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ESTIMATION OF EFFICIENCY OF ELECTRIC POWER BALANCE IN AUTOMOBILES

Summary. Increase in consumer power with the simultaneous reduction in the time and driving speed of personal automobiles results in systematic discharge of the batteries due to electric power balance inefficiency. The calculation methods for the evaluation of the electric power balance are inefficient, as a number of random factors (demand for electric power, driving speed, air temperature, technical condition of the units, etc.) influence the process of electric power generation, storage and consumption. The instrumental method for evaluation of the electric power balance efficiency assumes that the driver is informed about the battery charge condition prior to combustion engine startup, operational evaluation of the charge state change is performed during automobile driving and the driver is warned about critical reduction of charge state (including the forecast of its change for the period of the parking of the automobile in winter).

1. INTRODUCTION

The current pace of life is characterized by improvements in comfort and mobility, to which automobile transport is adapted the best. At the same time, personal automobiles are used inefficiently (standing idle) at home, the workplace and other places where automobile owners travel to most of the time. Often, automobiles are operated outdoors, and variations in temperature, humidity, etc, exist.

All of this frequently results in unsuccessful starting of the engine in the mornings, as the automobile battery has insufficient charge. More often, the reason for this involves a set of factors that the automobile manufacturers (for example, LADA Xray – Operating and Repair Manual) refer to as complex operating conditions:

- Operation of the automobile at low speeds (for example, during slow driving in the town, during short-distant driving or in a jam) or during idle engine operation, and automobiles driving for short distances of less than 10 km per drive every day on average, or automobiles with over 30% engine idle operation time per day (for example, special automobiles, taxi and training automobiles).
- Automobile parking outdoors in winter and intensive use of the air conditioner in summer.

In this case, for reduction of battery usage, manufacturers recommend avoiding consumption of electric power, if possible, for example, heating of the rear windows, seat heating, etc., or recharging the battery each month. It is difficult for drivers to determine the exact time at which the battery requires recharging, as standard automobile devices do not display this information. In monograph [1], “Procedure for Correction of Automobile Battery Charge Frequency in Winter,” an attempt is made to consider the automobile operation condition under various climatic conditions to develop recommendations on preventive charging of the battery (Fig. 1). However, changes in weather and climatic and road conditions, as well as a number and power of the used consumers within the wide ranges significantly reduce the significance of such recommendations for individual use.

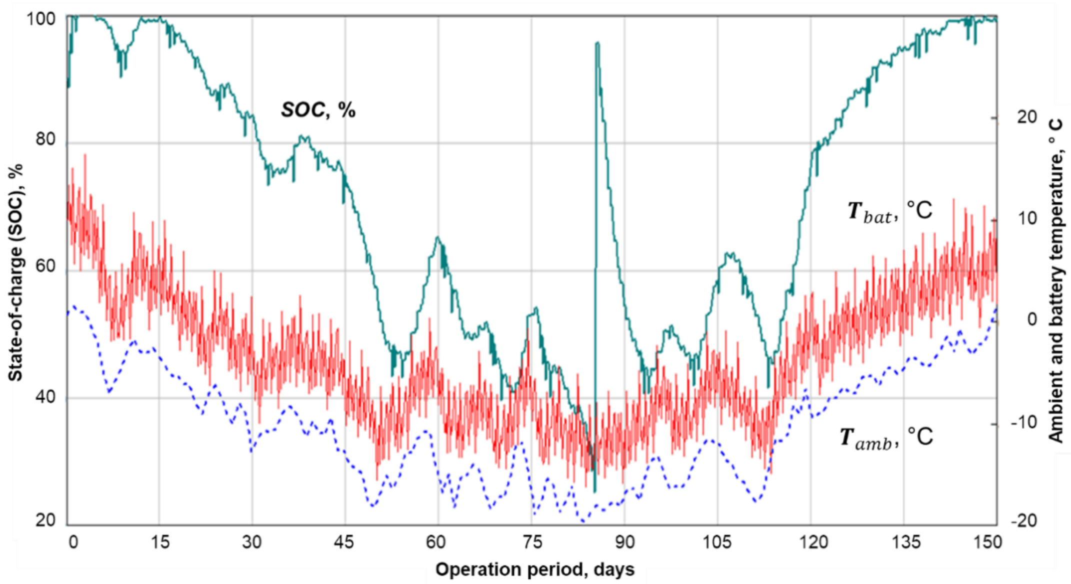


Fig. 1. Change in charge state and Temperature of the Battery during the Daily Operation of a Hyundai Solaris within the Period from November to March in Tyumen: SOC (state-of-charge) battery, %; Tbat – battery temperature, °C; and Tamb – ambient temperature, °C

The reason for starter battery discharge (besides its age and occurrence of faults [2]) is nonfulfillment of the electric power balance on the automobile: the power spent for power supply (especially starter) exceeds the power received from the automobile alternator. The efficiency of the automobile electric power balance can be evaluated by the following methods: calculation as per [3] (used at the stage of new automobile designing), based on statistics (based on the analysis of distribution of the involved consumers and engine rotational speed for automobiles or groups of automobiles) and use of instruments (with instruments installed in the automobile).

2. CALCULATION METHODS FOR ELECTRIC POWER BALANCE EFFICIENCY EVALUATION

Let us consider the first two methods by dividing them into two components: electric power generation and its consumption.

The automobile alternator is the main electric power source in the latest automobiles, as other methods for its generation can be ignored (solar cell batteries, thermoelectric alternators). The alternator current output depends on the rotor speed. During engine idle operation, the alternator can output (at a crankshaft pulley– alternator pulley transfer ratio from 1:2 to 1:3) only a part of its nominal current (about 50%) [4]. The nominal current is output as per the nameplate data at an alternator speed of 6000 1/min and higher. The potential possibility to generate electric power at alternator rotation with different speeds is based on the current and speed characteristics of the alternator (Fig. 2) [5-8].

To determine the scope of electric power generation, it is necessary to determine the so-called driving profile, except for the current and speed characteristics of the alternator. As an input parameter for electric power balance calculation, the driving profile is displayed by means of the relative speed rate of the engine operation. The curve indicates how a certain engine speed is achieved and exceeded.

At calculation method (OST 37.003.034-77) the profiled detected during development of the documentation, which disadvantage is automobile speed mode having changed under current conditions, are used. Therefore, [4] state that 35% of the automobile operation time decreases during idling. The results of our own experimental research have shown that this value for automobile is about 17% under town conditions (500 thousands of population) (Fig. 3) [5].

By combining the current and speed characteristics and schedule of the alternator operation frequency on the same coordinates, the hourly scope of the generated electric power can be determined.

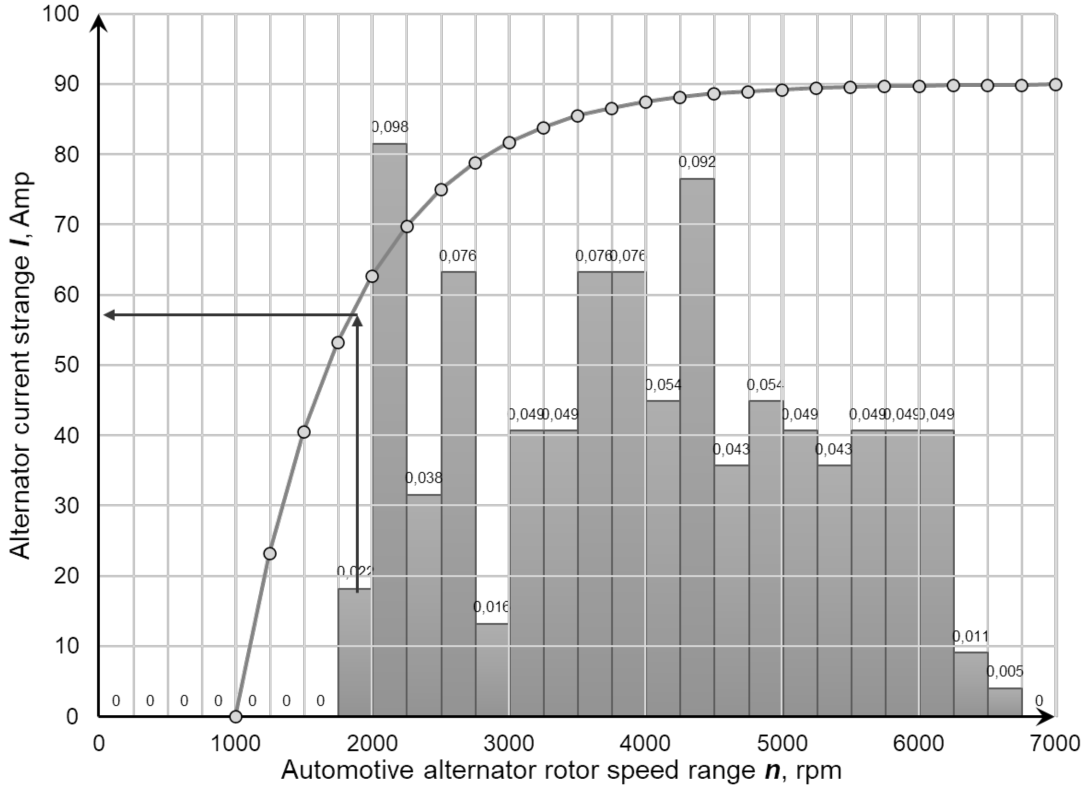


Fig. 2. Current and Speed Characteristics and Time Distribution of the Automobile Alternator Operation

$$q_a = \int_{n_0}^{n_{max}} I_a\,(n_a) \cdot t(n_a) dn_a \tag{1}$$

where $I_a(n_a)$ represents the current and speed characteristics of the alternator and $t(n_a)$ is the dependence of alternator operation time at a certain speed.

When determining the electric power consumption according to the standard current intensity of the consumers, the number and time of the relative operation can be considered as follows:

$$q_c = \sum_i^n I_{ci} \cdot k_{ti} \cdot t \cdot k_{ri} + \sum I_{ST} \cdot t_{crank} \cdot m \tag{2}$$

where I_{ci} is the nominal current of the i-th consumer, A; k_{ti} is the operation time factor of the i-th consumer; t is the operating time, hours; k_{ri} is the load factor (involvement degree) of the i-th consumer; I_{ST} is the starter current, A; t_{crank} is the time for one engine startup, h; and m is the number of engine startups.

The operation time factor and load factor are determined statistically and range from 5% to 100%. Calculation of the consumer current intensity by formula (2) yields increased values that are allowed when designing the automobile; however, the actual operation yields somewhat different results (Fig. 4) [5].

Then, the electric power balance efficiency is determined by the ratio:

$$q_a - q_c \geq 0 \tag{3}$$

Nonobservance of equation (3) results in progressive battery discharge (negative balance) [9-13].

During the automobile operation, the basic parameters are immediately changed to wide ranges; moreover, the electric power biases either in the positive or negative direction [14-16]. Thus, integration is required for its practical evaluation within the specified time period. In the calculation method, an 8-hour operation mode in the daytime and a 4-hour operation mode at night are accepted as such time periods. However, individual owners can use the automobile only within 0.5-1.0 hour per day; moreover, the operation time distribution will also be a random value.

Thus, the attempt to approximate the results of the calculation and statistical methods for electric power balance efficiency evaluation to the actual result is almost impossible, as a number of random factors (demand for electric power, driving speed, air temperature, technical condition of the units, etc.) influence the process of electric power generation, storage and consumption.

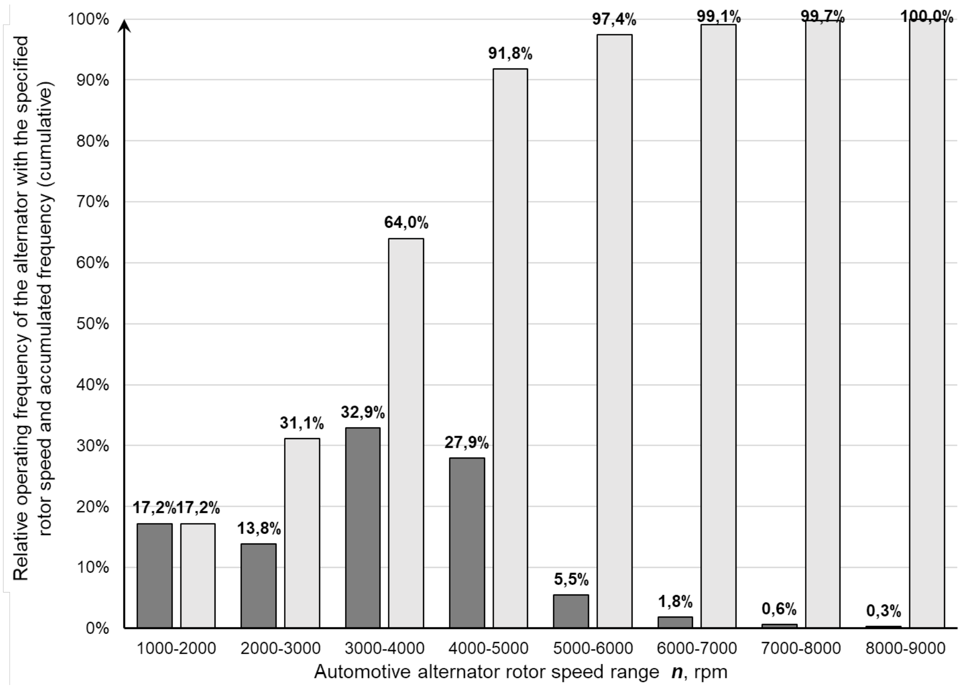


Fig. 3. Distribution of the Automobile Alternator Rotor Speed (the dark columns show the relative operation frequency and the light columns show the accumulated frequency (cumulative curve))

3. INSTRUMENTATION EVALUATION OF CHARGE BALANCE EFFICIENCY

On the Professional Probation 2.0 platform, AVTOVAZ company has presented a case, in which a new system of data collection (complex measurements) is developed for *evaluation of the automobile electric power balance* to determine starter characteristics (dry starting at -30°C) for measurement of voltages, currents and temperatures of the electrical equipment items and automobile parts under different climatic conditions. The instrument method assumes evaluation of electric power balance efficiency in the real-time mode and informing the driver and/or the automobile operating company.

The power supply system diagram for the latest automobile is shown in Fig. 5 [17]. Based on this diagram, for evaluation of electric power balance efficiency, the following diagnostic parameters can be used: onboard voltage, battery intensity (particularly, battery charge current), current intensity and rotor speed of an automobile alternator.

The practical use of the instrumental evaluation of the electric power balance efficiency assumes that the driver is informed about the *SOC* battery prior to combustion engine startup, operational evaluation of the charge state change is performed during automobile driving and the driver is warned about the critical decrease in charge (including the forecast of its change for the period of automobile parking in winter).

Of course, it is preferable to monitor the energy reserve in the battery, rather than continuously determining the ratio between the received and consumed electricity (3). However, the practical implementation of monitoring the state of charge of the battery on board the vehicle is complicated for a few reasons.

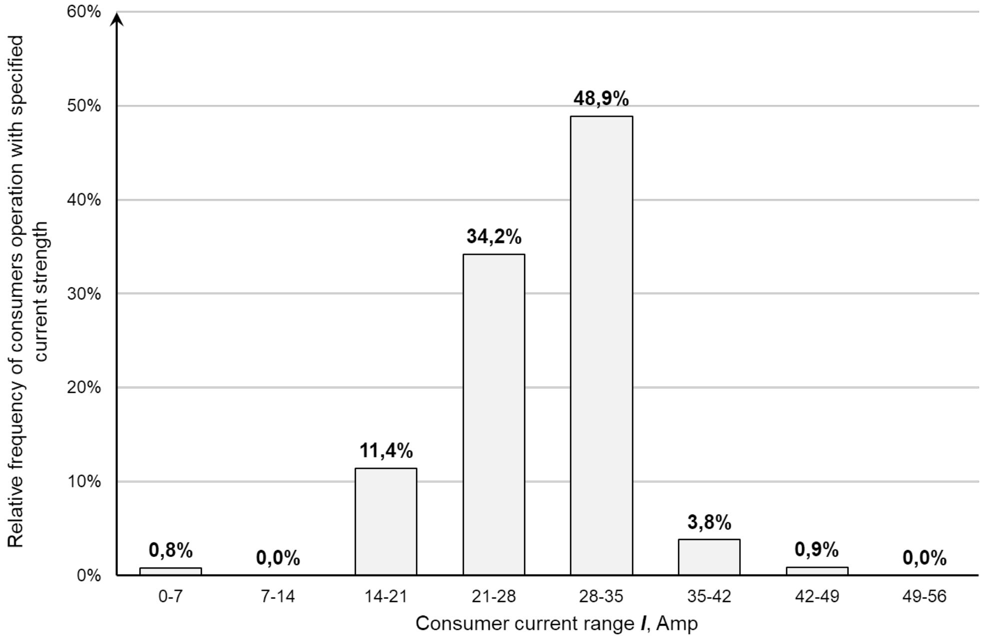


Fig. 4. Distribution of the current intensity of a passenger vehicle in urban traffic at night in winter

During the engine combustion operation, onboard voltage is always higher than battery voltage in the case of automobile alternator serviceability [18-20]. This complicates use of this parameter for operational evaluation of the battery charge state.

Widely used battery testers allow us to calculate the *SOC* (4) and the state-of-health (SOH) of the battery, which, during the test, should be de-energized (disconnected from power sources and consumers).

$$SOC = \frac{U_i - U_{min}}{U_{max} - U_{min}} \quad (4)$$

where U_i is the current value of voltage at battery terminals, volts; U_{max} is the maximum voltage value corresponding to a fully charged battery, volts; and U_{min} is the minimum allowable voltage, volts.

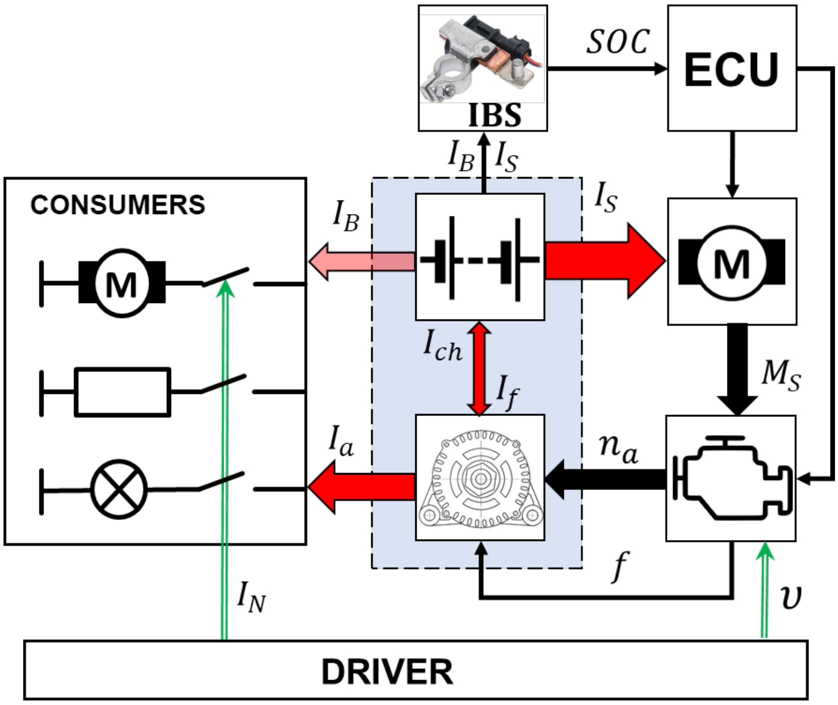
Even a short-term shutdown of the battery to assess the state of charge and operability can disable the electronic components of the on-board network due to pulsed overvoltage. This makes it difficult to use this principle of estimating the degree of battery charge on board a vehicle.

Technically, balance evaluation is efficient with an amperemeter measuring the battery current intensity. During automobile driving, the battery current intensity allows determining both the nature of flowing processes (battery charging or discharging) and quantitatively evaluating their efficiency (charge received from the automobile alternator). During the normal operation of the power supply system, the current intensity takes on a negative value during combustion engine startup and a small positive value during automobile driving [21-23].

The battery current during the start-up process can be used for the following:

– assessing the technical condition of the starter motor [24];
– assessing the technical condition of the internal combustion engine [20]; and
– diagnosing malfunctions of the battery itself [2, 20].

Implementation of the instrumentation evaluation for electric power balance efficiency requires installation of a battery current sensor. Automobiles equipped with the Start–Stop system include an electronic system for battery control, the basic component of which is such a sensor [25, 26]. The main purpose of this system is to evaluate the battery capability to start the combustion engine. Therefore, this system calculates the battery power margin based on the data of *SOC* and power consumption for starter power supply. However, this system does not inform the driver about a decrease in the battery charge state.



I_S – starter current; I_G – alternator current; I_f – alternator excitation winding current; I_B – battery current; I_C – battery charge current; I_N – consumer (load) current; M_S – starter rotation torque; n_G – automobile alternator rotor speed; f – frequency signal about combustion engine operation; and υ – automobile driving speed.

Fig. 5. Diagram of the power supply system of a modern passenger vehicle

The solution to this problem could be the development of an on-board system for assessing the operability of the power supply system, which consists of two components: an underhood unit located on the minus terminal of the battery and a cabin part equipped with a display and receiving information from the underhood unit through wireless communication. In addition to information about the state-of-charge, the driver will be provided information about the critical failures of the automotive alternator (Check generator) and the battery (Check battery).

Thus, the introduction of an on-board system for assessing the performance of the power supply system will reduce the likelihood of a sudden de-energization of the vehicle and reduce the associated social and economic damage.

4. CONCLUSIONS

Increase in consumer power with the simultaneous reduction in the time and the driving speed of personal automobiles results in systematic discharge of the batteries due to electric power balance inefficiency. The calculation methods for evaluation of the electric power balance are inefficient, as a number of random factors (demand for electric power, driving speed, air temperature, technical condition of the units, etc.) influence the process of electric power generation, storage and consumption. The instrumental method for evaluation of the electric power balance efficiency assumes that the driver is informed about the battery charge condition prior to combustion engine startup, operational evaluation of the charge state change is performed during automobile driving and the driver is warned about critical reduction of charge (including forecast of its change for the period of the automobile parking in winter).

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