# Lead Acid Battery Pack Charging Optimization

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***Abstract* - Still used as a rechargeable power sources, rechargeable batteries pack require attention primarily to ensure higher life operating. One of the factors that influence lifespan is the process of charging and discharging. For batteries is manifested in the so-called memory effect which manifests itself by decreasing the operating voltage, even when was loaded to its maximum capacity. The article presents this issue but also offers a solution direct applicable for lead-acid batteries. The principle has based on reducing the number of charge and discharge processes in a certain time. So the hysteresis characteristic becomes wider and the time between switching from charge mode in the discharge and vice versa is higher. Analysis of three algorithms, step-by-step set of operations, and implementation in an experimental device is the main goals of paper. Optimization technique represents here to maximize battery lifetime. The device developed has a microcontroller and proves useful with minimal changes in any situation, by replacing the existing or interposing circuit between the power source and battery. Designed circuit can have easily adapted to correspond for other types of batteries. It can integrate with minimal changes, additional functions such as current battery measure and temperature.**

**Keywords:** *hysteresis, lifespan, battery pack, charges processes, capacity.*

## I. INTRODUCTION

To ensure a reasonable lifespan, must take in consideration a series of procedures. Therefore, after a discharge the battery must charge in the shortest time. Delay in charging can bring shortcomings of active substances of boards, especially the positive ones. Charging batteries has great importance to extend their service life. Charging has monitoring by measurement and accomplished by control.

There is a more pronounced orientation towards automating the management of charging operations, offering significant advantages: operational staff reduced with qualification, yields increased and use of equipment is more reasonable; control, depriving the possible subjective interventions of staff, is much safer. Automation has facilitated by continuously improving the control devices, in this case, the microcontroller [1], [2].

Stop charging time determined by the battery voltage to avoid overloading and damaging the battery. End of charging has shown by the voltage and density of the electrolyte. At the same time in both kinds of plates is seen an important development of gases.

Charges performed late or incomplete results, as we know, serious systematic and irreversible sulfating of battery [2].

## II. CHARGING METHODS

Operating conditions and situations involved in the exploitation of accumulator batteries require different charging method and the carrying out of operation.

There are two basic methods: constant current charging and constant voltage charging, and some combinations of these [2].

The benefit of constant current charge is to allow easy measurement of the number of amp-hour battery and received so could appreciate the function and calculate yield.

Constant current charging method has limited applicability to automotive batteries, in garages and repair shops and small batteries. The current set at values that do not cause significant releases of gas. Charging with constant current load in increments uses constant current advantages and eliminates the disadvantages of this method. It starts with high current load; at 2.3 ... 2.4V per element, current is reduced by half and continue until up the voltage again reached the appropriate value; finally current conducting a further reduction of one third of the current second stage and continue charging.

At small and medium size batteries, this method has only two steps. First step have maximum charge current and the second have a constant current regarding 5-10% of nominal battery capacity [2].

Constant current charging with breaks or pauses steps are similar charging methods. Current constant charging has interrupted and only resumed after a break of 1 to 2 hours, with the suitable constant current. The breaks allow a good diffusion, voltage is reduced and the temperature almost never stop charging course. This method applied to some treatment to remove the abnormal condition of the battery. Charging with constant current is mandatory at new stationary batteries or after major repairs.

Charging with constant voltage occurs when a maintain voltage charging power source at a constant value. Current value depends, obviously, by voltage and can be particularly high at the beginning of charging if the battery fully discharged. To avoid these current shocks by devices and circuits that would not tolerate the charging circuit is used a fixed value resistor, whose value is determined on a case by case. It also establishes constant voltage between 2.1 and 2.75 V per battery cell, in relation to the construction of the battery and the result to give the charge. The advantages of this method of charging are reduced gas evolution; the ultimate charge current is small; absence of current shocks; current real value determined by the condition of the battery, less high temperature.

A drawback is less judicious use of current power source due to the variable current and loss in additional resistance [2], [3], [4].

Charging with constant voltage in steps reduces charging time because the initial voltage established to a high value and high current start.

Combined constant current - constant voltage charging, start with constant current until voltage reach 2.4V per battery cell and keep it constant voltage value. This method applied in the case of partial or quickly charges, to vehicle batteries. Initial current value may be higher if the battery deeply discharged.

Combined charging constant current – constant voltage – constant current have constant current at start and the end, allows close observation of battery operation. Charging with dominant constant voltage intermediate does not require supervision [4], [5].

## III. Design Elements

The device shown has designed for lead-acid batteries. It represents an example of possible implementation of low cost and compact solution of charging control. Useful for battery with a maximum capacity depends exclusively on the power circuit design, this device can be functional adapted and extended.

It started from the idea that the life of a battery depends on the limited number of charge-discharge operation. To reduce them in a given time interval, a solution can increase the interval between the upper and lower limits of the battery voltage making large charge–discharge operation (Fig. 1) . In addition, strict adherence curve for charging and discharging, ensure a minimum number of charging-discharging.

This device not uses only one threshold voltage to change the output command, like simple comparator. The idea is to have a lower and upper voltage limits, like a window comparator. The existence of hysteresis ensures a firm action and avoids frequent charging and discharging.

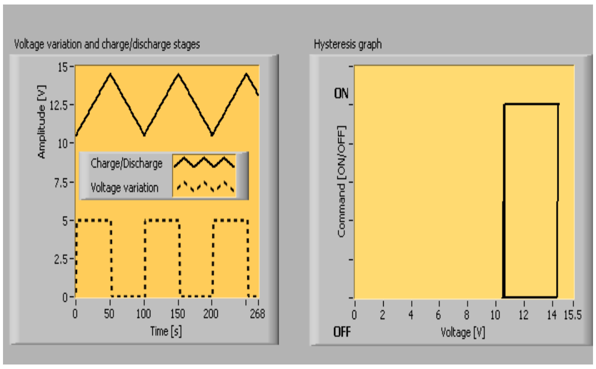


Fig. 1. Operating principle, the simulation.

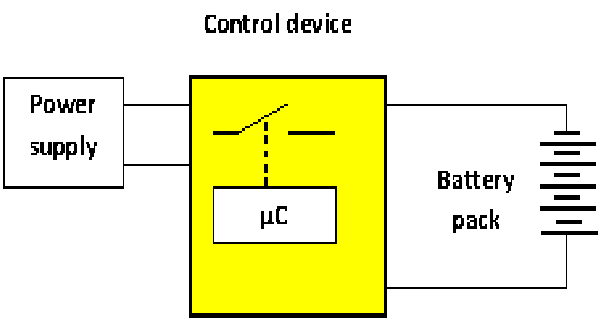


Fig. 2. Block diagram of the device.

The device presented can intercalate between power supply and battery (Fig. 2). It supposed that the load direct attached or by another circuit to the battery pack. Proposed device not affects the powering supply from battery [6].

The main components of the device are microcontroller (μC) from Microchip (18F452), power supply and power element. The microcontroller has implemented a program in which the key sequence is the hysteresis [7], [8], [9]. If it follows a small price, it may be used a power bipolar transistor for power element. Software has possibilities to change lower and upper limit of voltage. These limits defined for every battery pack depends about battery technology used. Another condition regarding voltage limits are about the load, as it supports voltage variation.

For hysteresis [10], there are three possible examples of routines. Representation as algorithm is clearer and reduced size the chart. "Output" is the command element for charging, with two states, “ON” and “OFF”.

```
; first example
output <– “OFF”
; first example
read U
if U < Umin then
            while U ≤ Umax
                        output <– “ON”
                        read U
      else
            output <– “OFF”
; second example
read U1
if U1 < Umin then
            output <– “ON”
      else
            if U1 > Umax then
                        output <– “OFF”
                  else
                  read U2
                  if U1 < U2 then
                        output <– “ON”
                        else
                        output <– “OFF”
; third example
read U
if U < Umin then
            output <– “ON”
      else
            if U > Umax then
                  output <– “OFF”
                  else
                  if output = “ON” then
                        output <– “ON”
                        else
                        output <– “OFF”
```

First two algorithms have some limitations. For example, first have a conditional loop, and microcontroller can go lock in the loop until limit exceed. This gives a varied activity and obstruct of functionality by locking.

The second algorithm uses two readings of voltage. In case of variable load, it is possible to deceive reading and the hysteresis is not complete. This problem has solved using supplementary code with an offset limit between voltage readings.

However, we searching a lower size microcontroller code, to have minimum size. This requisite can lead to low cost implementation with minimal memory microcontroller.

The best option can be the third form of algorithm. The actual implementation of the algorithm is a simplified but robust version of the third algorithm (Fig. 3). As shown, it is necessary to strictly tracking the minimum and maximum voltage thresholds (Umin and Umax). The output ("OUT") switch to "ON" or "OFF" states depending by battery voltage.

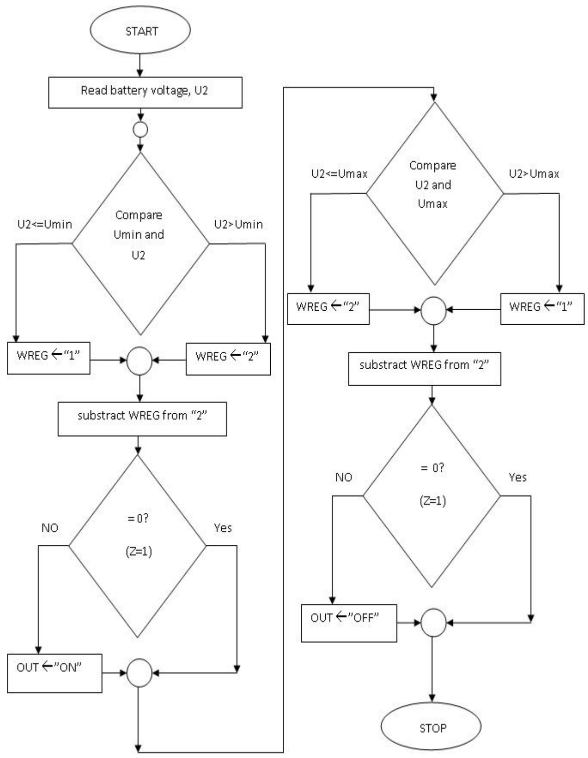


Fig. 3. Final implementation of algorithm.

Noting that if the initial battery voltage is between limits, charging and discharging process begins with discharge to the lower voltage limit. This is useful because is necessary to begin with a full charge from the initial point, the lower limit voltage. Anyway, here are many options to tackle the problem.

*; hysteresis sequence*

*call citeste_ADC; read analog input*

*movf NumL, U2;*

*call comparaUminU2; if Umin>=U2 then return "1" in WREG, else return "2"*

*decfsz W; decrement WREG, if 0, jump next instruction*

*goto mod1*

*bsf PORTC, 3; output "ON"*

*bsf PORTC, 1; signal "ON"*

*call temp2*

*mod1*

*call comparaU2Umax; if U2<Umax then return "2" in WREG, else return "1"*

*decfsz W; decrement WREG, if 0, jump next instruction*

*goto mod2*

*bcf PORTC, 3; output "OFF"*

*bcf PORTC, 1; signal "OFF"*

*call temp2*

*mod2*

*; end of hysteresis sequence*

This hysteresis sequence calls others routines. For example below is a listed compare routine from current voltage, U2, and lower limit, Umin. A routine to compare current value of battery voltage with upper voltage limits have similarities.

*comparaUminU2; if Umin>=U2 then return "1" in WREG, else return "2"*

*movf Umin,W*

*cpfsgt U2; compare U2 with WREG and jump if U2>Umin*

*goto U2maimic*

*retlw d'2'; go here when Umin < U2*

*U2maimic*

*retlw d'1'; go here when Umin >= U2*

*return*

*comparaU2Umax; if U2<Umax then return "2" in WREG, else return "1"*

*movf Umax,W*

*cpfslt U2; compare U2 with WREG and jump if U2<Umax*

*goto U2maimare*

*retlw d'2'; go here when U2 < Umax*

*U2maimare*

*retlw d'1'; go here when U2 >= Umax*

*return*

Designed schematics (Fig. 4) have only few components, because of microcontroller use. Schematics consist in a 5V stabilizer, microcontroller 18F452, a LCD device, power stage, control inputs (4 switches), signaling output (LED). Clock signal can cover any possible value and type, even RC oscillator, because the device cannot have critical timing.

In practice, design a MOSFET power stage (enhancement mode MOSFET) is a good option, because operating mode here is locked-saturated. Unlike bipolar transistor, MOSFET transistor has a higher efficiency at the same current, with lower heat losses (Fig. 5). Simulation results reveal huge difference between bipolar and MOSFET transistor technology efficiency (Fig. 6).

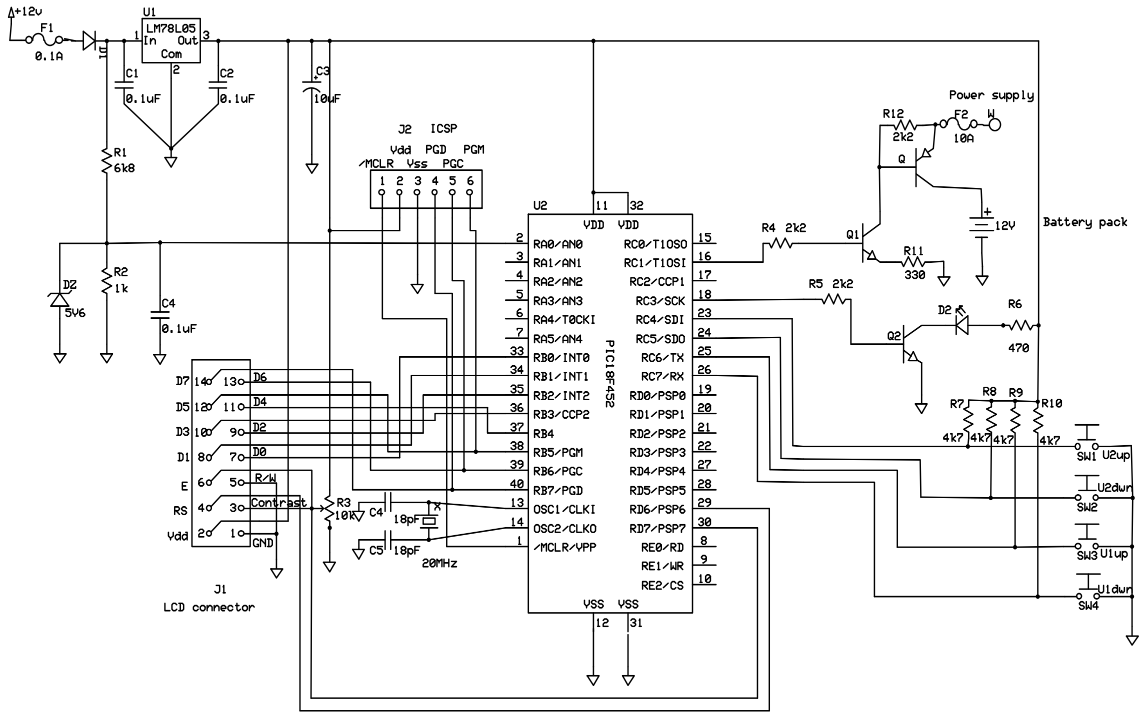


Fig. 4. Schematics of proposed device, PNP bipolar output.

Difference is significant (current capabilities at the same command), in the same conditions, 18 A at MOSFET transistor and 2 A at bipolar transistor (Fig. 6). Simulation conditions as well take into account real conditions such as non-zero-resistance power supply and battery pack. Here is not important response time of power transistor, because of toggle mode use. Has important power dissipation of power transistor.

Another possibility is the use of IGBT transistor. Insulated Gate Bipolar Transistor (IGBT) is a power electronic device with high input impedance and large bipolar current-carrying capability.

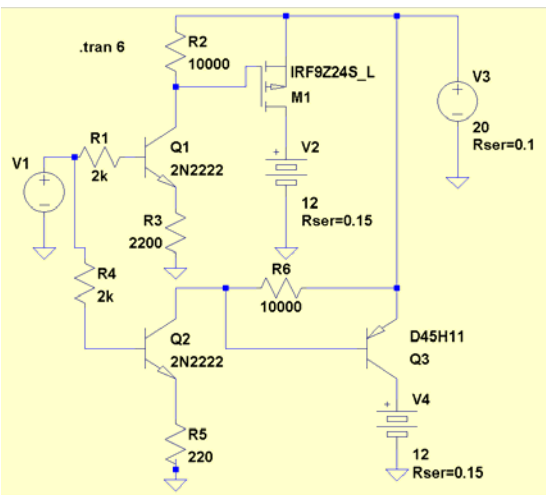


Fig. 5. Power stage simulation (MOSFET and bipolar).

View IGBT as a device with MOSFET input characteristics, bipolar output characteristic, and a voltage-controlled device. Thus, using the advantages of both Power MOSFET and bipolar transistor in a monolithic form, combines the best attributes of both to achieve optimal device characteristics.

The power component must have a heat sink, to increase lifespan of components. Device has a LCD display, not mandatory for functionality, but with very necessary to check the status of charging progression.

Battery packs voltage measurement use a voltage divider and represents a voltmeter with 25V range. This domain represents a compromise between resolution and covering range.

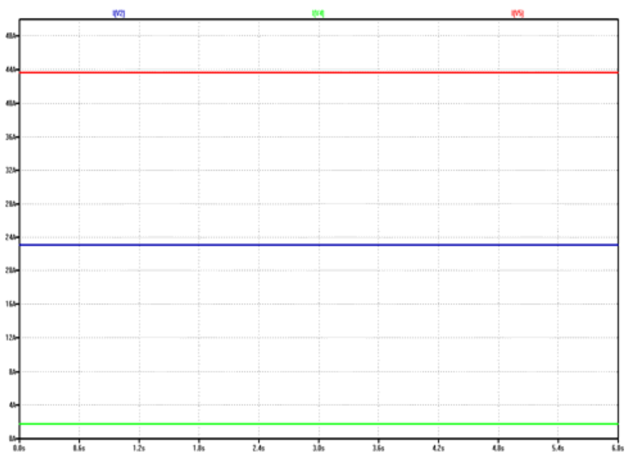

Fig. 6. Simulation result, output current (IGBT – top line, MOSFET - middle line and bipolar – bottom line).

Table I content experimental results of device. Voltage of battery increases from 9.5 V to 15 V and after, decrease; simultaneously follow the status of power transistor. Have obvious different behavior for charging and discharging, respectively. From data representation, Fig. 7, have required hysteresis. Experimental hysteresis has around 3.9 V and slightly customized from switches.

Device has high functionality and versatility, and can have compact layout. Experimental prototype, single side, has 11cm x 7 cm, because of size of microcontroller (40 pins) and connectors. Specific connectors connect additional components like LCD and in circuit serial programming (ICSP) connector.

Estimated cost of board, only components, is around 15 Euro.

TABLE I.
DEVICE STATUS CHANGES DEPENDING ON THE BATTERY VOLTAGE

| Voltage [V] | Output status | |
|---|---|---|
| | Charge | Discharge |
| 9.5 | ON | ON |
| 9.7 | ON | ON |
| 9.9 | ON | ON |
| 10.1 | ON | ON |
| 10.3 | ON | ON |
| 10.5 | ON | OFF |
| 10.7 | ON | OFF |
| 10.9 | ON | OFF |
| …. | ON | OFF |
| 13.9 | ON | OFF |
| 14.1 | ON | OFF |
| 14.3 | ON | OFF |
| 14.5 | OFF | OFF |
| 14.7 | OFF | OFF |
| 14.9 | OFF | OFF |

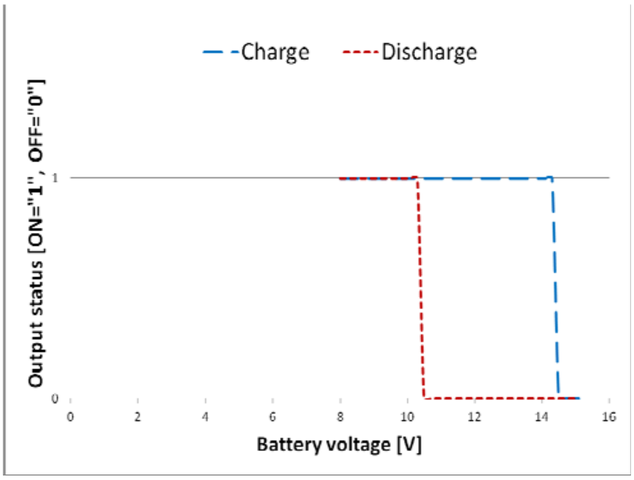


Fig. 7. Experimental device hysteresis.

## IV. CONCLUSIONS

For energy storage, batteries still represent the most common way. Increased service life to these has reflected in operating costs. However, it has other associated implications such as environmental protection.

A solution for battery life extension is the size interval of time between charges. In this sense, the achievement of a hysteresis in the charging and discharging is an example that has worked for lead-acid batteries. For complete testing designed device required significant time.

This device has multiple possibilities to extend its applicability. The device has use also in charging operation of different rechargeable battery pack (Li-ION, Li-Po, Cd-Ni) with minimum redesign, especially in software. Reconfiguration will consider typical charging feature for each type of battery separately.

Does not matter if charging method use constant current or voltage, the device monitor the voltage across battery pack and decide the action. The device itself does not deliver current or voltage to battery pack, but only control charge/discharge process to avoid abnormal conditions and prolongs battery life.

An interesting action, but intuitive, is about if power supply go down. In this case software keep the last state of command ("ON" or "OFF"), if battery pack voltage is between limits. Because this device has power by battery pack itself, is not necessary to save voltage limits or save in EEPROM the status of command, in the case of power loss.

If want to have more flexibility, one possibility has to have different voltage reading of power supply and battery pack, respectively. In this configuration exist five possible cases to be take in consideration when develop algorithm, Table II.

TABLE II.
DEVICE STATUS CHANGES VS. BATTERY VOLTAGE AND POWER SUPPLY

| Output status | Voltage [V] | |
|---|---|---|
| | Power supply | Battery pack |
| OFF | < 10.5 | <10.5 |
| OFF | < 10.5 | > 10.5 |
| ON | > 10.5, < 14.5 | < 10.5 |
| ON | > 14.5 | > 10.5, < 14.5 |
| OFF | > 14.5 | > 14.5 |

To reduce consumption, the backlight of device LCD can be turn off (Fig. 8). In addition, the four switches to adjust the voltage limits are visible. If reduce number of components to minimum, number of switch to two, instead four.

The LCD (16 x 2 characters) displays in real time, battery voltage, lower and upper voltage limits.

Using low cost electronic components or removing some of the components, the device can have a lower price and reduce the size of the device.

As shown in Figure 8, device has oversized cooling elements, to increase the safety and reliability. The most efficient power stage must have IGBT or MOSFET transistor. However, consumption has given, mainly by display element, LCD and indicators (LEDs).

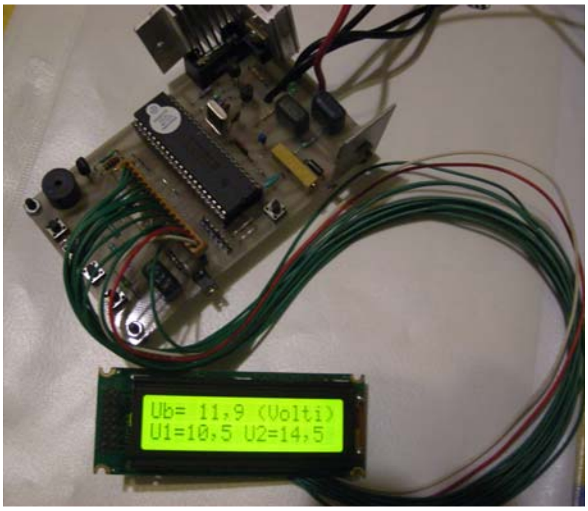


Fig. 8. Overview of designed device.

Main contributions consist in method design, principle of operation, developing microcontroller additional schematic, build-in software and make experimental device.

The main challenge to design this device was to develop a robust algorithm in order to achieve a hysteresis in the charging of battery pack.

Another options and future development of the device have at basis compact and small device, remove LCD (but keep adjusting possibility of voltage limits, using fixed steps of voltage for example and few LEDs to inspect), using small size microcontrollers and reduce device consumption (actual current is around 10 mA, without LCD back light). Reduce power consumption by using lower clock speed can ensure lower price also because in this case use internal RC microcontroller oscillator.

Overall, the device works as expected, highlighted by stable and accurate.

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## REFERENCES

[1] O. Tomuta, *Battery pack*, Technical Printing House, Bucharest, 1988.

[2] G. Clondescu, O. Tomuta, *Battery pack. Maintenance and Repair*, Technical Printing House, Bucharest, 1977.

[3] P. Hurley, *The Battery Builders Guide: How to Build, Rebuild and Recondition Lead-Acid Batteries,* Good Idea Creative Services Publisher, 2013.

[4] D. Pavlov, *Lead-acid Batteries: Science and Technology : a Handbook of Lead-acid Battery Technology and Its Influence on the Product*, Elsevier Science Limited, 2011.

[5] T. R. Crompton, *Battery Reference Book*, 3rd Edition, Newnes Publisher, 2000.

[6] C.D. Oancea, *Instrumentation*, MatrixRom Printing House, Bucharest, 2013.

[7] http://www.microchip.com/

[8] V. Surducan, W. Van Oijen, *PIC Microcontrolers for All*, Risoprint Printing House, Cluj-Napoca, 2004.

[9] I. Sztojanov, E. Borcoci, s.a., *From TTL Gate to Microprocessor*, Technical Printing House, Bucharest, 1987.

[10] I. Piroi, I. Tatucu, I. Ruja, E. Erina (Spunei), “Using virtual tools to calculate and record the hysteresis characteristic for a transformer, in order to know the magnetisation remanence” *Annals of the University of Craiova*, vol. II, no. 34, pp. 195–199, 2010.