IOP Conf. Series: Materials Science and Engineering **315** (2018) 012002 doi:10.1088/1757-899X/315/1/012002

Development, modeling and research of the system of automatic control and equalization of the charge state of a battery pack of a hybrid engine of a vehicle

S Bakhmutov[1], Y Sizov[2] and M Kim[2]

[1] FSUE "NAMI", Moscow, Russia
[2] Moscow Polytech University, Moscow, Russia

E-mail: sizovua@yandex.ru

Abstract. The article is devoted to the topical problem of developing effective means of monitoring and leveling the charge state of batteries in a power unit of hybrid and electric cars. A system for automatic control and equalization of the charge state of a battery pack of a combined power plant, the originality of which is protected by the Russian Federation patent, is developed and described. A distinctive feature of the device is the possibility of using it both in conditions of charging (power consumption) and in operating conditions (energy recovery). The device is characterized by high reliability, simplicity of the circuit-making solution, low self-consumption and low cost. To test the efficiency of the proposed device, its computer simulation and experimental research were carried out. As a result of multi factorial experiment, a regression equation has been obtained which makes it possible to judge the high efficiency of detecting the degree of inhomogeneity of controlled batteries with respect to the parameters of an equivalent replacement circuit: voltage, internal resistance and capacitance in the magnitude of the obtained coefficients of influence of each of these factors, and also take into account the effects of their pair interactions.

1. Introduction

In recent years, a fairly large number of works by devoted to the determination of the electrical parameters of elements in a battery has appeared. However, existing devices are disadvantageous: the design solution does not allow monitoring battery blocks with voltages above hundreds of volts, the charging currents are small in magnitude and charging of batteries is carried out only in the pulsed mode. The device for its implementation requires many additional components for each element of battery, there is no measurement of parameters during operation, automatic mode of operation and other shortcomings are not provided.

2. Purpose and Methods

The purpose of this work is:

1. Development of a system for automatic monitoring and equalization of the charge level of the battery pack of the hybrid power unit of the car according to the parameters of the internal resistance R, battery capacity C, voltage U, providing:

1.1. the ability to work both under conditions of energy output and under conditions of electric consumption;
1.2. automatic determination of the parameters of each battery in the composition of the AB and their alignment;
1.3. relative prostate of the circuit solution with a slight complication of the equipment with an increase in the number of monitored batteries in the unit.

2. Computer simulation of the developed scheme, experimental research and analysis of the results obtained.

To implement the tasks, an original automatic control system [1] was developed, the structural diagram of which is presented in Figure 1. The system works as follows. The signals from the microcontroller are fed to the address switching input of the dual demultiplexer with the number of outputs n. In each demultiplexer, the n accumulators of the battery are sequentially connected through n + 1 single-position keys with a small internal resistance to the common wires A and B. Pros of the accumulators with odd numbers are connected to the wire A and the pluses of the accumulators with even numbers are to the wire B. On the wires A and B occurs an alternation of positive and negative voltages, which are transmitted to the information processing unit.

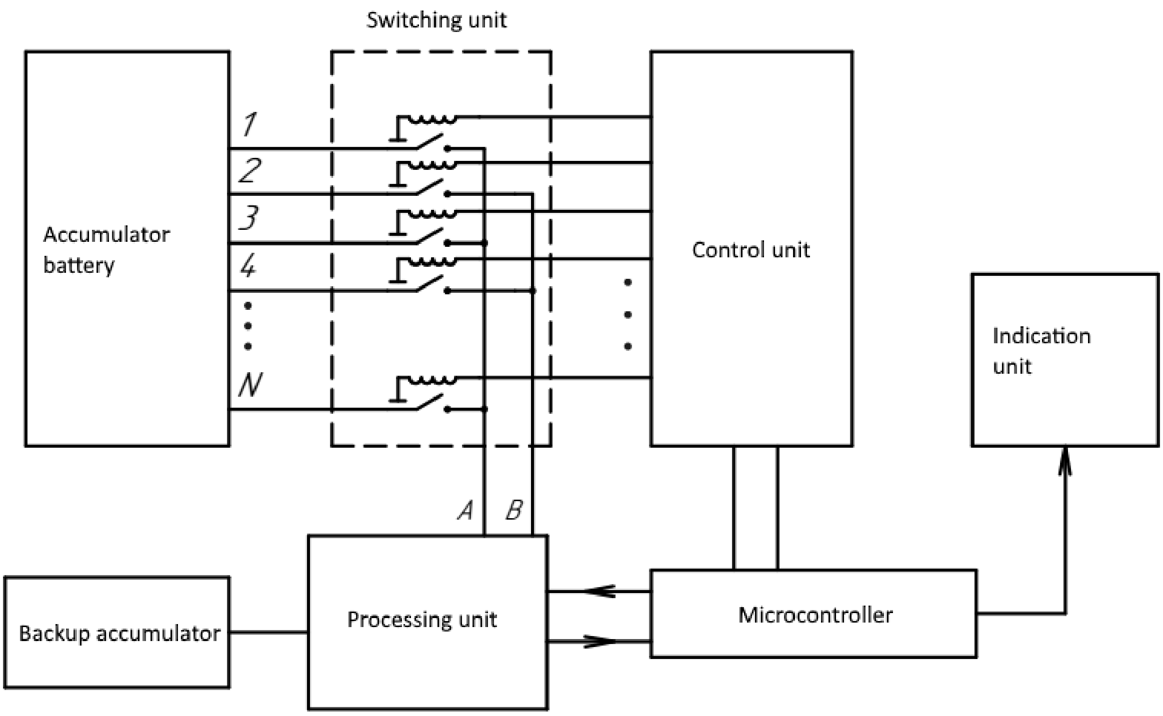

Figure 1. Structural diagram of the control and balancing system.

If the batteries have the same degree of charge, the voltage at the output of the information processing unit will be close to zero. If at least one of the battery packs is overcharged or undercharged, then the output will be a positive or negative mismatch pulse, with an amplitude proportional to the magnitude of the imbalance.

If the amplitude of the mismatch pulse exceeds the output of the information processing unit of the specified boundary voltage, the microcontroller sets the process of interrogation of the battery cells, fixing on the problem battery and indicates the serial number of the problem battery and the type of malfunction (recharge or undercharging) on the indicator display.

Simultaneously, the microcontroller generates a signal of the duration of the Tz recharging time. During that period the problematic battery is connected through the information processing unit to the backup battery cell and the charging state of the backup cell and the problem battery cell are equalized. Since problem accumulators can be either recharged or undercharged, the backup battery cell will maintain a charge level close to the arithmetic mean of all battery cells. At the end of the Tz period, the microcontroller will continue to poll the battery packs with the intermittent multiplexers of the control unit until another problem battery is encountered, etc. Thus, the system can work both in traffic conditions of the vehicle and when replenishing power from the charger.

A distinctive feature of the device is its ability to use it both in conditions of charging (power consumption) and in operating conditions (energy recovery), while the device is characterized by simplicity of circuit design, low power consumption, low cost and potentially high reliability.

If it is necessary to increase the number of elements in the battery, for example, up to 100 or more, the complexity of the electrical circuit is only due to a proportional increase in the number of keys and the number of outputs of the dual demultiplexers, which slightly increases the cost of the device.

3. Theoretical and experimental research, evaluation of results

To determine the operability of the developed electrical circuit, when measuring deviations of the battery parameters from the nominal values in the Multisim environment, a theoretical model of the system block was constructed, including eight controlled batteries, each of which was represented by the equivalent replacement circuit shown in Figure 2.

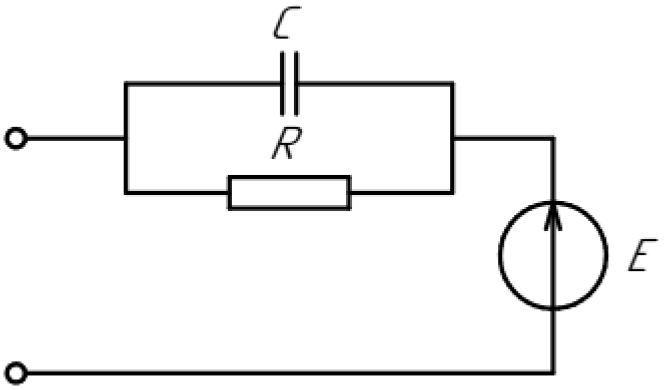

Figure 2. Equivalent battery replacement circuit. R-internal resistance; C - total capacity; E is the internal e.m.f.

In simulation, the input signal was generated by a virtual pulse generator, and the analysis of the output data was performed by a virtual oscilloscope. Figure 3 shows the time waveform of the output voltage of the signal processing unit at a battery sampling frequency of 100 Hz. The upper graph shows how the output voltage changes when the internal resistance of the fourth problem is deflected at 10% of the rated value. As it can be seen from the presented oscillogram, the useful signal is significantly allocated at the level of interference. The lower graph shows the time variation of the voltage on the batteries relative to the ground when they are sequentially interrogated, which shows that the fourth battery is problematic. Thus, the developed theoretical virtual model allows to carry out experimental research of the developed device with rather high accuracy.

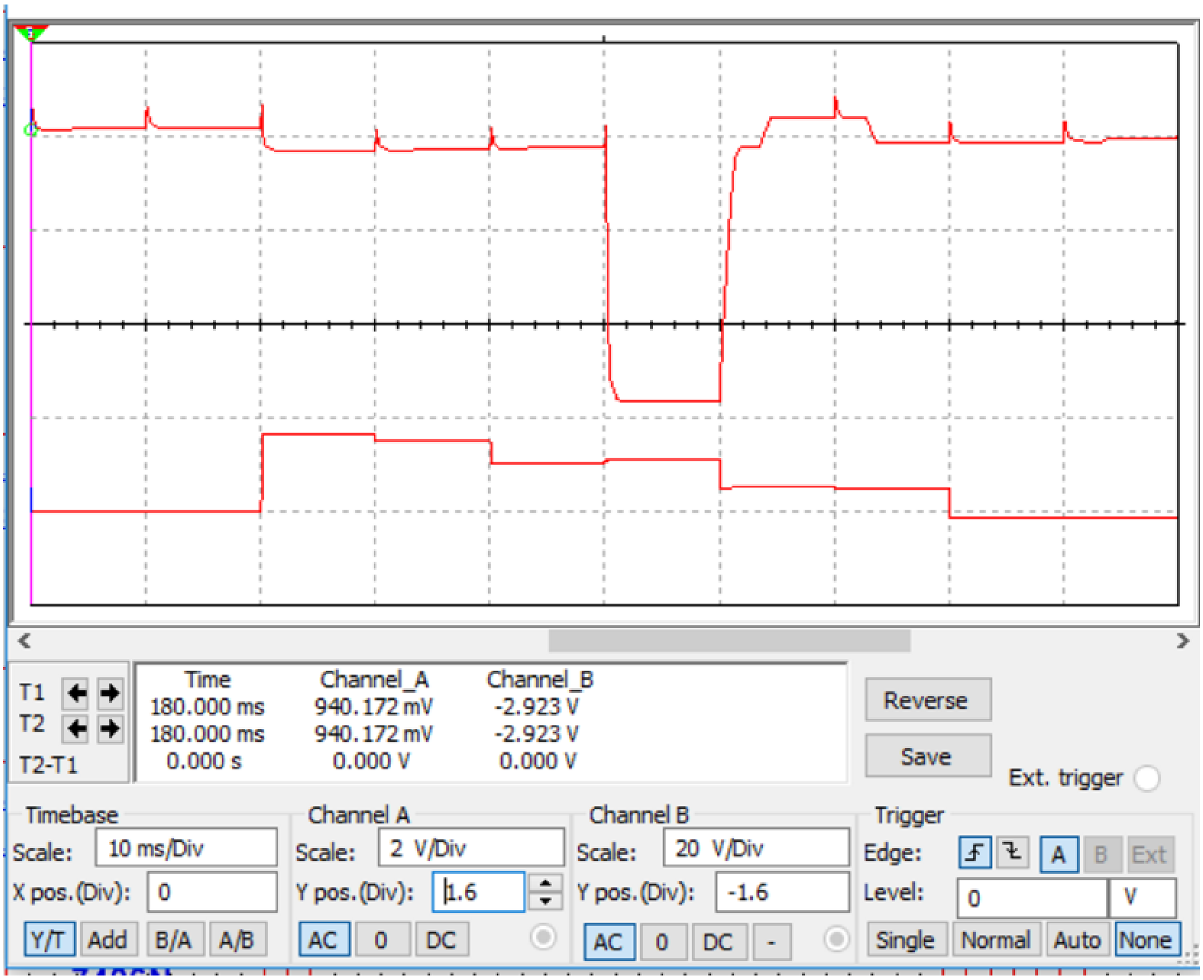

Figure 3. Oscillogram of the output voltage when a problematic battery is detected.

With a simple one-factor measurement of the degree of influence of individual parameters on the output voltage value due to their misalignment, it is impossible to estimate the real situation when all the influencing factors change simultaneously. It may be necessary to consider paired and triple effects and second-order effects. Therefore, as a method of experimental multifactor study, in determining the coefficients of influence of the three parameters of accumulators (U, R, C) on the virtual model, the B-plan [2,3,4] is chosen, which allows to reveal the second-order dependences. The results of the experiment are summarized in Table 1.

Table 1. The results of the experiment.

	Normalized values of factors			The natural values of factors			Output values				Average output value
	x_1	x_2	x_3	X_1	X_2	X_3	y_1	y_2	y_3	y_4	$\bar{y}$
1	1	1	1	5	0.03	12	0.38	0.378	0.382	0.381	0.380
2	-1	1	1	3	0.03	12	3.315	3.312	3.315	3.309	3.313
3	1	-1	1	5	0.01	12	0.809	0.812	0.811	0.812	0.811
4	1	1	-1	5	0.03	4	0.825	0.823	0.819	0.823	0.823
5	-1	-1	-1	3	0.01	4	2.04	2.043	2.039	2.04	2.041
6	1	-1	-1	5	0.01	4	0.808	0.808	0.81	0.809	0.809
7	-1	1	-1	3	0.03	4	3.318	3.315	3.318	3.32	3.318

	Normalized values of factors			The natural values of factors			Output values				Average output value
	x_1	x_2	x_3	X_1	X_2	X_3	y_1	y_2	y_3	y_4	$\bar{y}$
8	-1	-1	1	3	0.01	12	2.028	2.031	2.027	2.03	2.029
9	1	0	0	5	0.02	8	0.818	0.82	0.818	0.818	0.819
10	0	1	0	4	0.03	8	0.861	0.862	0.859	0.862	0.861
11	0	0	1	4	0.02	12	0.869	0.872	0.87	0.869	0.870
12	-1	0	0	3	0.02	8	2.683	2.679	2.685	2.68	2.682
13	0	-1	0	4	0.01	8	0.851	0.849	0.855	0.851	0.852
14	0	0	-1	4	0.02	4	0.858	0.862	0.859	0.86	0.860

The output value of Y in the experiments is the output voltage of the signal processing unit, measured in volts. To increase the accuracy of the measurements, the experiments were carried out at four-fold duplication at each point of the experiment, so the arithmetic mean values of the output value were written in the right column of the table. After checking the adequacy by the Fisher criterion, removing the insignificant coefficients by the Student's criterion and bringing it to the natural values of the influencing factors of the regression equation takes the form:

$$\hat{y} = -0{,}075 + 0{,}962x_1 - 0{,}824x_2 + 0{,}154x_3 + 0{,}109x_1^2 + 0{,}465x_2^2 - 0{,}232x_3^2 - 0{,}38x_1x_2 - 0{,}323x_1x_3 + 0{,}402x_2x_3$$

Where:
$\hat{y}$ - output voltage predicted by the regression equation;
x_1- voltage U;
x_2- resistance R;
x_3- capacitance C.

As can be seen from the regression equation obtained, only the effects of single factors (U, R) are significant, but also their paired effects. Also, the coefficients of linear coefficients at U and R were most significant, and the influence of the C-value is practically insignificant, and the coefficients for quadratic effects turned out to be of little significance. From what has been said, it follows that the regression equation has a practically linear form. Other advantages of the obtained regression equation include the ability to predict the magnitude of possible imbalance in the operating conditions from a known variation in battery battery parameters and to construct a more adequate model of a real battery [4].

4. Conclusion

Thus, the device allows:

- to carry out continuous monitoring of the battery charge level of the battery by the main parameters of voltage, internal resistance and capacity, indicating the serial number of the problem battery and the nature of the malfunction (undercharging or recharging);
- provide the ability to work both in conditions of energy output and in conditions of electric consumption;
- to provide relative simplicity of the circuit solution with insignificant complication of the equipment with increasing number of controlled batteries in the unit;
- provide selective recharging and alignment of problematic batteries from the backup battery with a high current for a certain period of time.

IOP Conf. Series: Materials Science and Engineering **315** (2018) 012002 doi:10.1088/1757-899X/315/1/012002

References

[1] Bakhmutov S, Sizov Y, Revonchenkov A, Chernokozov V, Gordeyev A and Kim M 2017 *The device for automatic control and equalization of the charge state of a battery pack of a combined power plant* (Russian Federation 2626378)

[2] Sizov Y, Kharitonov V and Chekmaryova Y 2014 Calculation and modeling of electric parameters of accumulators on transient processes *Bulletin of the Moscow State University Series "Engineering and Technology*" No. 4

[3] Kharitonov V, Gordeyev A and Lozhkina Y 2013 Modeling and research of electrical parameters of series-connected batteries *Bulletin of the Moscow State University Series "Engineering and Technology"* No. 4

[4] Bakhmutov S, Sizov Y and Kim M 2015 Development of a mathematical model and study of a traction battery of a hybrid power plant *Proc. NAMI* p 262