Study on sources of charging lead acid batteries

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Abstract. The paper presents the general characteristics of lead acid batteries and two charging methods of these batteries. For charging of lead batteries was used an intelligent power source K 8012 (from Velleman). The power source allows fixing the level of the battery voltage and battery capacity. The intelligent power source uses the joint method (at constant current and, then, at constant voltage) and warning that indicates different situations in the charging process. Other method of charging presented in the paper is at constant voltage using a stabilized power source. In the paper experimental measurements were carried out using data acquisition card SER 10 BIT (from Conrad) for charging/ discharging of a lead acid battery 12V/9Ah (using an intelligent power source) and charging of another high capacity lead acid battery 12V/47Ah/390 A (using a stabilized power source). At the discharging of the lead acid batteries it were used automotive lamps as electric loads.

1. Introduction

Lead is usually associated with other minerals Zinc, Copper, Silver. Natural properties such as mass, malleability, low melting point, corrosion resistance, electrical properties and prolonged resistance, making it indispensable in world industry. It has the highest rate of recycling of all materials of the world [1], [2].

A battery stores electrical energy for later use. It produces power from a chemical reaction produced between two different materials (positive and negative plates) that are placed into the electrolyte. Electrodes are immersed in a water solution of sulphuric acid. Through the so-called formatting (the procedures can differ from production to another), which consists mainly of the battery power supply, the electrodes transform, positive plates get brown coloured and covered with PbO_2, and negative plates get grey coloured and covered with blackish lead [3], [4].

In a normal lead acid battery approximate voltage is 2 V/cell; so a total voltage on a battery is 12 V (usually, 6 cells). The battery is faster discharge is an electric load between the positive and negative terminals. The electrodes are made of lead, allied with 5 ... 10% antimony which limits them to the anodic polarization corrosion. Constructive, they are grating from grill that have a larger surface area. The terminal + is made of lead with a paste of lead dioxide; the electrode can be so symbolized as PbO_2/Pb. The separator is a grill of PVC, hard rubber or cellulosic material impregnated with meant to prevent internal short-circuit between electrodes. Sulphuric acid electrolyte is 30 ... 40% ($\rho = 1.21...$ the 1.28 g/cm^3), depending on the battery type. Usually, the casing is made of plastic and for large batteries rubber resistant.

The characteristics of the battery are: E_{cell} = 2.14 V; $U_{initially}$ = 2.1...1.9 V; U_{final} = 1.6...1.75 V; W_g = 30...40 Wh/kg, number of loading-unloading cycles: 1000...8000, the life time is between 5 to 7 years, h_E = 75...85%. Usually the batteries have 3 or 6 series cells, with nominal voltage of 6V or 12V, used for cars [5-7].

During unloading shall consume sulphuric acid and produces water electrolyte solution, so it dilutes, so the concentration (c_{H2SO4}) of the electrolyte (or its density) is a measure of the degree of charge of the battery. It is recommended to not work with batteries for which c_{H2SO4} < 18%. The reaction of the electrolysis of $PbSO_4$, held to 2.2 V will be held prior to the electrolysis of water. When the electrolysis of lead sulphate is finished, start the electrolysis of water and battery "boils" i.e. hydrogen and oxygen gas on the electrodes and barbotage through the electrolyte liquid. Increase the life time of a lead battery is done through the right choice of materials and by correct exploiting [4], [7].

Although it presents some inconveniences related to especially great mass and fluid-electrolyte, lead acid battery is widely used primarily due to large voltage debited, the reversible reactions and the low secondary reactions. Continuously improved, studied and used as a reference, the battery will lead in the 3rd millennium will be an important source of energy.

2. Charging lead acid accumulators

There are the following methods for loading accumulators lead: loading with constant current, constant voltage, and mixed. Charging with constant current is achieved while maintaining the current at a fixed value throughout the loading process. The method has the advantage that it requires less time, but conducts to intense gas release in the final phase, when it starts the electrolysis of water. Charging with constant voltage is achieved while maintaining the voltage at a fixed value 2.3 V/cell. In this case the current shocks may occur at the beginning of the process, but avoid electrolyte boiling because, in the final phase, the charging current is lower. Mixed load consists of the combination of the two methods in order to eliminate their disadvantages, begins charging with constant current, and when the emission of gas starts it continues with constant voltage.
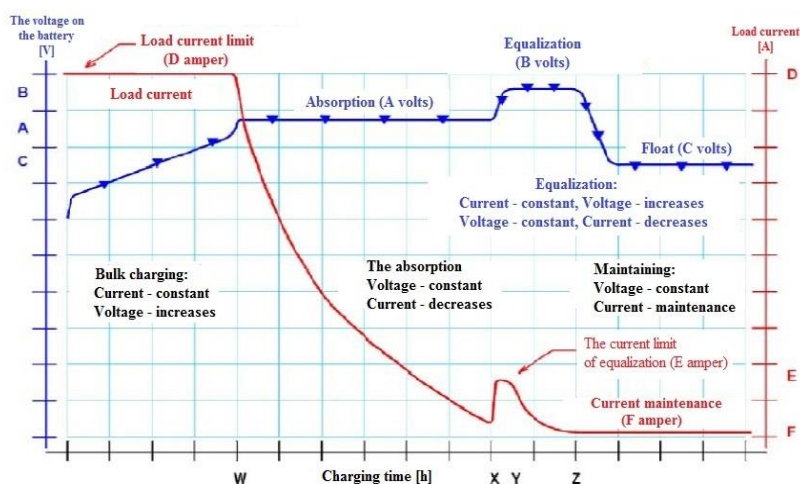

Figure 1. Loading characteristics of lead acid accumulators [8].

The charging lead acid batteries uses an algorithm based on voltage measurement algorithm, similar to the charging of lithium-ion batteries. Loading time is between 12-16 hours, or up to 36-48 hours in the case of very large capacity batteries. Using the large load currents, the load can be reduced up to 10 hours or less.

General, loading algorithm has four stages and is presented in Figure 1 [8]. Graph axis indicators represent general values for time and for charging current and voltage of the load. On the axis of the

voltage, A represents the voltage value maintained at a constant value during the absorption stage; C represents; B represents the value of the voltage maintained constant charger during the equalization stage; C represents the value of the constant voltage that keeps the charger during the maintenance stage (Float).

3. Intelligent charger for lead acid batteries

For charging of lead acid batteries with higher capacity can be used intelligence charging source K 8012 from Velleman (Figure 2). The intelligent charging source allows fixing the level of the battery voltage (6 V or 12 V) and battery capacity (less than 4 Ah or greater than 4 Ah). The source K 8012 has short-circuit protection, when connecting the battery terminals wrong and has four warning lights (LEDs): one that indicate the absence of battery, other that indicates the wrong connection of the battery to the source, a LED that indicates the battery charging process and one which indicates the full charge of the battery [9].

Figure 2. Intelligent charging source K 8012 – overview.

4. Experimental measurements with intelligent charging source K 8012 and lead acid battery 12 V, 9 Ah

For testing it used a data acquisition card (DAC) with 8 uni-polar analogue channels or 4 analogue differential channels with 12 bits (Conrad Electronic). The DAC connects to the RS 232 serial interface (with 9 poles) through the COM_1 or COM_2 from a personal computer (PC). It can purchase up to 8 analogue uni-polar signals in the wide 0 ... 5 V. For a resolution of 12 bits (4096 steps) correspond a voltage step by 1.22 mV (5/4095). To acquisition the signals it is used a Basic program created for this module. The DAC can be directly supply from the PC (switch S_2 Int) or external to a 9 V D.C. power source (switch S_2 Ext; power supply between the ground (GND) and U_B extern, 9 V D.C.) [10].

Communication with the PC is made through the serial interface and is a duplex communication (while the PC configuration issues for the following measurements, simultaneously receiving the result of the previous measurement). The transmission is performed on 16 bit, 12 bit of them are used for measuring, and 4 bits are used to address the selected channel and the type of measurement (uni-polar or differential).

The software used is Ser10Bit (in Basic). Without this software module can not be put into operation. Communication is performed on hexadecimal addresses that are enabled by the INP and OUT Basic commands.

The measurements were used in the experimental setup from figure 3. It uses two simple sources of voltage type MPS-6003S, one of the sources is used for intelligent charging source K 8012 and the

other power source is used to amplify voltage signals from the shunt resistance R_s (5 A/100 mV). The voltage on the R_s is applied an operational amplifier (from four available) type LM 324 configured in non-inverting summation. The resistors R_1 and R_2 were chosen so that 5 A current which would pass through the lead acid battery B results a 5 V voltage, after operational amplifier connected to channel CN_2 of DAC. The current measurement result (vertical) from graphs (Figures 4-7) is 1 A/div.
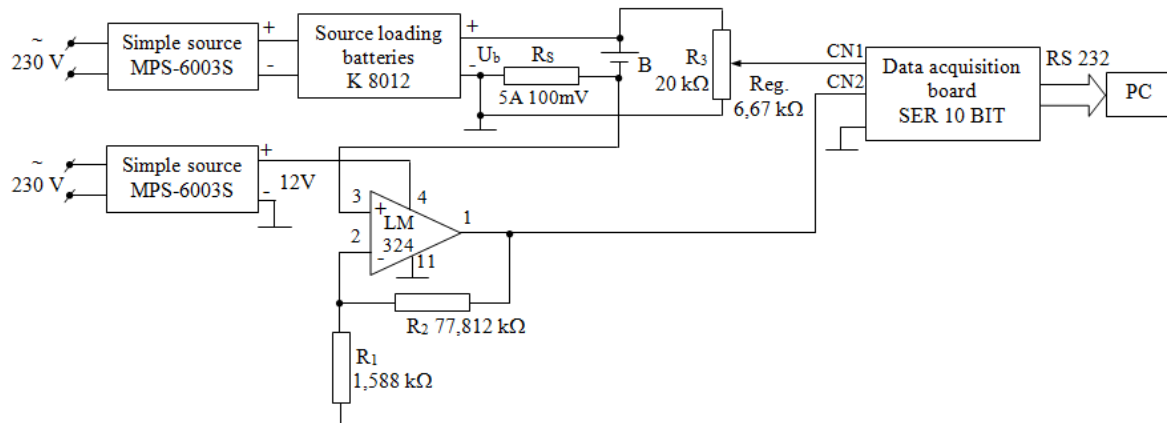

Figure 3. Experimental setup for charging lead acid battery with the source K 8012, 12 V, 9 Ah.

To measure the voltage on the battery has been used R_3 potentiometer, and the cursor was positioned at one-third of the value (from the GND). For the measurement from Figures 4-7 the voltage has 3 V/div. The cursor has been applied directly on channel 1 (CN_1) of the DAC. In this diagram setup of charging lead acid battery with intelligent source K 8012, - terminals are not common. The - terminal of the battery is not the same with - terminals of the power sources MPS-6003S. In fiure 3: CN_1 – voltage measurement channel (3V/div); CN_2 – current measurement channel (1A/div); B – lead acid battery 12 V, 9 Ah.
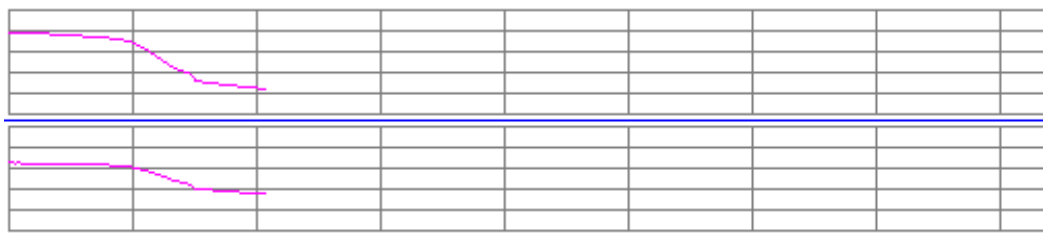

Figure 4. The voltage and current through the battery B 12 V, 9 Ah, at discharge, when it connected a 12 V/45 W lamp: up-voltage 3 V/div, down-current 1 A/div, time 30 min/div.
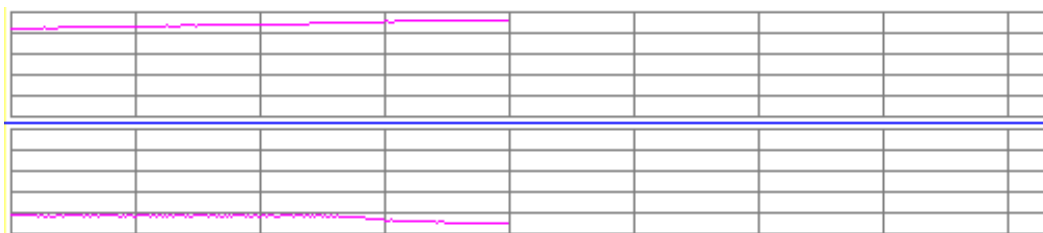

Figure 5. The voltage and current through the battery B 12 V, 9 Ah, charging through the intelligence charging source K 8012: up-voltage 3 V/div, down-current 1 A/div, time 1 hour/div.
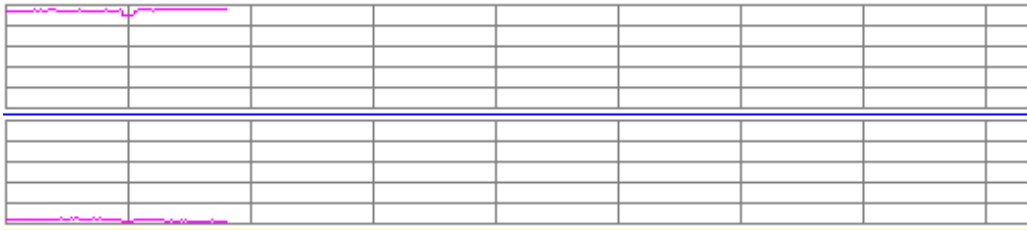
Figure 6. The voltage and current through the battery B 12 V, 9 Ah, at the beginning of charging through the intelligence charging source K 8012: up-voltage 3 V/div, down-current 1 A/div, time 1 hour/div.
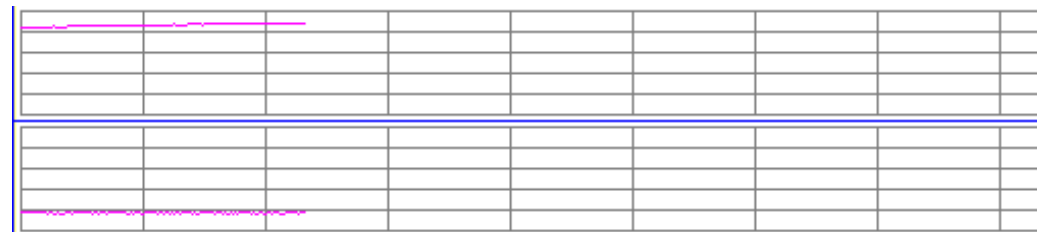

Figure 7. The voltage and current through the battery B 12 V, 9 Ah, for a short period of time, charging through the intelligence charging source K 8012: up-voltage 3 V/div, down-current 1 A/div, time 1 hour/div.

Figure 8. Overview from experimental setup with the lead acid battery (12 V, 9 Ah) charging from K 8012 source.

$$U_e = U_i \left(1 + \frac{R_2}{R_1} \right) \tag{1}$$

$$k_A = 1 + \frac{R_2}{R_1} \tag{2}$$

The intelligent power source K 8012 use the mixed charging: at current constant and voltage constant. At the charging of the battery 12 V, 9 Ah, the voltage increases slightly, and the current is maintained constant for a long period of time. Upon completion of charging the battery, the voltage

has maximum value and the current is limited at almost 0.1 A. At discharging the battery through a lamp, the voltage on the lamp decreases faster than the current. Voltage and current suddenly decrease, after a period of time.

5. Experimental measurements with power source and lead acid battery 12 V, 47 Ah, 390 A

The measurements were used with experimental setup from figure 9. The method used for charging is constant voltage. It uses a double voltage source AX 3003D-3 and a simple voltage source type MPS-6003S. Double voltage source is used for charging the battery B, and the other power source is used to amplify voltage signal from the shunt resistance R_s (100 mV/5 A). The voltage on the R_s is applied an operational amplifier (from four available) type LM 324 configured in non-inverting summation. The resistors R_1 and R_2 were chosen so that 5 A current which would pass through the lead acid battery B results a 5 V voltage, after operational amplifier connected to channel CN_2 of DAC. The current measurement result (vertical) from graphs (Figures 10-11) is 1 A/div. To measure the voltage on the battery has been used R_3 potentiometer, and the cursor was positioned at one-third of the value (from the GND); thus the measurement from figures 10-11, for voltage 3 V/div. The cursor has been applied directly on channel 1 (CN_1) of the DAC. In this diagram setup of charging lead acid battery with power sources AX 3003D-3 and MPS 6003S, - terminals are common. The - terminal of the battery is not the same with - terminals of the power sources (AX 3003D-3 and MPS 6003S).
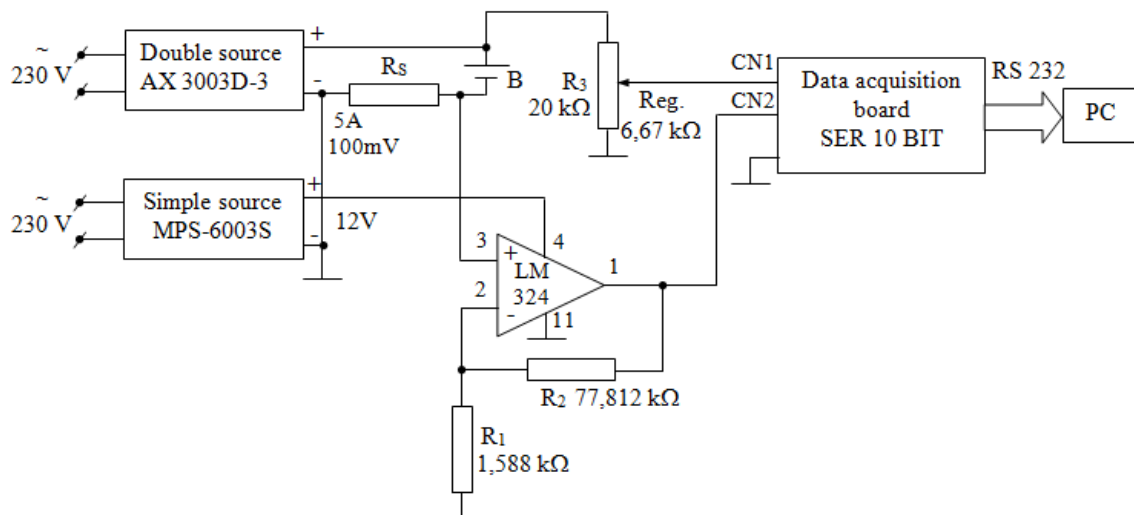

Figure 9. Experimental setup for charging lead acid battery B (12 V, 47 Ah, 390 A) with the power source AX 3003D-3.
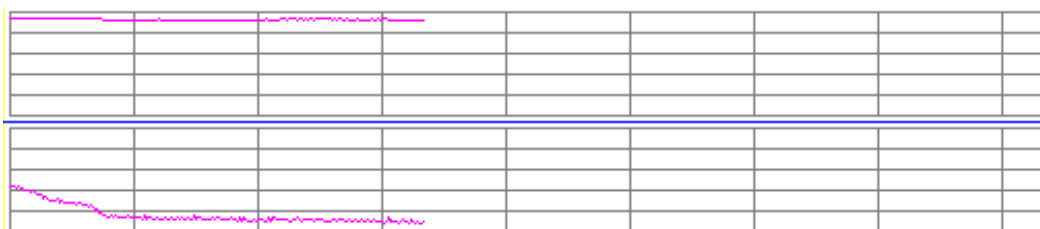

Figure 10. The voltage and current through a battery (12 V/47 Ah), discharging with constant voltage from a double source stabilized type AX 3003D-3, 13 V/6 A: up-voltage 3 V/div, down-current 1 A/div, time 1 hour/div.

Figure 11. The voltage and current through a battery (12 V/47 Ah), charging with constant voltage from a double source stabilized type AX 3003D-3, 13 V/6 A: up-voltage 3 V/div, down-current 1 A/div, time 1 hour/div**.**
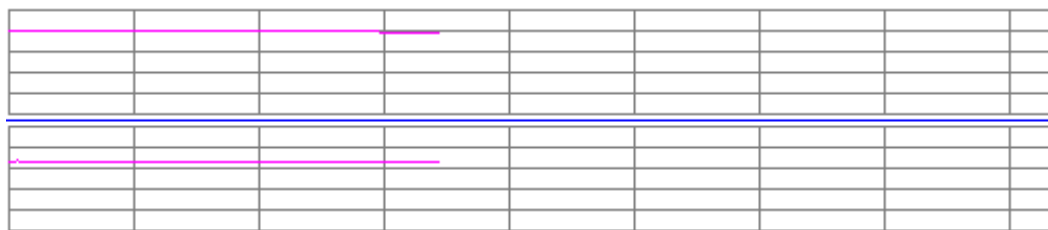

Figure 12. Overview from experimental setup with the lead acid battery (12 V, 47 Ah, 390 A) charging from power source AX 3003D-3**.**

At this experiment was used a large lead acid battery (12 V, 47 Ah) that was charging at the constant voltage. In Fig.10 when the battery is discharging through connecting two lamps of 12 V/45 W. It was found that after three and a half hours, a voltage drop occurs, due to the large capacity of the battery and the current has decreased due to the increase of the internal resistance of the battery (the battery is old). At the charging of the battery, the voltage grows more slowly, and the current is maintained constant for a long period of time.

6. Conclusions

The greatest enemies of lead acid batteries are over-charging and over-heating. For charging of lead acid batteries it can use three methods of charging: at constant current, constant voltage, or mixed (which is the best option). In this paper, were used two methods: mixed charging by using an intelligent charging source (source K 8012) and the constant voltage (stabilized power supply). Intelligence source K 8012 ensures joint charging: at constant current (a length of time), and then the constant voltage. Power supply K 8012 has protection for current limiting through battery. This allows for setting the level of the battery voltage and battery capacity. The source K 8012 has short-circuit protection, at the wrong connections of the battery terminals at the source, warning when the battery is missing and when is full charge. By using an intelligent charging source does not take place the

boiling, over-charging and over-heating of the lead acid battery, because the current limiting when it is considered that the battery has charged completely.

For lead acid batteries charging can be used a stabilized source with constant voltage. The battery must be supervised constantly, not to overcharge and boil. Some sources stabilized voltage sources have over-current protections and allow this, but it must be properly adjusted to limit the inrush current of the battery.

Although dedicated sources for charging lead acid batteries are more expensive, are recommended for charging them because in this way it ensures proper charging and a long life.

References

[1]   Buchmann I 2011 *Batteries in a Portable World - A Handbook on Rechargeable Batteries for Non-Engineers*, Third Edition, Cadex Electronics Inc., Richmond, Canada
[2]   Hariprakash B, Gaffoor S A and Shukla A K 2009 Lead-Acid Batteries for Partial-State-of-Charge Applications, *Journal of Power Sources* **191**(1) 149–153
[3]   Chen H Y, Li A J and Finlow D E 2009 The Lead and Lead-Acid Battery Industries During 2002 and 2007 in China, *Journal of Power Sources* **191**(1) 22–27
[4]   Wan X F, Wu J P and Hu H L 2009 *The Smart Battery Management System*, International Conference on Test and Measurement, ICTM '09, Hong Kong, China, December 5-6, pp 29-32
[5]   Linden D 2005 *Batteries and Fuel Cells, Standard Handbook of Electronic Engineering*, Fifth Edition, McGraw-Hill Book Co., New York, USA
[6]   Wong Y S, Hurley W G and Wolfle W H 2008 Charge Regimes for Valve-Regulated Lead-Acid Batteries: Performance Overview Inclusive of Temperature Compensation, *Journal of Power Sources* **183**(2) 783–791
[7]   *** 1989 *Battery Application Manual*, Gates Energy Products Inc., Gainesville, FL, USA
[8]   Cadar D V 2011 *Contributions to the battery management systems*, Technical University Cluj-Napoca, Romania, Doctoral Thesis
[9]   *** 2008 *K 8012 Lead Acid Battery Charger*, User's manual, Velleman, Belgium
[10]   *** 1996 *Ser 10 Bit Data Acquisition Card*, User's manual, Conrad, Germany