that it would become unstable under higher-load conditions [32].

During the 3-hour operational test, system monitoring indicated an initial battery state of charge (SoC) of 85%, with a corresponding current draw of 10.2 amperes from the 24V battery bank. After 3 hours of continuous operation, the system recorded a drop in SoC to 73%, while the current draw reduced to 4.6 amperes. This reduction in current draw is primarily attributed to the natural decline in battery terminal voltage as the SoC decreases, coupled with the increase in internal resistance within the battery as it discharges. In systems where the load behaves predominantly as a resistive or semi-variable load, current delivery depends on the available voltage. As voltage decreases with time as a result of battery discharging, the current flowing through constant resistance load also decreases with a proportional relationship to the voltage, following the Ohm Law. Also, the increase in internal resistance of the lead-acid batteries in the process of discharging further restricts the ability of the batteries to deliver back a high surge of the current. This characteristic has been well-recorded in models of battery performance and operating studies [33].

Case 2: Low Load Testing (42-Watt Combined Fan and Lights)

In the second case, the load of 42 watt was applied with application of 12-watt electric fan, and two 15-watt LED lights. The arrangement is a common low-load operating situation found in off-grid, backup, or photovoltaic (PV) storage systems. This load was provided on Batteries 3 to 8 and each was able to stay operational throughout the 3-hour test. The similarity in the inefficient performance of the six batteries signifies that although some batteries like Battery 3 (12.17 V) and Battery 4 (12.52 V) might show poor performance during high-load environments, they still had enough terminal voltage and operation capacities to charge reliably at lower load scenarios. The consistency of operational runtime rates of Batteries 3 (12.17 V), 4 (12.52 V), 5 (12.16 V), 6 (12.77 V), 7 (12.69 V) and 8 (12.16 V) confirm a degree of success in reconditioning capabilities of the batteries concerning functional performance standards during light-load consumption. However, it is important to recognize that despite the

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observed operational stability, these batteries may not have completely regained their original storage capacity or internal electrochemical condition [34].

3.4. Interpretation of the Diagnostic Results

The results obtained in both the high-load and low-load test scenarios substantiate the conclusion that the internal condition of the batteries remains the primary limiting factor affecting overall performance rather than the nature or magnitude of the external load. Persistent structural degradation caused by sulfation, corrosion, and extended deep discharges continues to impair battery performance despite the application of reconditioning measures [35]. The diagnostic results confirmed that most gel-type lead-acid batteries were in poor condition before reconditioning, characterized by low open-circuit voltage, low state of charge, high internal resistance, and diminished capacity due to prolonged neglect and sulfation [36]. Batteries 15 and 16 recorded the most critical values, indicating near-total failure. Post-reconditioning diagnostics showed marked improvements in Batteries 3 to 8, with OCV values reaching 12 volts and above and SoC levels exceeding 90%, reflecting partial electrochemical recovery through desulfation and controlled charging [37]. However, high internal resistance persisted in several units, indicating irreversible structural degradation [38]. Operational load tests supported these findings. In the 368-watt high-load test, only Batteries 5 and 6 sustained the 3-hour operation, while Batteries 3 and 4 failed within 0.05 minutes, highlighting the gap between surface charge recovery and sustained load capacity [32]. Conversely, in the 42-watt low-load test, Batteries 3 to 8 maintained operation for the full duration, with terminal voltages remaining above 12 volts, confirming limited but usable performance under reduced demand [34]. The results show that reconditioning can restore moderately degraded batteries but is ineffective for severely damaged ones, stressing the need for regular diagnostics and maintenance [35].

4. Conclusion and Recommendation

In this work, the potential of restoring worn-out gel-type lead-acid batteries through systematic reconditioning processes and load-testing processes on batteries was witnessed. The key results of the test are the following ones:

- The result of the poor maintenance would be cumulatively leading to a large drop in open-circuit voltage, state of charge, internal resistance, and charging/discharging capacity.
- The prevailing factors of decay came out to be sulfation, grid corrosion and inadequate preventive maintenance.
- The premature death of such batteries through slow charging caused quantifiable regeneration in moderately degrading batteries.
- When reconditioned, batteries in advanced stages of internal destruction were not suitable to be operated under the high-load operation processes.
- Most of the batteries could work reliably on the occasional loads of light to medium capacity and only a small number of them could feed consistent heavy loads with high-ampere demand.
- The systematic battery care, which incorporates the routine diagnostic tests and preventative care, would form crucial ways of enhancing battery lifetime and raising the dependability of the system.

The following are future directions that can be designed to sit on the findings of the current research study:

- Find out possible alternative conditioning methods which will suit more extensively the degraded batteries.
- Perform long term monitoring, to gain a project on the performance of reconditioned batteries in the field.
- Examine the cost-benefit analysis of reconditioning the battery and also of completely replacing it especially in the off grid renewable energy systems.
- Research can be done on the incorporation of smart battery monitoring systems that arm an early fault detection and automatic maintenance warning.
- Determine the plausible reduction of negative environmental impact of the adoption of this battery reconditioning activity on a larger scale, more so, with respect to electronic waste mitigation.

Declarations

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Competing Interests Statement

The authors declare that they have no competing interests related to this work.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

Availability of data and materials

Supplementary information is available from the authors upon reasonable request.

Institutional Review Board Statement

This study was approved by the Institutional Review Board of Don Honorio Ventura State University, Philippines.

Informed Consent

Not applicable for this study.

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