

Parameters observation of restoration capacity of industrial lead acid battery using high current pulses

N. S. M. Ibrahim¹, Asmarashid Ponniran², R. A. Rahman³, M. P. Martin⁴, A. Yassin⁵, A. Eahambram⁶, M. H. Aziz⁷

^{1,2,4} Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia

³ Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia

^{5,6,7} Renewcell (M) Sdn Bhd, Bandar Bukit Raja, Malaysia

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ABSTRACT

Batteries play an essential role on most of the electrical equipment and electrical engineering tools. However, one of the drawbacks of lead acid batteries is PbSO₄ accumulates on the battery plates, which significantly cause deterioration. Therefore, this study discusses the discharge capacity performance evaluation of the industrial lead acid battery. The selective method to improve the discharge capacity is using high current pulses method. This method is performed to restore the capacity of lead acid batteries that use a maximum direct current (DC) of up to 500 A produces instantaneous heat from 27°C to 48°C to dissolve the PbSO₄ on the plates. This study uses an 840 Ah, 36 V flooded lead acid batteries for a forklift for the evaluation test. Besides, this paper explores the behavior of critical formation parameters, such as the discharge capacity of the cells. From the experimental results, it can be concluded that the discharge capacity of the flooded lead acid battery can be increase by using high current pulses method. The comparative findings for the overall percentage of discharge capacity of the batteries improved from 68% to 99% after the restoration capacity.

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Corresponding Author:

Asmarashid Ponniran,
Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia,
86400 Parit Raja, Johor, Malaysia,
Email: asmar@uthm.edu.my

1. INTRODUCTION

In recent years have seen advances in the production and consumption of secondary batteries for various industrial applications. A secondary battery or storage battery is a cell or combination of cells in which the chemical reactions are reversible. The main function of the batteries or energy storage devices is as an alternative to the power source [1, 2]. Lead acid battery is the first secondary battery that has been invented by Gaston Planté in the year 1859 [3, 4]. A lead acid cell consists of two plates, which are a positive plate that made of lead antimony alloy grids coated with lead oxide (PbO₂) and a negative plate that made of spongy lead (Pb) [5]. Both plates are dipped in the electrolytes, a solution of sulfuric acid (H₂SO₄) and water (H₂O) [6]. The concentration of the electrolyte depends on the design of the battery. These reactions between positive, negative plates and electrolytes have convert the chemical energy into electrical energy [7]. In a unit cell of a lead acid battery, there is the movement of electrons in two physically separated chemical reactions that are oxidation away and reduction reactions [8]. During discharge, the chemical energy is converted into

electrical energy and will supply electricity to the load [9]. In charging process, the plates absorb electricity from the DC power supply to convert to chemical energy. Furthermore, the nominal cell voltage for one cell lead acid battery is 2.0 V and open-circuit voltages that are the voltages under a no-load condition are 2.1 V. The operating voltage between 1.8 V and 2.0 V and is commonly 1.75 V on moderate and low-drain discharges. On charge state, the voltage may vary from 2.3 V up to 2.8 V with a proper charging [10]. The lead acid battery consists of multiple unit cells in parallel or in series or both to achieve the desired power and voltage rating [11].

The main concern of the lead acid battery is lead sulfate (PbSO_4) that attach to the plates during the discharging process [12, 13]. The PbSO_4 consists of two different types, soft and hard. Soft or amorphous PbSO_4 is an active material, the size is smaller and conductive whereas hard PbSO_4 is inactive material and the size is bigger. Theoretically, the PbSO_4 absorbs the charging power when the battery is charged and transforms it into a liquid compound, H_2SO_4 [14]. In practice, however, hard PbSO_4 does not dilute back into the electrolyte solution for H_2SO_4 but remain attached to the plates. Naturally, the deposition of hard PbSO_4 on the surface of the plates during discharging activities would affect battery performance.

As the discharged process continues, the internal resistance of cell increases and the conductive surface area of the plates becomes smaller due to the formation of PbSO_4 . As a result, the hard PbSO_4 on the battery positive and negative plates contributes to the capacity loss. It causes the battery has less ability to deliver the discharge current to the load [15, 16]. In addition, the low capacity lead acid batteries will be going through the recycling process. Lead acid batteries generally consist of four parts which are electrolyte, alloy and lead alloy, lead paste and organic and plastic materials containing many toxic, dangerous, flammable and produce explosive substances that create potential sources of risk. Therefore, the process of recycling the lead acid batteries will produce high carbon dioxide (CO_2) that will contribute to the global warming. Thus, to prolong the lifespan of the lead acid battery is an important issue for minimizing recycling lead acid batteries.

Over the years, numerous studies have been conducted to improve the performance of lead acid batteries, intending to increase the number of life cycles and lessen the sulfation physical processes [17]. The conventional solution is to add additives such as carbon powder, carbon nanotubes, titanium dioxide, glass fibres, silicon dioxide, aluminium oxide and boric acid [18-20]. However, the drawback of these methods is labor-intensive, which needing a large number of workforces to handle the process. Other than that, the application of low current and high current pulses method to restore the capacity of the lead acid batteries is also possible [21, 22]. However, both methods have their merit and demerit. Therefore, this study to observe performance characteristic between without and with the application of high current pulses to reduce the soft and hard PbSO_4 on the plates. The high current pulses produce instantaneous heat to force the electrons to move from one plate to another and cause the chemical reaction to occur.

This study presents the discharge capacity performance evaluation of the industrial lead acid battery using high current pulses to enhance the performance of batteries. Therefore, this paper begins by describing the configuration of lead acid batteries and the formation of the PbSO_4 during discharging. Then, the paper explained the concept and process of restoring capacity of lead acid batteries using high current pulses method. For the experimental results, the 36 V, 840 Ah flooded lead acid batteries to run the motor in the forklift were used. This paper then emphasizes on the experiment before and after application of high current pulses method for important parameters such as discharge capacity. From the comparison, it shows that the uses of high current pulses can increase the discharge capacity of the lead acid batteries.

2. REALIZATION OF HIGH CURRENT PULSES METHOD IN RESTORING CAPACITY OF LEAD ACID BATTERIES

The high current pulses method is implemented to restore the capacity of the lead acid battery in order to enhance the performance of the battery. This invented method used high current pulses that produces instantaneous heat to dissolve the PbSO_4 in the batteries [21]. The generated heat in the batteries causes the rise of cell temperature. The temperature is directly proportional to the kinetic energy of the particles (1). [The increasing of the kinetic energy of the PbSO_4 particles will force and cause the movement of the electrons. Thus, the reverse chemical reaction will occur in which the hard PbSO_4 that attached to the plates will be converted back to the electrolyte solution [12].

$$E_k = \frac{3}{2} RT \quad (1)$$

E: Average kinetic energy

R:8.314 J/ mol □ K
T:Temperature

2.1. Electrical principle to generate high current pulses

The high current which is injected in the batteries causes the cell temperature to increase [23]. The temperature is then controlled with a controller that requires battery and transformer feedback such as cell temperature, cell voltage, battery voltage and the transformer temperature. Figure 1 shows a controlled 3-phase rectifier converter using thyristor to produce DC voltage for the restoration capacity process of the batteries. The controller processes the output from the battery and transformer and transformer firing angle to the thyristor. An appropriate switching scheme (firing angle) is implemented to control the thyristor [24]. Thus, the restoration capacity of lead acid batteries using high current pulses will increase the speed of charging and avoid the increasing of temperature constantly [25, 26]. The high current pulses method will extend the life cycle of the batteries compared to the conventional technique that uses constant current [27-29].

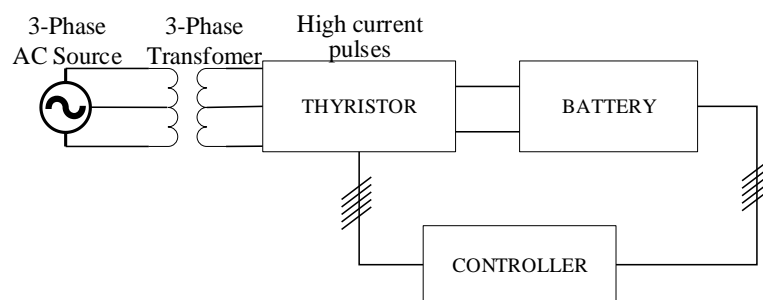


Figure 1. Controlled 3-phase rectifier converter for high current pulses generator (battery desulfator)

3. EXPERIMENTAL SET UP

In this experiment, the flooded lead acid battery used is to run the engine on the forklift and have been kept in uncharged condition for more than 7 months. During the load test, the battery only lasts for 3 hours 27 minutes after charging for 12 hours. The specifications of the flooded lead acid batteries as tabulated in Table 1. In the restoration capacity process, the reference cell is one of the batteries that have the lowest voltage value. The feedback from the reference cell is set as the parameters to determine the high current pulses to be injected into the batteries. Figure 2 shows the connection of the battery desulfator and the lead acid batteries. The positive and negative probes of the battery desulfator are connected to the positive and negative terminals of the series lead acid batteries. The cell voltage sensor and temperature sensor are connected to the battery reference and provide feedback for the processing of high current pulses. The general process of restoring the capacity of lead acid battery using high current pulses method is shown in Figure 3. Critical parameters such as discharge capacity are observed from the experiment.

Table 1. The specifications of the battery used for this experiment

Type	Flooded lead acid
Brand	12PZB900
Nominal capacity	840 Ah
Discharge rate	5 H @ 6 H
Nominal voltage	36 V
Cell voltage	2 V
	Maximum Voltage: 2.2 V
	Minimum Voltage: 1.8 V
Number of cells	18 units
Depth of Discharge (DOD)	80% - 60%

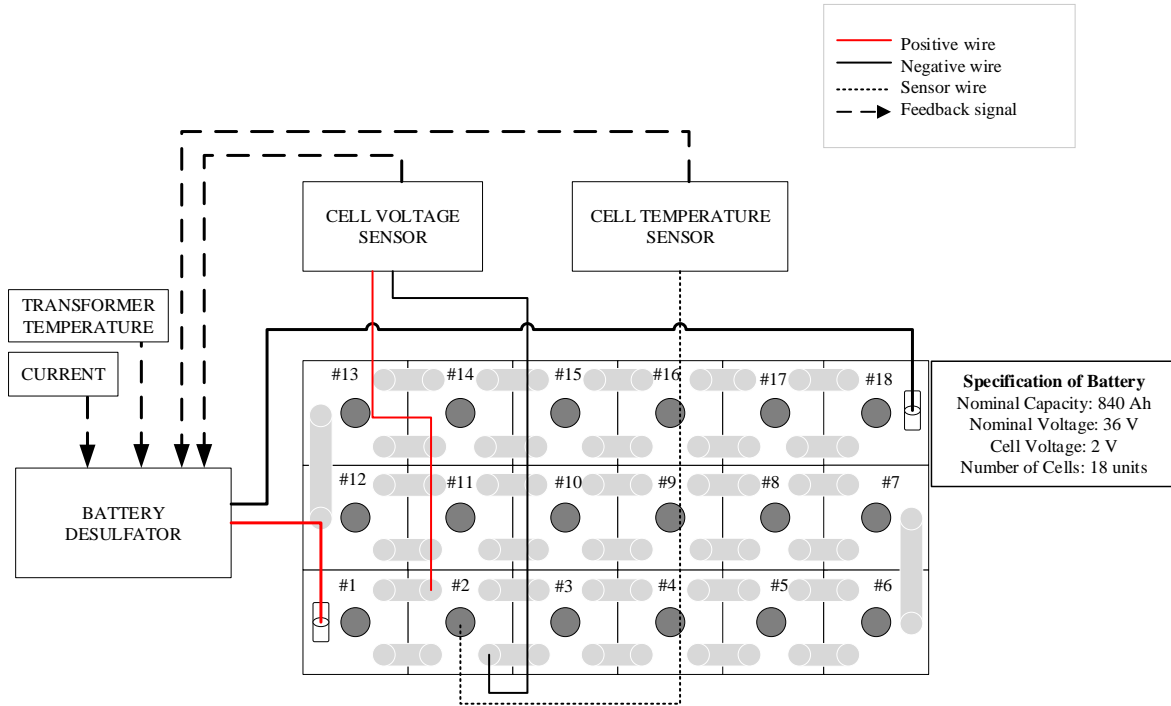


Figure 2. The connection of the battery desulfator, cell voltage sensor and temperature sensor to the lead acid battery.

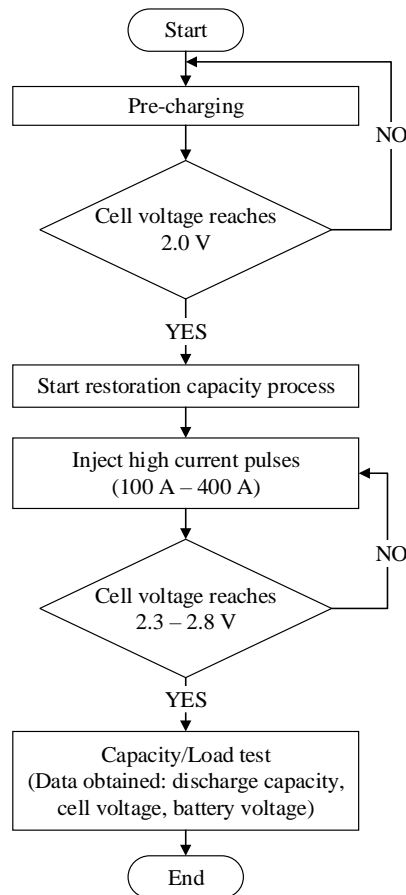


Figure 3. General process taken to restore the capacity of lead acid batteries

Figure 4 shows the battery desulfator that is constructed by connecting two parts. The first part is from the grid to filter and step down from 415 V to 105 V by transformer. For second part is the converters will produce high current pulses and its control by thyristor [30].

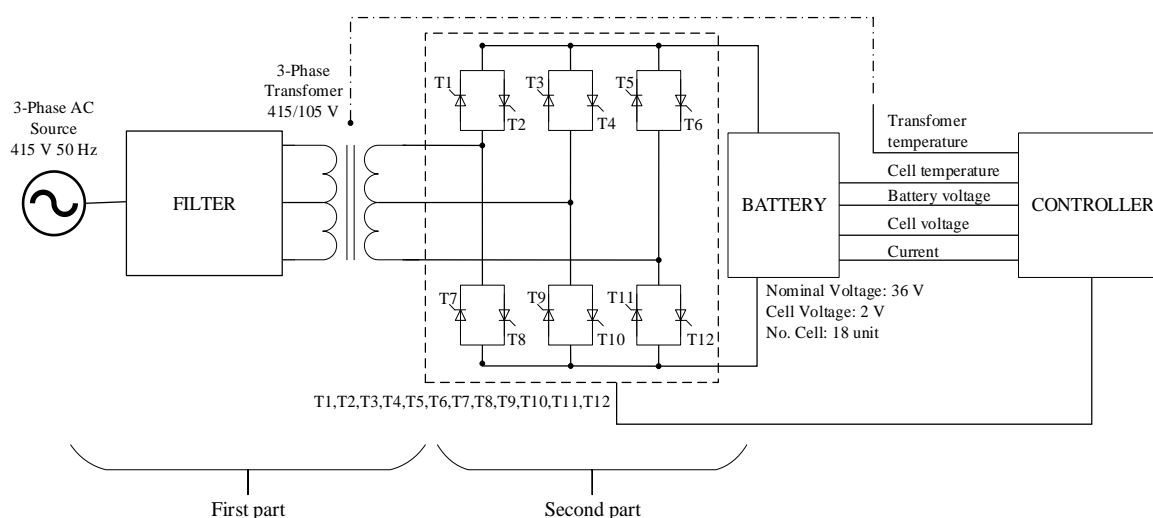


Figure 4. Battery desulfator for restoration capacity of lead acid batteries

4. RESULTS AND DISCUSSION

The hard PbSO_4 accumulated on the plates during discharge can be a significant problem in the lead acid batteries. This problem results in a degradation of the capacity of the lead acid batteries and leads to reduction in the life cycle of the batteries. The capacity of the lead acid batteries can be increased by using the high current pulses. The instantaneous heat produced during the restoration process will allow the reversible chemical reaction occurred to break the hard PbSO_4 into the electrolyte. In this study, the experiment is conducted to compare the discharge capacity of the flooded lead acid batteries without and with the use of high current pulses.

In general, the capacity of a battery is the amount of available charge under specified conditions of discharge, expressed in ampere-hours (Ah). Referring to Figure 5, the discharge capacity measured during the capacity test shows the improvement of the discharge capacity of lead acid batteries. The plates that clear from PbSO_4 will provide a higher ability to draw large current, thus will increase the discharge capacity of the cells. The larger discharge capacity will be resulting in a long time of discharge of the batteries.

Cell number #2 shows the most significant difference, with 30% of discharge capacity between before and after the restoration capacity process occurred. Even though cell number #2 has the lowest value of discharge capacity with 60%, but after the restoration capacity, the discharge capacity can be enhanced until 90%. It is proven that the restoration capacity using high current pulses can break the PbSO_4 on both plates. Furthermore, cell number #18 shows no changes between before and after with 100% because cell number #18 has been replaced with a new cell before undergoing the restoring capacity process. The average discharge capacity for before and after the process of restoration capacity is 69.61% and 92.67%, respectively.

The implementation of high current pulses method can overcome the deterioration of batteries due to PbSO_4 . The total discharge capacity of the batteries after going through the restoration capacity process is 834 Ah while before is 573 Ah. The results from this experiment, the overall percentage of discharge capacity of the batteries improved from 68% to 99% after the restoration capacity process.

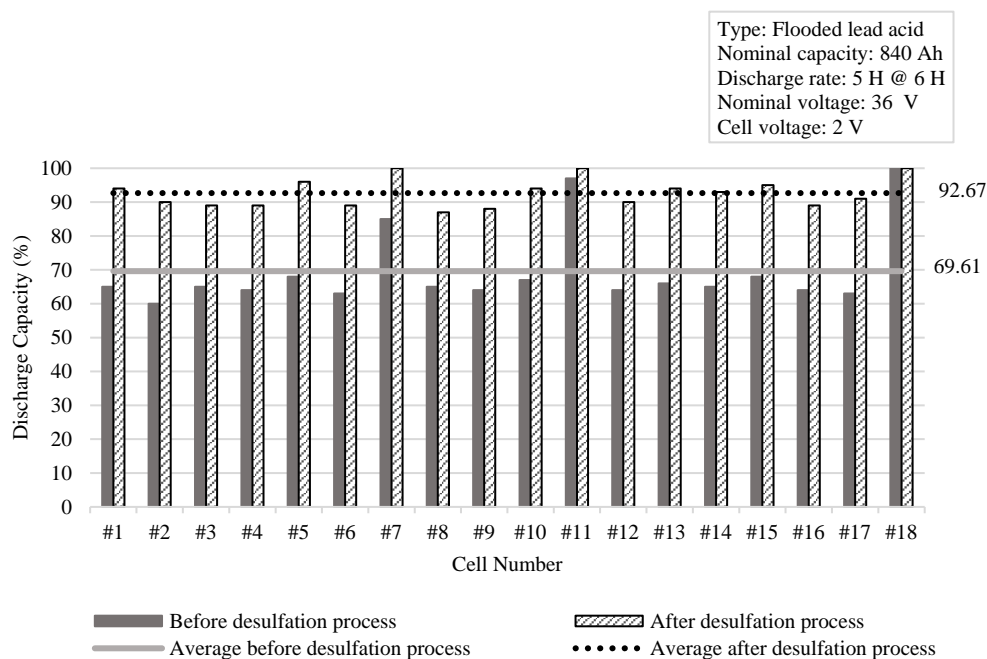


Figure 5. Graph comparison of the discharge capacity of lead acid batteries before and after restoration capacity process

5. CONCLUSION

This paper presents the restoration capacity of the industrial lead acid batteries using high current pulses. The restoration capacity of the 840 Ah, 36 V flooded lead acid batteries has been successful in this study. The degradation of the lead acid batteries due to the existence of the lead sulfate ($PbSO_4$) attach to the plates can be solved using high current pulses method. The high current pulses produce instantaneous heat to convert the $PbSO_4$ into the active electrolyte and cause the chemical reaction to occur. The development of the high current pulses method has given many benefits to the industries. One of the advantages is this method can improve the performance in terms of its discharge capacity. The discharge capacity of the lead acid batteries can be improved by up to 31%. From the findings discussed, the restoration capacity of lead acid batteries using high current pulses can prolong the time of discharge from 3 hours 27 minutes to 5 hours. It can also extend the life cycle and enhances the life span of the batteries.

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