THE GENERATION OF THE RESONANCE PHENOMENON IN ACCUMULATORS THROUGH CHARGING PULSES

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Abstract: Inside the process of charging batteries with pulses, besides the desulfation phenomenon, there is also another phenomenon, that is caused by the abrupt slope of the pulse. This fact is shown in the signal forms obtained from precise voltage measurements between the battery electrodes. During the transition periods of pulses at microscopic level there is a succession of consecutive and parallel processes, that change from the state of equilibrium to state of charge. If we choose properly the pulse for charging, the system can go in state of resonance.

Keywords: *Resonance With Pulses, Charging Of Accumulators, Lead-Acid Battery.*

I. INTRODUCTION

What is the the charging with pulses of an accumulator hiding? Is it worth to focalise our attention on this type of charging? Does it present a supplementary importance compared to the classical types of charging? Due to the fact that in the charging and discharging processes of the accumulators we have a multitude of different particles which take part in the electochemical reactions and we have their different times of reactions, we can be sure that there are some particular cases in which they can help each other. The charging through pulses occupies a modest place in the study of the classical charging methods [1] and it doesn`t seem to be interesting anymore. In some cases the charging through pulses is achieved by trains of pulses, with the duration reaching the superiour charging voltage, followed by a pause of relaxation of the particles [2]. These times depend on the accumulator`s state of charge [3].

There are promising studies refering to the pulse modified invariant current [4] and to the high voltage and frequency pulses [5]. In this case a pulse generator has a pulse output voltage ranging from 12 up to 20,000 volts, having a characteristic pulse frequency in the range of 1 kHz to 1 MHz and a pulse duration per cycle of 10^{-6} to 10^{-8} seconds.

Good results were obtained in the case of charging through positive pulses of long duration and of the negative ones of short duration (through which in some cases the phenomenon of sulphating is blocked - this prolongs life and improves the accumulators performances). A study [6] shows that the experimental results of consecutive orthogonal arrays reveal that charging eficiency is not obviously affected by pulse amplitude, duty ratio and frequency. In the same time it shows that pulse charge scheme is not superior to constant current charging. These aspects are generally true with a few exceptions, that the present article is trying to put in evidence, by presenting some experimental results.

II. THE USED EQUIPMENT

For monitoring the variation of voltage at the terminals of the accumulator it was used a device especially built for this purpose [7] with some minor modifications. This device has a microcontroller, applies at charging trains of pulses with the voltage of duration and pause set by a software with the resolution of 100 nanoseconds and the voltage of 14V. It measures the voltage at the terminals of the accumulator with the resolution of 12 bits within the interval of 10,7V-13,7V. This data is sent by an USB port to the external computer for storing and processing. Since the reading frequency of the analog-digital convertors (ADC) is up to 2,8Mhz, it was commanded the measuring by two ADC-s simultaneous split range between themselves of the voltage at the terminals. The software is set in the way that, in the case of a train of pulses, the duration of this is prolonged until the end of the last pulse. This being necessary for being able to study the effect of the train of pulses, which ends in the same conditions no matter the length of the period of the pulse. The measuring happens in the following way: after the software is charged, all the components of the kit are initialized and we wait for 5 seconds, this period of time being enough for all to start function and the circuits to be stabilized. Then the measuring of voltage is being started without charging for 1 second, followed by trains of pulses of 1 seconds during 5 seconds after which the charging and the measuring are being stopped. The ADC is being set at collecting the data at maximum speed, and these are being sent continuously to the buffer, from which they are being sent through the USB port to the external computer. During the measurements the necessary number of readings of the voltage values (at the terminals) was assured, in order to obtain conclusive graphs in this sense and for being able to draw the corresponding conclusions. The accumulator used is of type Starlight Lx1245ST [12V4, 5Ah].

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III. THEORETICAL GROUNDS

If we study from algorithmic point of view the electrochemical reaction at the electrodes [8], we can see that we have several stages with different times, that form together the entire internal process of energy transformation. The fact that the reactions are in different phases at molecular level and they develop in parallel, show that the kinetic equations that describe these processes have degree n. The global state of the system can be described through the sum of the state of their components.

The experimental results [9] show a strong influence of the transition periods (during the switching time from equilibrium state to charging state), on the quantities of input energy to battery. The value of input energy to battery is proportional with pulse duration just in some duty cycle domains. This fact can lead us to the existence of another phenomenon that depends just on the transition period.

In order to generate the phenomenon of resonance it is necessary for some phenomena or processes to enter into oscillations, meaning that, through the given pulses, these should oscillate between two states (a charging state and a state without charging). As such these oscillations bring a personal contribution in the favor of obtaining a superior efficiency. In this category we could enumerate aspects connected to the speed and orientation of the particles, to the direction and the speed of the electrochemical reactions and to the inertness that specifies each one [7]. In other words, due to the inertness that has to be overtaken in each particular case, it is necessary to generate oscillations so that the inertness itself to help us to overtake it.

At the passing of the accumulator from the state of equilibrium to the state of charging there is a transition period in which, in the moment of application of a voltage superior to its own, a specific signal appears [7], after which the voltage increases abruptly, flattening towards reaching the final charging voltage.

The specific signal (Figure 1.) at the moment of applying the exterior voltage shows a little growth in the first phase, which corresponds to the effect of the action of the electrical field on the particles, that are oriented towards the direction of charging (and of the electrochemical process in this sense).

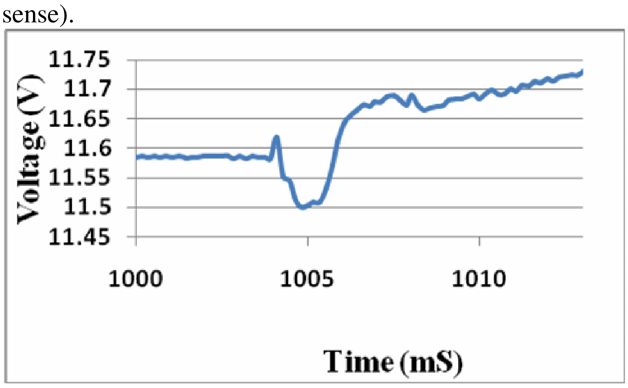

Figure 1. The specific signal at the moment of applying the charging

In the state of equilibrium the electrochemical reactions are produced in both senses (charging/discharging) in equal quantities and thus at the global level we obtain constant values. Likewise the movement of the particles is different, some of them move towards the charging direction, some towards the discharging direction, but these too give a zero resultant at the global level. Thus in the state of equilibrium too we have a continuous movement of the particles and likewise the electrochemical reactions and processes are in a process of development (only that a change of energy with the exterior environment is not being produced). The first phase of increase of the voltage at the terminals is obtained as the result of the existence of the reactions in the charging direction and of the movement of the particles in this sense. This increase is minor, because we have only a few movements of this kind in the state of equilibrium. In the next phase we obtain a sudden deduction of the voltage at the terminals under the voltage from the state of equilibrium. This can be explained by the phenomenon of inertness of the particles, of the electrochemical reactions and processes, which develop a behavior contrary to the action of the electrical field. The phenomenon of inertness is the effect of the action and reaction in this case, namely the internal system is opposing in the first phase, developing a force opposed to the exterior effect of the electrical field. Looking from another point of view we can explain this by the deduction of the number of the particles orientated towards the charging direction due to the fact that these had transformed as the result of the reactions in this sense. This number reducing, and not having yet the majority of the particles orientated towards the charging processes, the voltage at the terminals decreases, due to the decreasing of the bearers of charging obtained in this direction. This deduction reaches a minimal value, a moment when the mobilization of the other particles towards the charging direction will start. This is followed by a sudden increase of the voltage at the terminals, overtaking the voltage of the initial equilibrium. In this phase the effect of the electrical field reaches the maximum through the movement of the available particles towards the charging direction and likewise the quantity of the material which takes part at the reactions is increasing. In this phase the particles, which in the previous phase didn't take part in the reactions (and their movement hasn`t been towards the sense of charging and they have been orienting in this sense until now), will start to behave towards the direction of charging. We can observe that the abrupt slope of the deduction and increasing phase looks almost symmetrical to the vertical axis of the graphic. This shows an elastic behavior of these processes. It is similar to the total reflection of the light on a plane surface where the angle of incidence is equal to angle of reflection. In this phase we have the most abrupt slope of increase among all the charging phases which shows that in this phase the efficiency of the charging process is at maximum. As a result this phase is the most important. By obtaining a resonance frequency it is obvious that it will be pursued that this phase should dominate throughout the whole charging process. This phase of sudden increase will reach a maximum, afterwards the effect of the decrease of the number of particles which have been mobilized will be felt, followed by a minor decrease of the voltage at the terminals (due to this fact). This oscillation of the line of the graphic is growing dim and it will then stabilize at a constant decreasing easy increase which corresponds to the classical known uniform charging.

When the accumulator passes from the phase of charging to the phase of repose (or equilibrium) we also have in the period of transition a variation of the voltage at the terminals, which is not only decreasing (and it does not present only an damped oscillation) (Figure 2.).

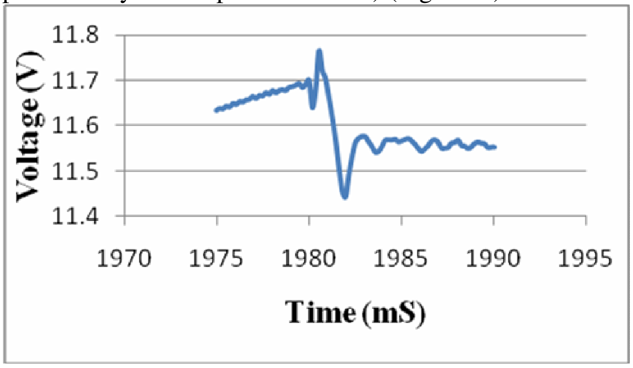

Figure 2. The specific signal at the moment of interrupting the charging

In the first phase, from the moment in which the electrical field of the exterior action (of the charging) disappears, we observe a minor decrease of the voltage at the terminals which indicates a normal (expected) reaction. A small part of the particles that take part in the charging process - under the influence of the electrical field generated from the exterior - will stop their activity in this sense. This phase ends with the appearance of the minimum prime, moment in which, the available particles are almost over with the change of the sense of orientation towards the direction of ending the charging. After this minimum, a symmetrical increase with the first phase appears, that will pass over the value of the initial voltage from the moment of interrupting the charging process and will come to a value almost double compared to the difference in the first phase. This phase of abrupt increase of the voltage at the terminals shows as well an inertness of the system towards the applied exterior action (in this case of the interruption of the charging voltage). The system is opposing to the change of state, as a result of the exterior action. The particles already involved in the charging process tend to continue their way towards finalizing it due to their inertness, of the electrochemical processes and reactions existing in the development. This phase reaches a maximum, a moment when the reactions taking part in the process end, and after that a phase of decreasing the voltage at the terminals will start. It has to be remembered that in every moment we have reactions in different senses, even in the state of equilibrium and that only the dominance of a state contrary to the other state (the difference between the number of the particles found in reaction in one sense and the number of reactions found in the other sense) will indicate the state in which the accumulator is in at the global level. At the disappearance of the exterior influence (of the charging) the accumulator will tend towards its interior state of equilibrium and thus the sudden decrease of level of the voltage at the terminals can be explained. Due to the speed of the decreasing of the charging reactions, through the interior inertness of the system we observe a decreasing of the voltage under the level of the voltage from the state of its own equilibrium. Seen from another point of view, we observe the acceleration of the reactions contrary to the charging and the effect of releasing the particles from the influence of the electrical field generated from the exterior. This phase reaches a minimum level of the voltage at the terminals under the voltage of equilibrium, a moment when the effect of inertness reaches the maximum and the reversion towards the state of equilibrium (without charging) starts again. The slopes of the phases mentioned previously are approximately symmetrical (the adjacent ones) and approximately parallel (the pairs from the same sense), which indicates the almost perfect elastic nature of the orientation of the particles` movement and of the quantities of the elements found in the reactions from one sense and the other. The last phase of the transition between the charging phase and the pause (or equilibrium phase) is that of the reversion with damped oscillations. Through this the passage is done from a superior level of voltage to an inferior one - contrary to the voltage of equilibrium - until reaching it and the stabilization of this value. The duration of the periods of the specific signals of the two phases differ, meaning that the signal of the charging phase is longer (almost double) than the signal of the interrupting phase. This aspect means that the inertness from the part of the system at charging is higher than at reversion. It can also be noticed that the two forms of specific signals are similar and of contrary, which is normal, because the action on the system in the two cases is a contrary one. The duration of these periods depend on the construction of the accumulator, on the composing elements and on many other factors.

The form of a charging pulse is composed from: the specific signal of transition at charging, of the charging itself, of the specific signal of transition at the interruption of the charging (and reversing at the initial state of pause through damped oscillations) (figure 3).

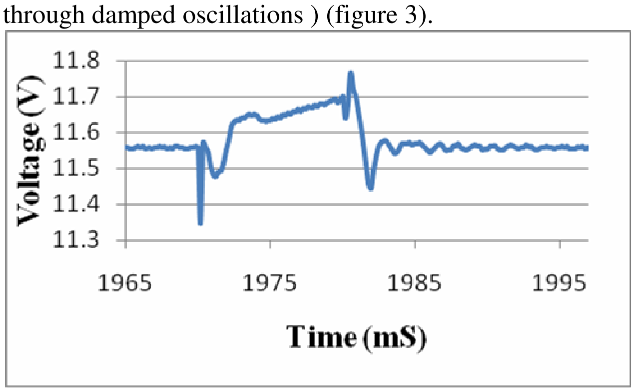

Figure 3. The form of a short charging pulse

At the same time we also mention the fact that the pulse from the graphic is one of short duration (10 ms) and it represents a very small portion of the increasing slope of the voltage at the terminals (which is obtained while approaching the value of the long standing charging voltage).

We can observe a sudden reduction of the voltage at first, immediately followed by the recurrence of the initial level in a very short time. These kind of very abrupt increases and decreases even in the opposite sense appear very often and some of them are even periodic. An explanation of this phenomenon can be found in the discontinuity of the electrolyte. More exactly in the fact that the composing elements from the entire volume of the electrolytes have different concentrations and the chemical boundings form different geometrical forms in the boundings between the molecules, atoms or ions. Thus due to the different molecular groupings of the volume, mass and charging in the reaction zone, these lead to the sudden acceleration or deceleration of the electrochemical processes at the anode and cathode. These signals, in the majority of the cases do not appear in the repose period, just in the zone of the charging pulses. This fact shows that the system at global level suffers at some extent an interior agitation, if we can call it like that, due to the exterior intervention on its state of equilibrium. Next we will analyze the obtained signals, without taking into consideration this phenomenon, because it does not present any interest in the sense of obtaining the phenomenon of resonance.

Another very important aspect which appears in some situations is that when two specific signals (at the beginning and at the ending of the charging) approach each other and interfere with each other to some extent, it results in an amplification or a diminution of the first signal`s effect. For example the starting specific signal, before reaching its final phase, is modified (as the result of the exterior intervention of interrupting the charging) and the specific final signal appears as overlapped over the starting one. The results are different forms of distorted signals which depend on the duration of the pulse and on the pause applied between the pulses, as well as on the levels of the equilibrium and charging voltages in the respective moment.

These distorted signals (resulting from the interference of the two specific signals) do not present any interest in the majority of the cases, as their maximum and minimum values correspond approximately to the minimum and maximum values of the resulting signal with the same type of pulse, only without interference between them (at a distance long enough between them not to interfere). In these cases we are not talking about the generation of the resonance phenomenon, only about a modification of the resulting signal`s form.

The phenomenon of resonance in question is appears the more rarely, when through the interference of the two specific signals results a signal of a form having the minimum and maximum values superior to those without interference taken as a reference. Thus the values of the voltages at the terminals increase over the values of reference and the increasing period will be prolonged correspondingly. The increase of the maximum and minimum values may not be in equilibrium, namely it may not be symmetrical towards the axis level of the voltage of equilibrium. For example the difference between the maximum value in the case of the signal with interference and the maximum value of the reference signal can be bigger or smaller than the difference between their minimum values. This aspect presents interest, since it shows the dominance of the electrochemical reactions and of the charging/discharging processes in the accumulator. The difference of maximums can be positive and negative and also the difference of minimums can be positive or negative, also there are crossed cases too. In the crossed cases we assist at an increasing or a decreasing of the form of the signal compared to the value of the equilibrium voltage.

IV. THE GENERATION OF THE RESONANCE PHENOMENON

In order to obtain the resonance at charging, we will pursue to have the highest difference between the maximum of the signal with interference and of the signal without one (without deteriorating the components of the ensemble). One specific of the phenomenon of resonance is the increase of the value of the voltage at the terminals over the maximum value of the voltage at charging (which already means danger in exploitation). During the measurements we obtained results at different pulses, in which the maximum value, (or the minimum value) - as a result of approaching the state of resonance - has exceeded the superior (respectively the inferior) limit of the measurement domain of the calibrated device. It is possible that in the case of exceeding the maximum value to have been exceeded even the possible maximum value of charging.

The form of the signal which is approaching the state of resonance resembles to a triangular signal, with more or less deviations from the symmetrical form. This aspect shows that the two specific signals interfere, thus the slopes of the same direction coincide and the second is in continuation of the first one, and as such amplifying its effect. In the majority of cases when approaching the resonance, the final form appears already at the first pulse (or at the first ones), and it remains the same during the whole train of pulses applied (with a few exceptions when a distorted one appears among the others). There are also cases when the amplified signal appears after tens or hundreds of pulses. This shows that an adequate number of pulses are needed at charging, for the system to pass from an inferior energy level to a superior one with a higher amplitude.

A confirmation of a close state of resonance is also the fact that in these cases we have maximum values for the duration of the pulses and the given pause between them, and at the adjacent values of the pauses we have inferior values to the previous ones.

Since we have at both specific signals more slopes of increase and decrease, (that can interfere with each other), more types of interferences can be obtained. From the experiments we made it results an increase of the number of maximum values (close state of resonance) with the diminution of the duration of the pulse over the whole range of possible pauses. This aspect can suggest in many cases only the existence of certain superior concords of its own frequency of resonance.

Often the increase of the voltage value at the terminals can be associated with the increase of energy of the system (at some pulses of frequency and some specific duty cycle). This fact shows that the system receives a supplementary quantity of energy through the phenomenon of resonance.

V. EXPERIMENTAL RESULTS

The significant graphics were obtained:

- the signals in the scale of duration of pulses between 100 microseconds and 10 milliseconds and
- the duration of pauses between the pulses between 100 microseconds and 30 milliseconds according to the width of the chosen pulse.

The measurements were done for the following duration of the pulses: 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1400, 2000, 3000, 4000, 5000, 10000 microseconds. The duration of the pauses between the pulses were starting from 100 microseconds until a value in which the interferences disappear or the effect of an oscillation connected to resonance grows indistinct and they cannot be clearly distinguished due to the tolerance in measurement of the device. In all cases trains of pulses were generated of approximately 1 second with the pauses between them of also 1 second. The total time of measurement was 7 seconds, in which there were performed 40000 measurements.

In general the starting, the final and the intermediary pulses are interesting, which present a passing from a form of the signal into another from the train of pulses. These graphs have significant growths in amplitude although these kinds of behavior can be observed in several measurements.

Some measurements with the same parameters were repeated 10-20 times to exclude the possibility of some erroneous results. In these cases small differences were observed at some signals compared to the measured majority. This can be explained with the tolerance in measurement of the device and with the electrochemical phenomena, in which small differences at some details can influence the values of the voltage (and in some cases they can even change the form of the signal).

V.1. WIDTH OF PULSE 5 MS

The graph of signal with 5ms pulses width is presented to figure 4-8.

The approximately triangular form and the higher amplitude (figure 5) compared to the reference one (figure 4) with the multiple differences between the charging voltage and the pause.

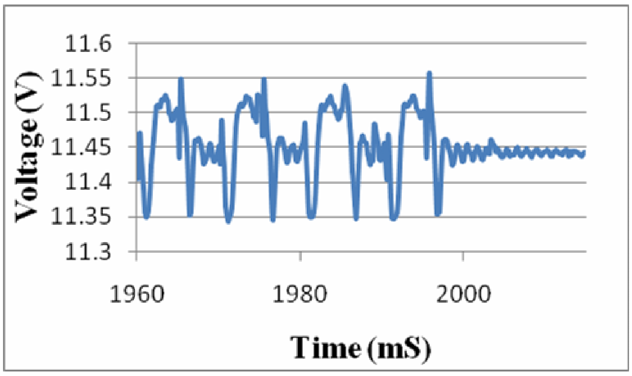

Figure 4. The form of the signal of reference with the period of 10 ms

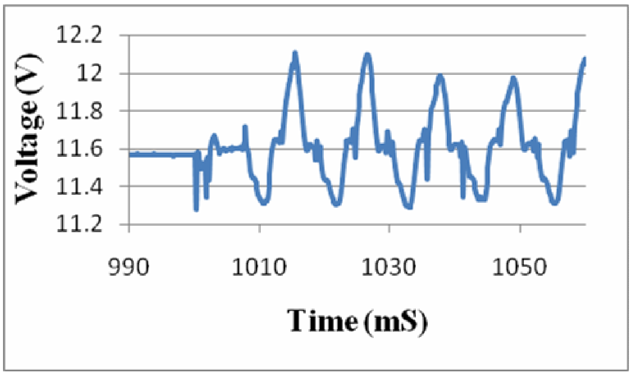

Fig. 5. The period of the signal 5,5 ms (first pulses)

The amplitude of the signal (figure 6) already reaches the maximum measurable value of the device at the first pulses.

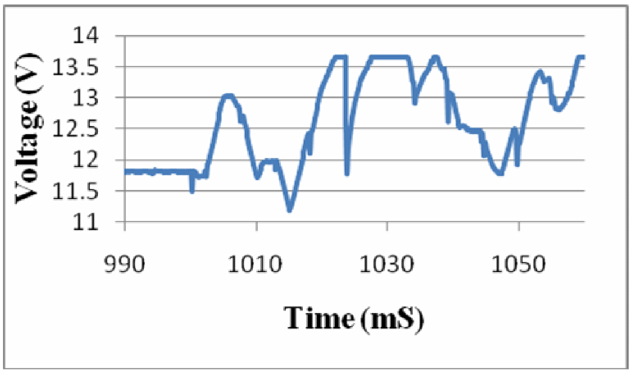

Figure 6. The period of signal 5,2 ms (first pulses)

At the end of the train of pulses (figure7) the voltage at the terminals of the accumulator increases for a long time above the maximum measurable value with this device.

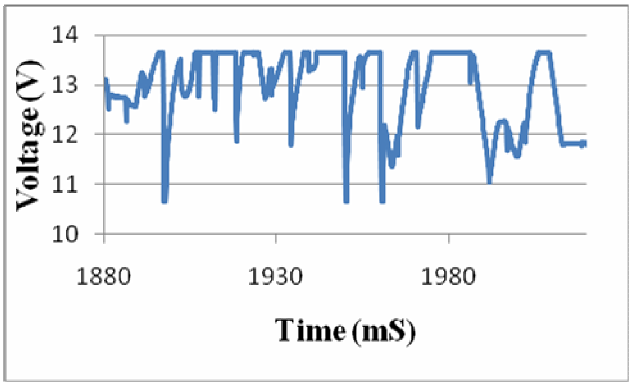

Figure 7. The period of signal 5,2 ms (last pulses)

At the first pulses (figure 8) we have a tendency of growth, but this cannot be maintained and it stabilizes around some average values.

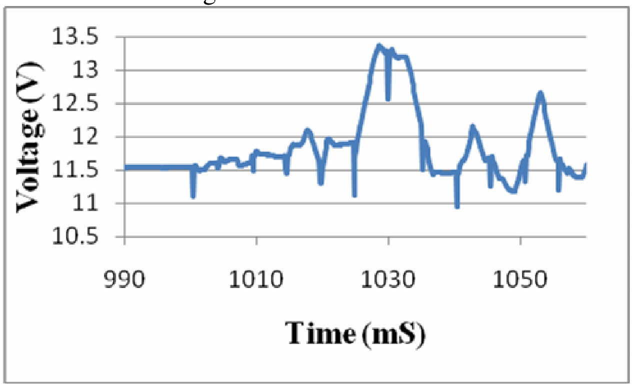

Figure 8. The period of signal 5,1 ms (first pulses)

Only at the frequency of 192,3 Hz and the duty cycle of 96% (figure 6-7), we have a maximum growth of the value at the terminals, and at adjacent values these values tend towards the classical reference value.

V.2. WIDTH OF PULSE 3 MS

This graph for width of pulse of 3 ms presents interest from the point of view of the system trying to enter in the state of resonance. This is noteworthy for the multitude of different forms of the signal among the same train of pulses. For reference we have the form of the signal with the period of 10 ms without interference in figure 9.

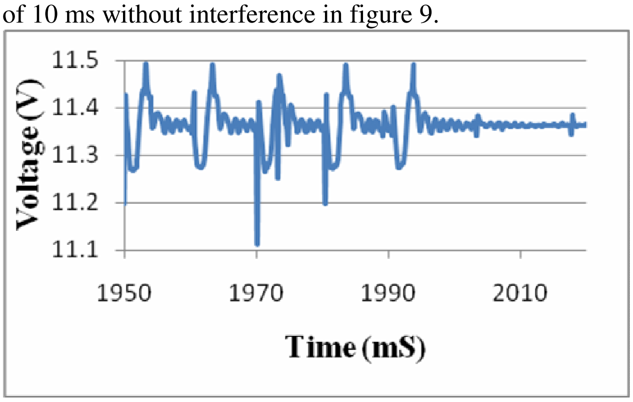

Figure 9. The form of the signal of reference with the period of 10 mS

By decreasing the period of the signal, the values of the voltages remain approximately at the same level until the value of the period of 3,5 ms pulse, from where the maximums of the signals start to increase. There is a very interesting fact at the period of 3,3 ms, where among the train of pulses with the duration of 1 second we noticed four different types of signals.

The first two types of pulses from the start of the train of pulses (3,3 ms) are presented in figure 10.

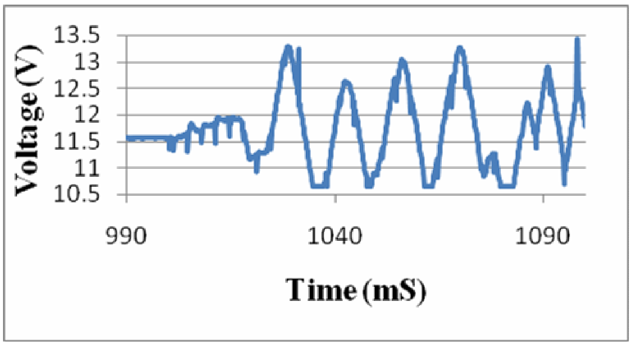

Figure 10. The form of the signal at the start of the train of pulses with the period of 3,3 ms

We distinguish in this case the first type of signal which increases towards the value of 12V, and after some periods the signal is transformed into the second type having the maximums around the value of 13V. The latter can not be maintained and after some periods it is tarnsformed into the third type of signal having the lowest maximums.

The third type of signal is maintained for approximately 450 mS after which it will transform into the fourth type of signal (figure 11).

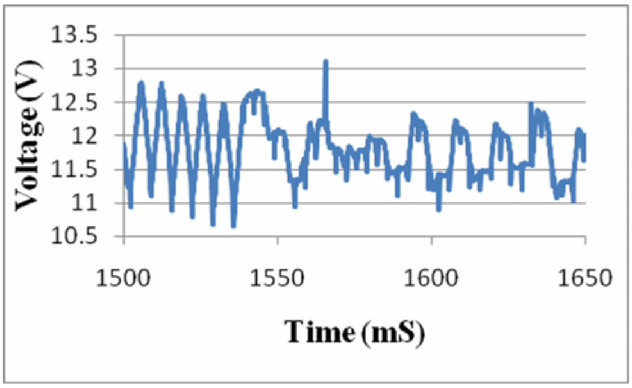

Figure 11. The form of the signal with the period of 3,3 ms at the passing between the 3rd and the 4th type of signal

The fourth type of signal is maintained until the end of the period of the train of pulses.

The fact that along the duration of 1 second of the train of pulses with the frequency of 303 Hz and the duty cycle of 90%, we have four different forms of the voltage at the terminals. This fact shows a tendency of the system towards the state of resonance and on the other hand the instability of the system in these phases. We can associate the four types of signals with four different energy levels of the system. Every level is higher or lower, according to the maximum value of the form of the signal from the graphic of the voltage at the terminals. An inferior power level corresponds to an inferior maximum value, and a superior power level corresponds to a higher maximum value. The passing from an inferior power level to a superior one is due to a quantitative accumulation of an interior energy of the system, which will produce a power quality leap. The opposite type of passing, meaning the one from a superior power level to an inferior one, is due to the lowering of the interior energy of the system until a critical value which will lead to losing that power level. With this device we can't monitorize the value of the interior energy of the system, we can only observe the passing from one level to another.

V.3. WIDTH OF PULSE 300 µS

The other interesting graphs are at width of pulse of 300 µs, these are presented in figures 12-15.

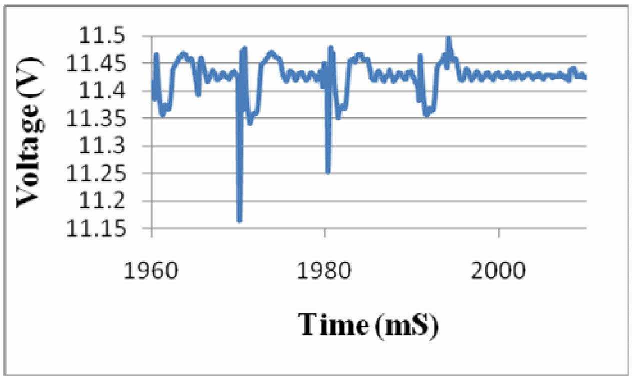

Figure 12. The form of the signal of reference with the period of 10 ms

We have an almost perfect coincidence of the slopes in the same direction of the two specific signals (figure 13), which amplify among each other towards the values of reference (figure 12).

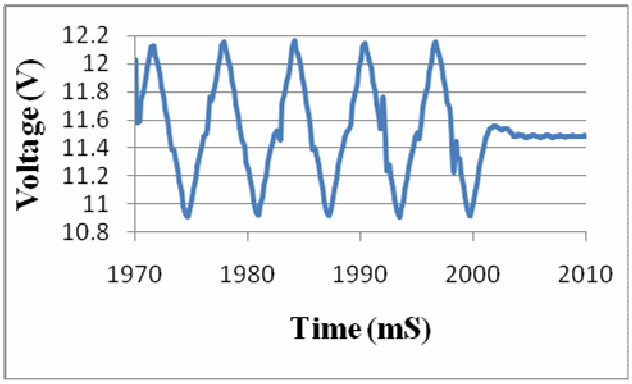

Figure 13. The period of the signal 3,1 ms (last pulses)

It can obtain in plus an increase of the average value of the voltage at the terminals, until reaching the maximum limit value, which is maintained along the duration of the train of pulses (figure 14).

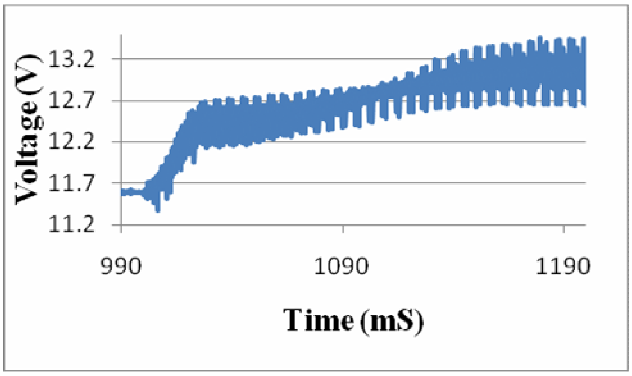

Figure 14. The period of the signal 400 µs (first pulses)

It is possible that in this case (2,5MHz and duty cycle 75%) we are the closest to the frequency of resonance. This due to the fact that the resulted signal on one hand is amplified until bringing nearer to the maximum value at charging, and after interrupting the train of pulses instead of decreasing immediately (as we would expect) it will increase easily and it will maintain at a superior value for more than 10 periods of the generating pulse (figure 15).

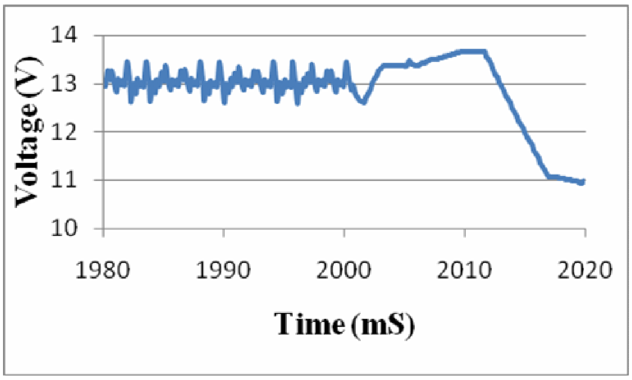

Figure15. The period of the signal 400 µs (last pulses)

Since the present report is based on only a certain type of lead-acid accumulator by which the measurements were done, these values are still waiting to be confirmed in the case of other types of accumulators, but for sure the research in this direction will be successful in all the cases.

VI. CONCLUSION

From the performed measurements and from the study of the electrochemical phenomena which are produced in the transition period (both at commutation towards charging and at interrupting the charging), results that the system sometimes has the tendency to enter in resonance, which is showed in different ways. In all cases regarding this type we see an increase of the amplitude of the signal compared to the chosen signal of reference. In some of these cases the amplitude had increased even over the maximum limit of the measuring domain or it had decreased under its minimum limit.

In a particular case (2,5MHz, duty cycle of 75%), we could notice the existence of the charging signal also after interrupting the train of pulses (even after a time of over 10 periods of the charging pulse), once even an increase of the voltage value. This shows a very possible zone in which the system enters the state of resonance. It also it worth mentioning the fact that we are dealing with a multitude of harmonics of the frequency of the basic signal. This is emphasized in the cases in which we have more maximum values among the same width of the pulse and at the variation of the period (or at the pauses between the pulses). This aspect can be explained also by the multitude of interferences of the two specific signals on both sides of the charging pulse. These slightly differ from each other and when they get closer there are more types of overlays which generate different effects (the amplification of the signal or its extinction), depending on the increasing and decreasing slope which interacts between the two specific signals.

From some significant results we can deduce that the resonance frequency and their harmonics, depend on the difference of the charging voltage and the open voltage value. It obviously also depends on both: the frequency of the applied pulse and on its duty cycle.

Taking into account the experimental results obtained by other researchers in this domain and also the ones that are presented here, we can affirm that the generation of electrochemical resonance phenomenon inside the battery is a large domain of interest. The theoretical background can be found in an interdisciplinary domain that touches lot of branches of chemistry (in particular physical chemistry, chemical kinetics, electrochemistry, inorganic chemistry, surface chemistry), of physical domains (in particular quantum mechanics, thermodynamics, the atomic, nuclear and molecular physics, particle physics, fluid mechanics) of electronics domains (in particular electrostatics, electrodynamics, electromagnetism) and energetics.

Since it is a resonance phenomenon in the transformation from chemistry energy to electrical energy and opposite, the system receives an additional quantity of energy, unknown till now. This way the management of electrical energy of battery systems could start a new global direction that can modify the classical concept about this.

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