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Desulfation of Lead Acid Battery with Pulse Charging

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Abstract
Lead acid batteries are prone to capacity loss and premature failure due to sulfation, the accumulation of lead sulfate crystals on the battery plates during prolonged discharge or undercharging. This paper explores the use of pulse charging as an effective desulfation technique to restore battery capacity and extend service life. Pulse charging involves applying high-frequency electrical pulses to break down lead sulfate crystals and facilitate their dissolution back into the electrolyte. Experimental studies demonstrate that this method can significantly improve battery performance, with capacity recovery after treatment. The pulse charging circuit designs and frequency considerations are discussed, alongside practical applications and limitations of the technology. Pulse desulfation offers a cost-effective, environmentally friendly approach to prolonging lead acid battery life, making it highly valuable for automotive, renewable energy and industrial applications.
Keywords: *Lead acid battery, battery aging, sulfation, pulse charging*

1. Introduction
Lead acid batteries are widely used in various applications despite their relatively low energy density due to their cost-effectiveness. However, a common issue affecting their performance and lifespan is sulfation-a process that gradually diminishes battery capacity and efficiency. Pulse charging technology has emerged as an effective method to combat this problem, with research showing significant improvements in battery capacity restoration and extension of battery life cycles During normal battery operation, lead sulfate forms naturally during discharge but dissolves during recharging [1]. The problem occurs when the battery remains in a discharged state for extended periods, causing these lead sulfate crystals to grow larger and become more difficult to dissolve. This results in reduced battery capacity and performance over time. There are two distinct types of sulfation - reversible (soft) and permanent (hard). Reversible sulfation can be addressed through proper charging techniques, while permanent sulfation occurs when a battery has remained in a low state of charge for weeks or months, making restoration highly unlikely. The difference between these types can often be detected through the voltage discharge curve-a battery with reversible sulfation might maintain a stable voltage profile under discharge, while one with permanent sulfation will show rapid voltage drops under load. Sulfation is an inevitable part of lead acid battery chemistry, but its progression can be significantly accelerated by several factors like, leaving batteries in a discharged state for extended periods, inadequate charging practices, infrequent use of the battery, operating at high temperatures and chronic undercharging [2]. As sulfation progresses, it creates a physical barrier on the plates that impedes the

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electrochemical reactions necessary for energy storage and release, effectively reducing the battery's usable capacity [3]. Pulse charging represents a promising approach to reversing sulfation by applying short, high-current or high-voltage pulses to the battery rather than a continuous charging current [4]. This technique works on the principle that properly timed electrical pulses can break down the crystalline structure of lead sulfate deposits, allowing them to dissolve back into the electrolyte solution [5]. At a molecular level, pulse desulfation involves sending electrical pulses at specific frequencies, typically between 2 and 6 MHz, which corresponds to the resonant frequency of the battery. During this process, the sulfer ions collide with the plates, helping to dissolve the lead sulfate deposits [6]. The carefully regulated rise time, pulse width, and frequency of these pulses prevent new sulfation while breaking down existing crystals. The effectiveness of pulse charging for desulfation stems from the fact that the high-frequency pulses provide sufficient energy to break the molecular bonds between lead and sulfate molecules without requiring substantial overall energy input or risking damage to the battery. Following separation, the sulfate ions regain their electrical conductivity, allowing the battery to restore its capacity [8]. Pulse charging represents a promising approach to reversing sulfation by applying short, high-current or high-voltage pulses to the battery rather than a continuous charging current. This technique works on the principle that properly timed electrical pulses can break down the crystalline structure of lead sulfate deposits, allowing them to dissolve back into the electrolyte solution. At a molecular level, pulse desulfation involves sending electrical pulses at specific frequencies, typically between 2 and 6 MHz, which corresponds to the resonant frequency of the battery. During this process, the sulfur ions collide with the plates, helping to dissolve the lead sulfate deposits. The carefully regulated rise time, pulse width, and frequency of these pulses prevent new sulfation while breaking down existing crystals [9]. The effectiveness of pulse charging for desulfation stems from the fact that the high-frequency pulses provide sufficient energy to break the molecular bonds between lead and sulfate molecules without requiring substantial overall energy input or risking damage to the battery. Following separation, the sulfate ions regain their electrical conductivity, allowing the battery to restore its capacity. Research has shown that pulse frequency plays a critical role in the effectiveness of desulfation. Laboratory tests indicate that frequencies greater than 5 KHz are particularly suitable for desulfation processes. More advanced desulfators operate at even higher frequencies, with some designs using the 2-6 MHz range to match the battery's resonant frequency for optimal results [10]. In experimental field tests conducted with a 5 KHz frequency over 72 hours, fourteen out of sixteen batteries showed positive changes in desulfation levels, with performance improvements reaching up to 93% of a new battery's capacity[11]. These results support the efficacy of pulse charging at appropriate frequencies for battery restoration [12]. The photographs of typical sulphated battery terminals and battery cells are shown in figure 1 and figure 2 respectively.

Figure 1 Sulfated Battery Terminals [1]

Figure 2 Sulphated Battery Cells [1]

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2. Proposed System

Desulfation of lead-acid batteries is a process aimed at reversing sulfation. The desulfation typically involves applying controlled high-frequency electrical pulses or specialized charging techniques to break down the stubborn sulfate deposits. These pulses create micro-oscillations that dissolve the crystals, restoring the active material on the plates and improving the battery's performance and lifespan. A desulfation chargers aid in reviving aging batteries and enhancing sustainability by delaying replacement. (Figure 3)

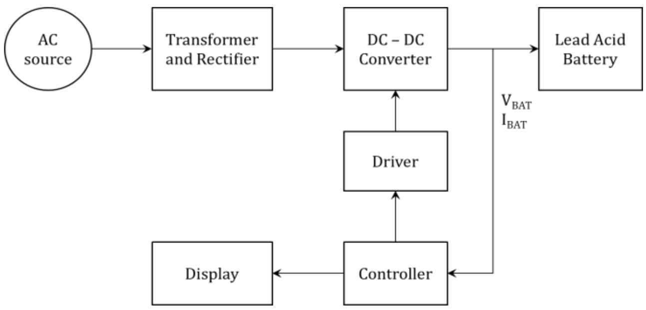

Figure 3 Block Diagram of Pulse Charger [2]

The functional block diagram of a pulse charger is seen in figure 2.1. A pulse charger for lead-acid batteries, operates through a systematic process to ensure efficient charging and desulfation. The system begins with an AC power source, which supplies the initial energy. This alternating current is first stepped down to a safer voltage level using a transformer and then converted into DC via a rectifier. The unregulated DC output is further refined by a DC-DC buck converter, which adjusts the voltage and current to precise levels suitable for pulse charging. The controller, acting as the central intelligence, generates high-frequency electrical pulses instead of a continuous DC supply. These pulses are critical for breaking down sulfate crystals on the battery plates, a process that reverses sulfation and restores battery capacity. The driver circuit provides isolation between low voltage controller and high voltage power circuit. The buck converter hence injects the high-current pulses into the battery, ensuring sufficient energy is delivered to dissolve hardened deposits. Throughout the charging cycle, the controller continuously monitors the battery voltage and battery current to prevent overcharging and dynamically adjusts pulse width or frequency based on real-time conditions. A display unit provides visual feedback, such as charge status or voltage levels, often represented by a bar indicator. By integrating pulse-based charging, this system not only charges the lead-acid battery efficiently but also extends its lifespan through desulfation, making it a sustainable solution for maintaining aging batteries. The design flow for pulse charger is illustrated with flow chart in figure 4

Table 1 System Summary

Particulars	Component/specification
Source	230V, 250Hz
Transformer	230/24V, 50HZ, 5A
Rectifier diodes	6A4
Rectifier filter capacitor	1000 µF, 100V
Buck converter MOSFET	IRF 150
MOISFET Driver	PC817
Filter capacitor	470 µF, 100V
Controller	Arduino Uno
Voltage sensor	Voltage divider arrangement – 10K, 1K
Current sensor	ACS712, 20A
Display	16X2 LCD

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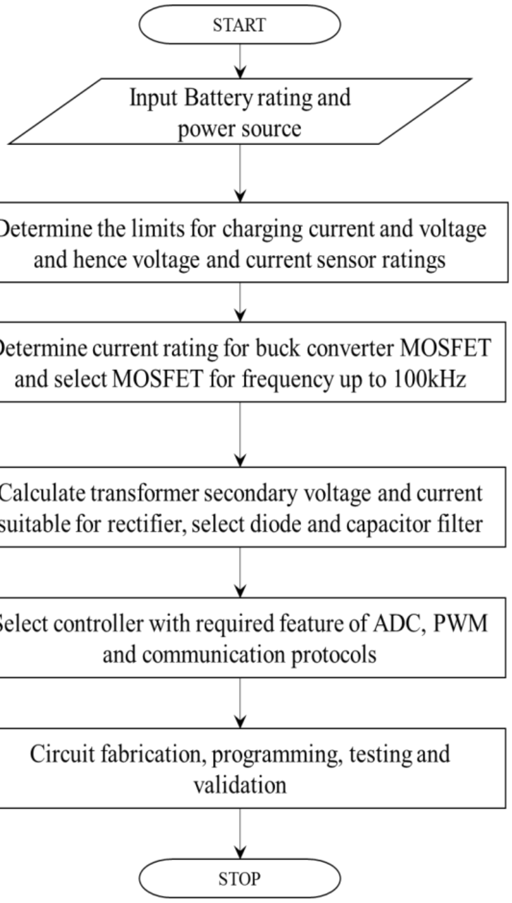

Figure 4 Pulse Charger Design Flow [2]

A pulse charger is designed for desulfation and charging of lead acid battery of 12V, 10Ah capacity. The specifications of the selected components are mentioned in table 2.1 and the photograph of developed system is shown in figure 4.

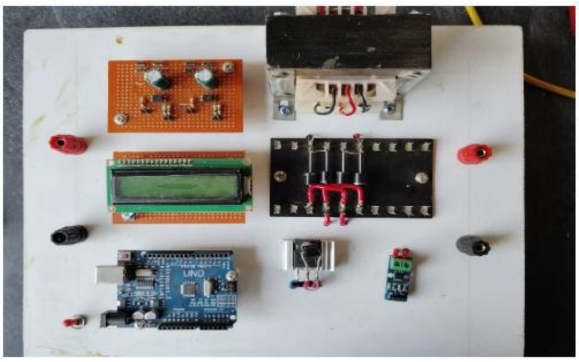

Figure 4 Photograph of Developed Pulse Charger

3. Results and Discussion

The lead acid battery charging system is developed to work in two modes. In first mode, the system delivers a constant voltage of 15V for charging of lead acid battery in constant voltage mode. In this mode of operation, the battery draws high current in initial phase of charging and as the battery charge level increases, the value of charging current goes on decreasing. The readings of charge level and current are mentioned in table 2

Table 2 Observations of Constant Voltage Charging

State of charge	Charging current	Battery Voltage
10%	2.2 A	11.9 V
30%	1.8 A	12.2 V
50%	1.6 A	12.8 V
70%	1.2 A	13.3 V
90%	0.7 A	14.1 V

In pulse charging mode of operation, instead of providing a regulated DC voltage for battery charging, a short burst pulses ranging from 5 Hz to 64 kHz are given to the battery for initiating the desulfation. These pulses cause vibrations in the battery and break sulphate crystals in the active material. The waveforms of pulse charging are shown in figure 6.

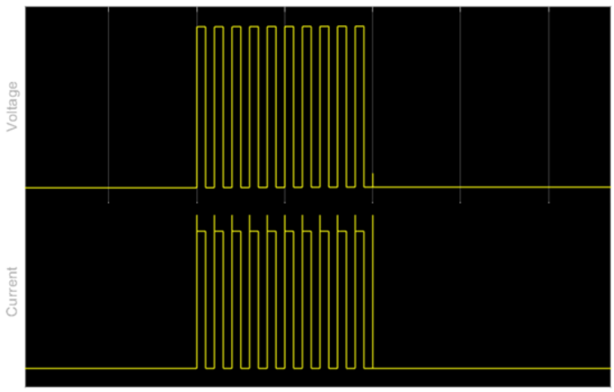

Figure 6 Pulse Charging Voltage and Current Waveform [3]

In comparison with the constant voltage charging, pulse charging operates between pulse charging burst and rest period. During rest period, no voltage is applied to the battery, which reduces heat generation as well as battery internal resistance, thus allowing the efficient charging of the battery.

Conclusion

Pulse charging for desulfation represents an effective approach to extending the useful life of lead acid batteries by addressing one of their primary failure modes. The application of high-frequency electrical pulses can break down lead sulfate crystals that form during normal battery operation, restoring capacity and improving performance characteristics. As battery technologies continue to evolve, pulse desulfation techniques remain relevant for maximizing the value and lifespan of lead acid batteries, which continue to be widely used due to their cost-effectiveness. Future research directions might include optimizing pulse parameters for specific battery types, developing more efficient circuit designs, and investigating the economic viability of commercial desulfation services or devices.

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