Lead-acid battery desulfation using a high-frequency pulse desulfator in standalone PV systems

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Article Info

Article history:

Received Aug 4, 2023
Revised Jun 23, 2024
Accepted Jul 19, 2024

Keywords:

Desulfator
Lead acid battery
Pulse charging
PV panel
Sulfation

ABSTRACT

The work presented in this article contributes to the study of a standalone photovoltaic (PV) system with battery storage by creating an electronic board that allows for the recovery of the battery's capacity using pulse technology that uses high-energy pulses from the PV panel to break down and remove the sulfation buildup, which is a contributing factor in the failure of most lead-acid batteries. Different methods or treatments can be used to lessen the impact of sulfation or even get rid of it and achieve battery rejuvenation. Battery sulfation is a process in which sulfate crystals form on the plates of a lead-acid battery, impeding its ability to retain a charge, and decreasing the battery's overall effectiveness. This process can happen due to various reasons, such as charging for a shorter time than required, charging for a longer period of time than required, or even not charging it for quite some time. Sulfation affects a battery's lifespan and comes with adverse effects on its performance, though it can be prevented.

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1. INTRODUCTION

Many different types of lead-acid batteries are manufactured for different uses. The current photovoltaic market is not large enough to justify the manufacture of a lead-acid battery design radically different from the standard products that are manufactured in larger quantities for other uses, although slightly modified solar battery types are available. We can essentially classify lead-acid batteries in two ways: open or sealed construction and mass-produced or industrial types.

The mechanism of lead-acid batteries relies on ions being stored during charging and transferred to plomb plaques during discharge. Sulfate within the electrolyte participates in the reaction with positive and negative plomb plates during energy transfer. Insufficient sulfate input leads to plaque sulfation overload. A physical indicator of the electrochemical reaction happening inside a battery, caused by the plumb-acide combination, is this buildup. This is a crucial element leading to battery breakdown [1].

The battery's charging performance is modified by chemical variations within the battery. Despite its typical occurrence, extreme sulfation can be hazardous [2]. Sulfation may arise when heaps are abandoned for too long, even in freshly built or aged piles. Almost 82% of lead-acid batteries' failures are associated with sulfate crystal growth. These factors influence the formation of crystals during the charging process.

A French company has received a patent for a regeneration method known as the Phoenix method. Batteries are subjected to a treatment that involves injecting varying and modulable frequency sequences into them for a set number of hours (depending on the state and power of the battery). The effect of this treatment is to completely dissolve the crystals and impurities that have accumulated on the batterie's internal plates. The batteries so treated regain storage and electrical conductivity functions identical to those of a new battery.

Lead-acid batteries can be recharged, and they are capable of enduring numerous cycles of charging and discharging [3]. However, it is impossible to restore the positive plate after 4 or 5 years of typical battery use. As a result, a few-month-old battery may be effectively recharged, and the rate of 80% operational restoration can be achieved. More time passes and less is achievable, natural degradation due to a rise in temperature of the battery is unavoidable [4].

This article has eight sections: i) section 2 explains sulfation accumulation leads to battery problems, ii) section 3 discusses pulse technology, iii) section 4 describes some desulfation strategies and presents the simulation circuit of the proposed strategy, iv) section 5 shows materials and methods, v) section 6 results and discussion; and vi) section 7 concludes.

2. SULFATION ACCUMULATION LEADS TO BATTERY PROBLEMS

According to the Battery Council International (BCI) manual, page 58: “because a battery is primarily a chemical "device," its charge properties are frequently altered by chemical changes within the battery itself. Sulfation, for example, while common, can become a major issue if allowed to become excessive. Because sulfation can occur when heaps are ignored for extended periods of time, it can occur in both new and used piles.”

Approximately 85% of lead-acid battery issues stem from sulfate crystal deposition. Time, battery capacity, and the usage pattern are elements that influence crystal buildup and formation speed [5]-[7]. Excessive sulfating can interfere with battery functionality. Although the sulfating process occurs sooner or later, it can also be accelerated by a variety of events, including, but without limiting itself:

- Terminals corrosion can impede the efficient functioning of a battery.
- Maintaining a discharge state.
- As temperature increases, sulfating rate accelerates with every 10 degrees Celsius increase.

The ideal amount of sulfation is necessary for smooth energy transfer, yet excess can cause complications [8], [9].

The accumulation of sulfates significantly contributes to other typical causes of battery breakdown [10], [11]. Many projects have been undertaken to address this degradation. It is about the growth of plomb sulfate cristaux in low-charge situations. While charging, large cristaux are less easily transformed. During a recharge, the little cristaux respond first. The accumulation of plomb sulfate in the form of large crystals reduces the amount of active matter available and hence the available capacity. Figure 1 depicts a scanning electron microscope (SEM) image of a sulfated electrode with larges crystals [12].

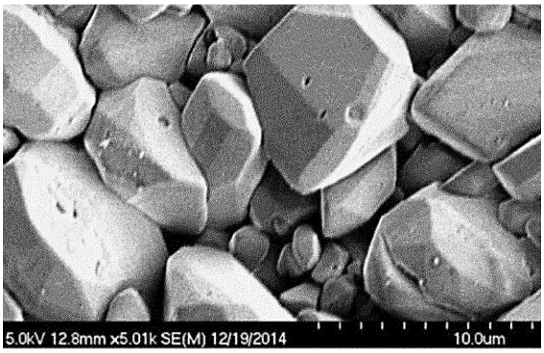


Figure 1. Micrograph of a sulfated electrode

3. THE PULSE TECHNOLOGY

The principle behind using high-current pulses to restore battery capacity involves applying short bursts of high-current electrical pulses to the battery. Crystal formation on battery plates can be reversed by the technology, allowing sulfates to resume conducting electricity [13]-[16]. There is a way to reverse the sulfation process in a battery. This involves sending electrical pulses at the battery's resonant frequency, between 2 and 6 MHz. During this process, the sulfur ions collide with the plates, dissolving the lead sulfate [17]. Introducing a pulse that tightly regulates rise time, pulse width, and resonant frequency prevents sulfation formation. Managing the form and magnitude of the impulse is crucial for success. Following separation, the sulfate ions regain their ability to conduct electricity. Since individual molecules possess sufficient energy to dissolve and melt sulfur crystals, minimal energy input is required for the whole process. The low-power pulse does not threaten the battery's wellbeing. Lead-acid batteries of varying capacities can utilize pulse technology, as shown in Figure 2, there is a big difference between battery plate testing with and without desulfators.

Included among these batteries are models with valve regulation, along with maintenance-free, hybrid, antimony plate, and calcium plate options. Educational talks on conservation were given by park employees. Thanks to pulse technology, PV systems, autos, and tools can now enjoy benefits that were once impossible.

Pulse engineering's most notable perk is its capacity to largely enhance battery capability by avoiding plate sulfation. Unobstructed energy transfer occurs when using clean plates, allowing for total battery capacity usage. This has lots of advantages:

- An increase in battery efficiency: Boosting battery performance by 100% requires keeping the electrolyte sulfates active and the battery plates free of sulfate accumulation. The pulse technology keeps plates' sulfates from reforming. Provided the technology remains active, the batteries will maintain peak performance.
- Increasing the battery's life: Pulse technology enhances the useful lifespan of batteries considerably. At the BCI yearly meeting, Patrick T. expounded upon the three fundamental factors influencing battery durability. 14 April 1997, Moseley. “We believe that optimum battery life is primarily dependent on three factors related to: According to the researchers, ensuring suitable charging practices, adequate compression of the active material, and perhaps maintaining the ideal shape of the material concludes their findings.” Reducing sulfation buildup leads to enhanced battery performance over its entire operational period. [18], [19].

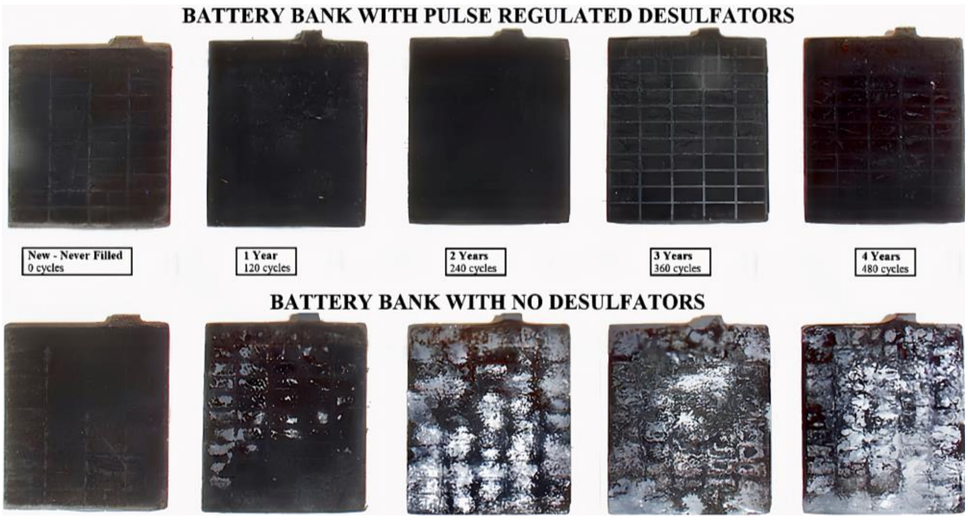


Figure 2. 4 years comparative battery plate testing [20]

4. DESULFATION STRATEGIES

The suggested desulfation circuit represents a substantial development in battery management technology, enabling more precise control and maybe better results, even though existing desulfation procedures have been somewhat effective. This section discusses the traditional desulfation techniques compared to the proposed desulfation circuit.

4.1. Overview on desulfation techniques

Taking into consideration several existing techniques and methodologies such as those of Couper this fundamental circuit helps in desulfating the low to medium-sized battery types [21]. The incorporation of the circuit has reduced charges demand in many systems by a significant margin. The circuit schematic of desulfation by resonance frequency method is shown in Figure 3.

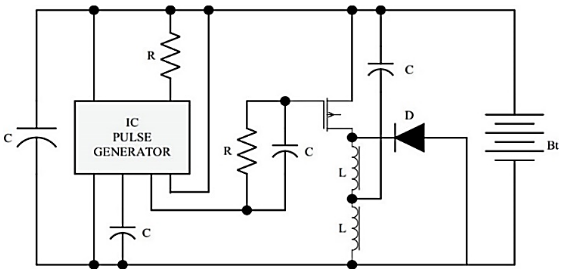


Figure 3. The circuit schematic of desulfation by resonance frequency method

Gelbman [22] shows how to charge the lead-acid battery using a device of charging and desulfation to provide it with a direct flow present of electric energy in mass charging mode. In this case, at the time when the battery attains fully charged voltage the mechanical formation assumes float charge mode. Whence the battery voltage reduces to become a float.

It remains maintained for a period below the fully charged voltage, otherwise known as over-voltage. When the mechanical assembly is in float charge mode, the battery charging current is switched extremely rapidly between "on" and "off" so that the battery voltage remains constant, and sulfation of the battery is prevented. When the battery voltage lowers to a certain level below the float voltage, the bulk charge mode returns.

Mahmood *et al.* [23] contributed in producing and testing a multi circle control framework for controlling a PV/battery hybrid system. This technique manages the imperatives of PV power converter, and bidirectional battery power converter. Three different working conditions have therefore been sorted out based on discharge curve of the battery into which charge flows and limitations, for managing the stream of power through the system during battery-charging current flows. Another solar or battery charge controller by Tesfahunegn *et al.* [24] shows one control function combining both MPPT and over-voltage controls. In another instance, a little flag model of lead-acid battery was used to describe the design of dual loop control.

4.2. The proposed strategy

The simulation is a very effective tool for figuring out how the device will operate after it is put into use. Before beginning a project, it is wise to model it and virtually test its operation. Figure 4 depicts the desulfation circuit, containing a PV panel and Arduino Nano.

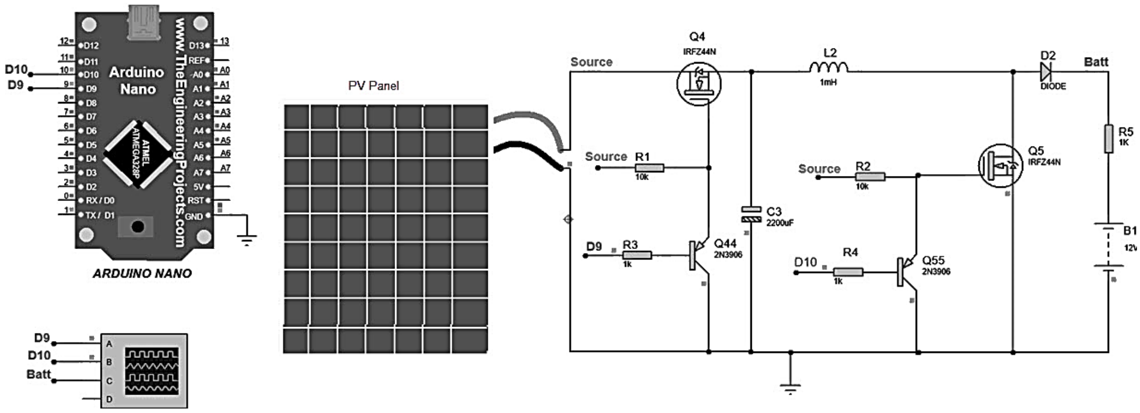


Figure 4. The desulfation circuit

Due to its charge, when MOSFET Q4 is closed, the voltage across capacitor C3 is the same as the supply voltage. In a sulfated battery, current flow is prevented by the battery's extremely high series resistance. Consequently, the L2 coil's energy reserves will be insufficient. By blocking the MOSFET Q5, the source through coil L2 is quickly short-circuited, causing it to store the most amount of energy possible due to extremely high currents. In this instance, the coil L2 acts as a current source. Next, we disable the two MOSFETs Q4 and Q5.

The coil, which turns into a voltage source when the current flowing through it is interrupted, is what causes the overvoltage and subsequent current peak to be produced through the battery. Because of the series of peaks occurring at a specific frequency, the molecular bonds between lead and sulphate are broken. Figure 5 displays the simulation results.

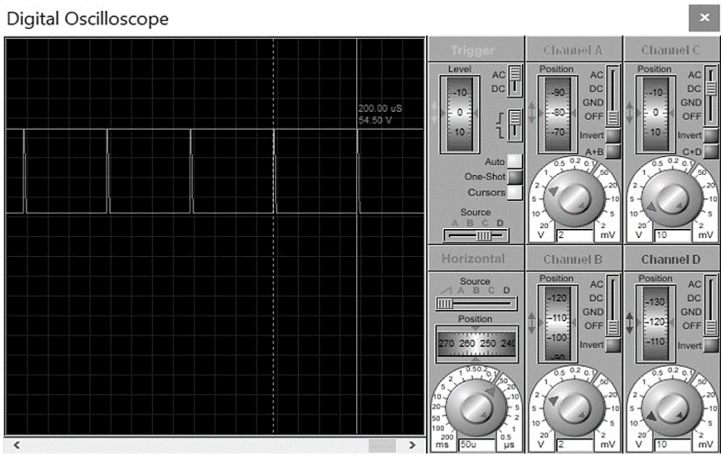


Figure 5. Pulses with high frequency that are simulated

5. MATERIALS AND METHODS

On a breadboard, we constructed the desulfation circuit from Figure 4. As a result, we connected the circuit to a fully sulfated 12 V-5 Ah gel battery, observed the output on an oscilloscope, we got the high frequency pulses, as shown in Figure 6, and confirmed that the circuit behaved as predicted. The oscilloscope was set to 500 us horizontal sweep and 5 v/div vertical, and then horizontal sweep of 100 ns is showed successively in close detail in Figures 7 and 8. Pulses that have a peak-to-peak voltage of 17 V are present, as we can see. It is typical for the molecular bond between the sulphate (SO4) and lead (Pb) molecules to disintegrate because of the secession of these current peaks at various frequencies. To ensure the proper operation of our circuit, an experiment was conducted using two 12 V/100 Ah plomb acide batteries that had been used in a photovoltaic system for over two years. We then charged the two batteries for an extended period to ensure full charge.

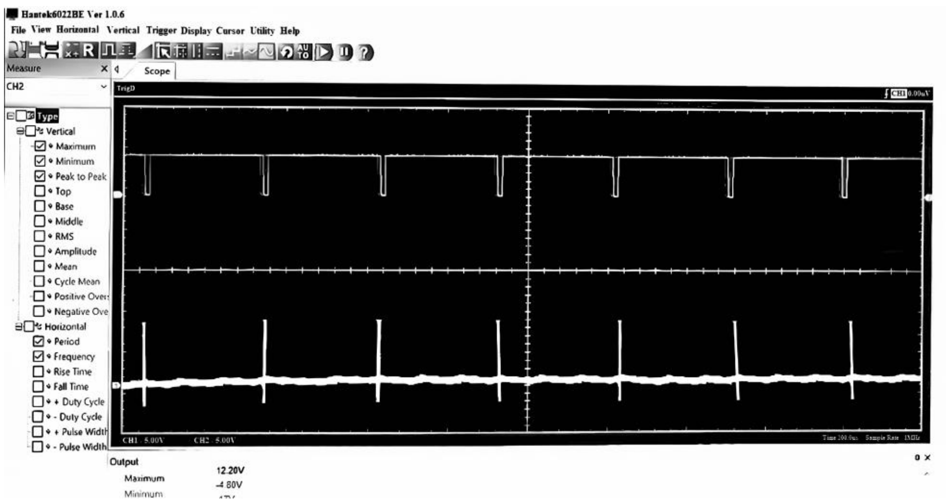


Figure 6. The desulfation circuit's output signal

Prior to the desulfation experiment, discharge tests were undertaken to ascertain the capacities of each battery. It was linked to a computer and a typical electronic load battery discharger-analyzer. The batteries were discharged at a constant current rate of C/10 with a discharge-end voltage of 1.96 V/cell. The discharger software recorded the discharge result components. The batteries were then linked to a pulse desulfator, which desulfated them. Finally, the three weeks running time was followed by a second discharge test on each battery in order to determine their capacities after those two weeks.

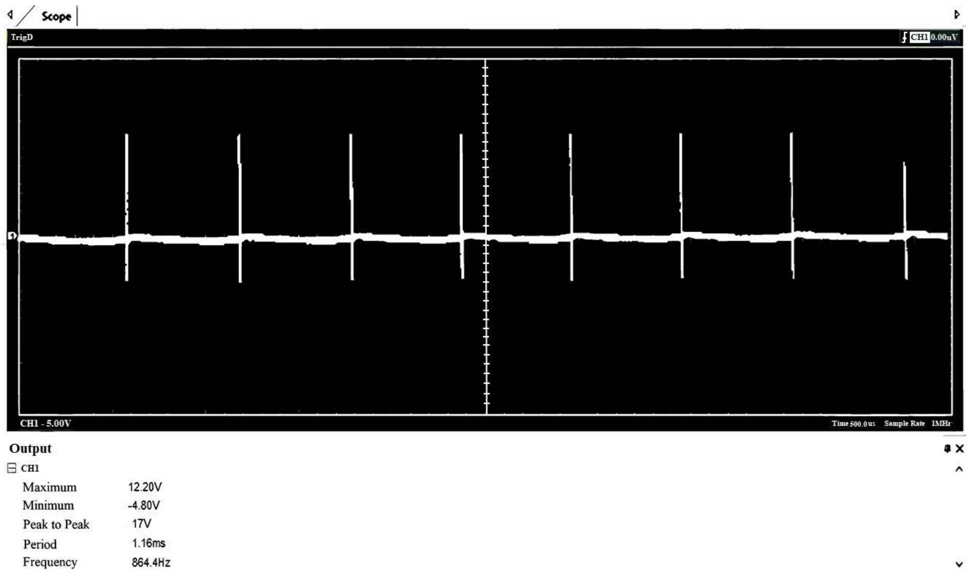


Figure 7. 5 Ah sulfated lead acid battery desulfation signal (500 us)

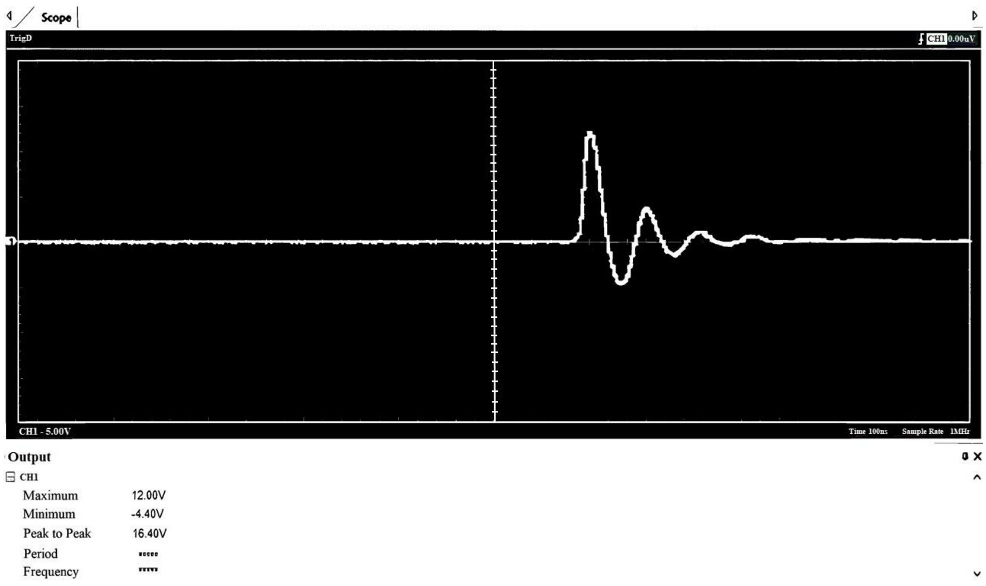


Figure 8. 5 Ah sulfated lead acid battery desulfation signal (100 ns)

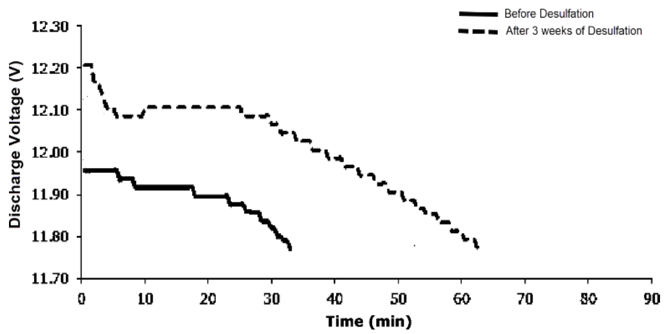
6. RESULTS AND DISCUSSION

For each of the two batteries, two discharge tests were undertaken and the battery discharge voltage was plotted against time. The first discharge test is made before the desulfation experiment and the second discharge after 3 weeks of desulfating the batteries. The plot appears in Figures 9(a) and 9(b) for both batteries. The graphs showed that the desulfation process led to certain changes in the batteries' capacity, since the discharge curve of one and the same battery for two tests was almost going to a separate way.

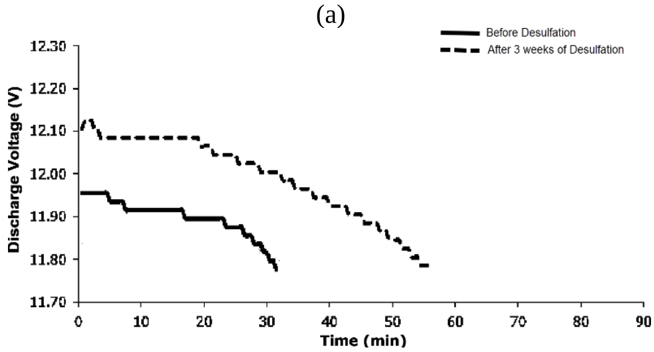
This research, therefore, supports the assertions of United States PatentS5677612 [25] which developed high-frequency pulse desulfators and projected to be effective in sulfated batteries which is common. Figure 10 shows the chart presenting delivered capacities before desulfation and three weeks after. According to this chart, the batteries exhibited improvements of varying levels with respect to their capacity after almost 21 days.

Bateries are attained a remarquable increase in capacity after desulfation. However, when the desulfator has entirely melted the deposited crystalline lead sulfurate, this could be because the battery has dried up its electrolytes due to overcharging the batteries that can dry out the electrolyte. This implies that desulfators which double as chargers and come with features to protect the battery from overcharge are best compared to those that are not chargers where they operate hand-in-hand with an external charger such was the case during this desulfation exercise as Gelbman argues. This might also be because of the 10 A discharge current or due to aging weakness leading to the batteries becoming unable to withstand the DOD.

Be aware that if you connect the desulfator to a different battery, the readings may be different. These pulses' characteristics are also influenced by the battery's characteristics and the supply voltage. The actual output pulses can be impacted by anything, even the length of the connecting wires.



(a)



(b)

Figure 9. Discharge voltage plot against time for (a) battery 1 and (b) battery 2

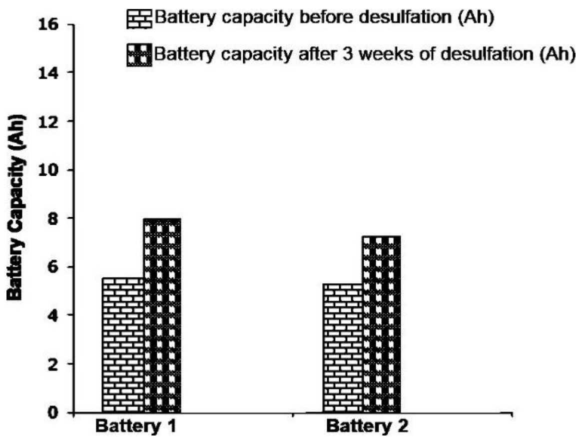


Figure 10. The capacity of the two batteries before and after desulfation for three weeks

7. CONCLUSION

This study uses high-frequency pulse desulfator to demonstrate the possibility for repair industrial lead acid batteries. This investigation has successfully demonstrated the restoration capacity of two 12V/100 Ah plomb acide batteries that had been used in a photovoltaic system for over two years. A typical desulfator for batteries through the pulsation or oscillation of high-frequency pulses the sulfate crystals and then restores the battery's efficiency in holding a charge. Application of a desulfator on a regular basis makes the batteries perform well and even prolong their lifespan. Bear in mind that desulfators are an efficient solution in particular cases while those batteries which have been damaged too severely or have other problems can't be revived. Besides that, adequate maintenance and charging strategies also play a key role in extending the life span of lead acid batteries.

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