Charging balance management system modeling and implementation in intelligent vehicle with combined power system

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Abstract. The article presents the results of mathematical modeling and implementation of algorithms for ensuring the charge balance of an automotive low-voltage battery as part of an intelligent vehicle control system with a hybrid power system. The aim of the research is to evaluate the effectiveness of the proposed complex of mathematical models in calculating the control parameters of the DCDC converter to achieve a positive charge balance of the low-voltage battery. The work evaluates the boundary conditions of the system and adapts the mathematical models and algorithms implemented in the program code of the controller as part of the current model of an intelligent vehicle with a combined power system. The following parameters are evaluated as criteria for the optimality of the proposed models: SOC - state of charge (%), battery charge (A*h), charge and discharge current of the battery (A), voltage on the battery during its charge, in the absence of a charging current and at rest (V). A full-scale experiment was carried out, experimental data and graphs were obtained. Optimal control coefficients for the processes of charge and discharge of the battery, current characteristics, the dynamics of their changes during operation, experimental time-current dependences during the operation of each component of the low-voltage power supply network were studied. The results of the work make it possible to make adjustments to the charge balance management model and contribute to improving the energy balance of the power grid, increasing the efficiency and service life of batteries, forming requirements for power systems and their subsequent implementation.

1. Introduction

The main objective of modern intelligent vehicles, which is to increase the efficiency of use of fuel and energy resources, is to achieve the greatest efficiency of electrical and electronic systems [1]. This became possible with the use of a combined power system, which contributes to the double conversion of energy: from electrical to mechanical and vice versa. At the same time, important tasks are efficient use of battery power, reducing self-discharge currents, stabilizing the supply voltage of the on-board network, maintaining the battery charge at a high level for restarting systems and a hybrid installation, optimal loading of control systems and increasing the resource of use of components [8].

A hybrid installation is a complex system and consists of many components, such as an electric machine that serves as a starter and generator, a high-voltage battery that accumulates charge for
subsequent engine start-up and power supply of electronic systems, an inverter energy converter for powering the electric drive at the time of starting and charging the high-voltage battery after starting the engine, DCDC converter, as well as a current sensor and a charge control system [3]. It is believed that the system works efficiently provided that the generated and stored energy is enough for all consumers and there are practically no self-discharge currents.

In hybrid systems, it is customary to distinguish two electrical networks: a high-voltage 300-400V and a low-voltage 12-24V. Due to the fact that the largest number of consumers in the vehicle that use electric energy are part of a low-voltage power supply with a nominal voltage of 12V, it is most important to first achieve the effectiveness of a low-voltage power supply of 12V, obtain a positive charge balance of the battery and provide conditions for the most optimal operating mode DCDC power converters, and timely prevent leakage of current from the battery when DCDC voltage converters open are obtained [5].

The aim of this work is to obtain quantitative characteristics and evaluate the effectiveness of the proposed methods for controlling the charge balance of a car battery in the mains with a nominal voltage of 12V, assess the impact of delays in the operation of the control system on the battery charge, determine the magnitude of the error in calculating the current settings of the converters, compare the control methods of DCDC converters.

To achieve this goal, you need to solve several problems:

1. Assess the reliability of the choice of charge balance control mode;
2. Evaluate the operation of the low-voltage battery diagnostic model;
3. Evaluate the operation of the model for monitoring the residual battery;
4. Evaluate the operation of the model disconnecting powerful consumers;
5. Evaluate the performance of the DCDC converters control model.

The results of mathematical modeling and full-scale experiment will allow us to draw conclusions about the effectiveness of the proposed mathematical models and methods for controlling the charge balance, to evaluate the accuracy and speed of reaction to deviations of the system from the state of a positive charge balance. Subsequently, the results of the work will contribute to the improvement of the proposed methods and form a deeper understanding of the processes of charge and discharge of the battery, affecting its charge balance.

2. A set of models for the positive charge balance of an automotive low-voltage battery
In order to evaluate the proposed method for controlling the charge balance of a car, it is necessary to simulate a set of charge balance models, which includes five mathematical models performed in the MATLAB Simulink environment (figure 1) [7]:

- manager of control modes - “Control Mode Manager” (CMM);
- low-voltage battery diagnostic model - “Diagnostics Model” (DM);
- model for monitoring the residual charge of the battery - “Residual Charge Control” (RCC);
- Consumer Shutdown Model (CSM);
- DCDC control model - “DCDC Control Model” (DCM).

It should be noted that each of the models performs a separate function, which is performed when the conditions determined by the charge balance control mode manager (CMM) are met. It is also worth considering that there are two states when the control model is working: when the control unit is in active mode in one of the operating states and when the unit is in sleep mode and wakes up in order to evaluate the charge balance of the low-voltage battery.
Figure 1. Structure of models for managing the charge balance.

The manager of control modes receives input about the vehicle operating mode – “VehicleMode”, which determines the status of the connected terminals and the power supply mode of the vehicle, and based on this information activates the corresponding control models for the following signals:

- “DM_Activate” activates the low-voltage battery diagnostic model;
- “RCC_Activate” activates the model for monitoring the residual charge of the battery in the presence of leakage currents;
- “CSM_Activate” activates a model for controlling the disconnection of powerful consumers to unload the power grid;
- “DCM_Activate” activates the DCDC drive control model.

The mode manager is a simple logical function and does not affect the speed and accuracy of calculation and control of the charge balance of the low-voltage battery.

3. Testing the diagnostic model
Let us consider in more detail the DM model, which is responsible for the diagnosis of a low-voltage battery and contributes to the choice of its charging mode. The input of the DM_Activate model receives signals from an electronic intelligent sensor of a low-voltage battery:

- “EBS_BattVolt” - voltage at the battery terminals;
- “EBS_GlobalError” - status of the global error of the battery sensor;
• "EBS_RespError" - error status of the battery sensor communication;
• "EBS_IBatt" - error status of battery current measurement;
• "EBS UBatt" - error status of battery voltage change;
• "EBS SoC" - battery charge;
• "EBS SoH" - battery life.

Based on the “EBS_BattVolt” signal, the diagnostic model detects and generates the programmed battery failure status, which indicates the following:
• low battery voltage (voltage at the battery terminals is lower than 10.5V for 10s) - “UndervoltageFlag”;
• overvoltage (voltage at the battery terminals is higher than 16V for 10s) - “OvervoltageFlag”;
• deep discharge of low-voltage battery (voltage at the battery terminals is lower than 9.5V for 60s) - “DeepDischargeFlag”;
• loss of sufficient contact between the terminals and the battery poles (caused, for example, by a broken cable, blown fuses, short circuit, oxidation of conductive contact surfaces, change in contact zone resistance) - “DisconnectedBattFlag”.

The signal “EBS SoC” contains the actual charge of the battery, which the battery sensor integrates over the entire period of its operation and, after checking for reliability, it is converted into the signal “SoC_Status”. Further, by comparing the current charge level with the set thresholds, the required battery mode is determined.

The following battery level statuses are highlighted in the model:
• Fully discharged battery: "EBS SoC" < Limit1;
• Fast battery charge: Limit2 > "EBS SoC" ≥ Limit1;
• Normal battery charge: Limit3 > "EBS SoC" ≥ Limit2;
• Fully charged battery: “EBS SoC” ≥ Limit3;
• Error - in case of a prolonged state, “EBS SoC” = 100% or “EBS SoC” = 0%.

The described limits in a practical experiment will have the following values that are as close as possible to the real ones:
• Limit1 = 45%;
• Limit2 = 65%;
• Limit3 = 98%.

The signal "EBS SoH" contains the value of the level of wear of the battery and determines the corresponding status:
• “AgedBattFlag” - battery aging status. It means that there is a deviation of the battery from the declared technical characteristics;
• “NotSufficientBattFlag” - battery unusability status. It means that the battery is unsuitable for further operation as part of the car, which is determined by the model of the battery sensor.

The presence of any of the signals from the intelligent battery sensor: “EBS_GlobalError”, “EBS_RespError”, “EBS_IBatt” or “EBS UBatt” - generates a battery sensor error - “BattSensorErrFlag”, which is stored in the controller memory and puts the model into emergency operation by default.

Experimental studies showing the reliability of the model are presented in figure 2 and figure 3.

Figure 2 illustrates the definition of signs that indicate the low-voltage battery exiting from the optimal operating mode, in which a deviation of the operating voltage or resource characteristics occurs. Diagrams of determining deviations from the normal mode for reduced (less than 11V) voltage, increased (more than 16V) voltage, critically low voltage (less than 9.5V), aging of the battery and its failure, which is determined by the amount of stored charge, are presented (in percent, %) ceteris paribus compared to a new battery. Figure 3 conventionally shows the boundaries of the battery charge modes, when changing between them, the control strategy of the DCDC converters changes to a new strategy, providing a charge for a low-voltage battery and power on-board network.
Figure 2. Critical battery conditions.
4. Testing the model for calculating leakage currents
The model, which provides control of leakage currents, has a number of features. This model works both in the active state of the unit, when the DCDC inverters are turned off to take into account the current (5-40A) that flows before all consumers are turned off and switched to low power mode (I < 5mA), and in the inactive state, when the control unit wakes up under various conditions related to the settings of the intelligent battery sensor. Conventionally, two modes of operation of the model can be designated as the following:
- Prepare to sleep mode - readiness mode for disconnecting consumers;
- Awake mode - conditional wakeup mode of a block.

Each of the modes, before the control unit is ready to turn off the power lines and go to sleep, requires sending the configuration to the smart battery sensor, which will indicate that it will subsequently be the source of awakening of the control unit.

The most common and common parameters are:
- Wake up time (c) - required for periodic monitoring of the battery charge in order to detect its discharge and turn off consumers that may be active in low power mode;
- Wake up by charge (A * h) - the level of charge at which the control unit spills and disconnects active consumers;
- Wake up by current (A) - current at which the control unit wakes up in order to detect the source of consumption and limit the discharge current;
- Wake up charge current (A) - the current at which the control unit wakes up in order to turn on special systems that must be in an active state while the battery is charging.
The DeepSleep flag is not a current sensor setting, it is a derivative function and serves to ensure that all consumers in other systems are instantly de-energized to prevent self-discharge of the battery.

The following signals are input signals to the residual charge control model:

- **EBS_GlobalError (Bool)** - a sign of an error during the operation of the battery sensor, which sets the model to default mode: data from the sensor is ignored, and predefined values substitute for them;
- **EBS_SOC (%)** - the actual battery charge, which is used to compare it with threshold values to which it can fall;
- **EBS_BattCurr (A)** - battery current, which monitors the presence of current leakage and determines the limits of acceptable consumption for each of the operating modes of the control unit when the DCDC converters are turned off;
- **EBS_WakeupByChrg (Bool), EBS_WakeUpByCrnt (Bool), EBS_WakeUpByTime (Bool)** - the signs by which the control unit identifies the reason for waking up and, further, activates the necessary script for the vehicle’s power supply manager.

Testing the model consists in checking how the numerical data used for the configuration of the current sensor is calculated, as well as checking the correctness of the formation of a sign that allows you to limit the consumption of all active devices and determine the correctness of the formation of error flags when the consumption current does not fall for the calculated time.

The experiment presents a graph (figure 4) for the latter case, in which flags are shown that determine the formation of an error indicator, provided that the consumer current does not drop to a predetermined threshold at a set time, which indicates a deviation in the operation of the systems.
Figure 4. Determination of an error in the operation of systems powered by the on-board voltage network of 12 V, when consumers are disconnected before entering Sleep mode by means of a time-current characteristic.

1 - boundaries of the current consumption, 2 - filtered value of the current consumption, 3 - a sign of an error in the operation of any of the systems when it is necessary to timely reduce the current consumption.

5. Testing the model for disconnecting powerful consumers

The model for disconnecting powerful consumers consists of a mathematical function and a logical one. The mathematical function of the battery charge, the level of wear and the current through the battery allows you to estimate the time during which the battery is charged up to 100% or discharged to 0%. The logical function evaluates the steepness of the graph, which allows us to draw conclusions about which group of consumers should be turned off to improve the situation with current consumption in the on-board network. Consumer groups depend on where the curve is located, leaving 0% (when charging) or 100% (when discharging) relative to the ordinate axis. If there is a charge, then the curve lying between the ordinate axis and the first graph allows you to judge that the battery is charging quickly and does not require disconnecting powerful consumers. If the charge time curve were between 3 and 4 curves, this would indicate that it is necessary to disconnect a certain group of consumers in order to shift the graph to the left to 1 or 2 curves. The discharge is determined in a similar way, but the opposite. Thus, the longer the discharge time, the less consumers need to be disconnected at this moment. But if it turns out that the graph shifts closer to the ordinate axis, closer to 8 or 7 curves, then an immediate reaction is required to prevent the battery from quickly discharging.

Figure 5. Graph of boundary conditions for which it is necessary to disconnect powerful consumers from the mains.

1 - consumer shutdown level “0”, positive current, estimated charging time up to 100% - 3600 sec;
2 - consumer shutdown level “1”, positive current, estimated charging time up to 100% - 7200 sec;
3 - consumer shutdown level “2”, positive current, estimated charging time up to 100% - 10800 sec;
4 - consumer shutdown level “3”, positive current, estimated charging time up to 100% - 32767 sec;  
5 - consumer shutdown level “0”, negative current, estimated discharge time up to 0% - 32767 sec;  
6 - consumer shutdown level “1”, negative current, estimated discharge time up to 0% - 10800 sec;  
7 - consumer shutdown level “2”, negative current, estimated discharge time up to 0% - 7200 sec;  
8 - consumer shutdown level “3”, negative current, estimated discharge time up to 0% - 3600 sec.  

The experiment showed that the proposed method allows one to predict in advance the remaining time for which the battery will be charged or discharged when the DCDC converters are turned off, which contributes to a premature decision to disconnect consumers. The time for which you can make a forecast about how the charge will change is about 10-100 ms, which is fast enough for the system under test. And it also allows you to divide all consumers into several groups, due to their power, criticality and safety. 

As a result of this, the application of the proposed model allows one to reduce the time of consumers' exposure to the battery and prevent battery discharge, where for each of the modes its own border is calculated and a group of consumers is selected depending on their consumption of electric energy (Ah).  

6. DCDC control model for positive charge balance of low-voltage battery  
The control model of the DCDC converters calculates the current and voltage limit settings for each of the two converters at the same time that the mode control model permits its operation.  

Limitations are calculated based on the following parameters:  
- "EBS_BattVolt" - battery voltage (V);  
- “EBS_SoC” - battery charge (%);  
- "EBS_TempBattVld" - the reliability of the readings from the battery sensor;  
- “EBS_BattTemp” - temperature value from the battery sensor (°C);  
- "DCDC1_I" - the actual current of the first DCDC converter (A);  
- "DCDC1_Error" - error in the readings of the first DCDC converter;  
- "DCDC2_I" - the actual current of the second DCDC converter (A);  
- “DCDC2_Error” - error in the readings of the second DCDC converter;  
- "Imax_perm" - the maximum total continuous current for the first and second converters, stated in the technical specifications (A).
As mentioned earlier, in this concept, one of the converters is loaded to the maximum value, and, after that, the second converter starts loading. This allows you to minimize the participation of one of the converters [2].

As practice has shown, this method contains several disadvantages due to the fact that only one of the converters is constantly loaded. The second one is at rest at this time, and its power keys are closed. To transfer the system to the active state, a certain time will be required, which will create a lag in the current of the converters from that required by the system, which will briefly load the battery with high currents, instead of charging it [4]. This is clearly shown in figure 7.

**Figure 6.** Model for calculating currents and voltages set point for two DCDC converters according to the previously proposed concept.
Figure 7. Realization of current request by converters according to the previously proposed concept of calculating the current setpoint by two DCDC converters.

1 - EEPMve_I_maxDcdc1 - requested current setpoint limitation from DCDC1 (A);
2 - EEPMve_I_maxDcdc2 - requested limitation of the current setpoint from DCDC2 (A);
3 - SWINve_I_LoVltgDcdc1 - the actual current of the DCDC1 converter (A);
4 - SWINve_I_LoVltgDcdc2 - the actual current of the DCDC2 converter (A);
5 - SWINve_I_IBS_LvBatCurr - current of the battery when it is charged from two DCDC converters (A).

Looking at the graph obtained, we can conclude that the control of the current setpoint of the converter in a system consisting of two DCDC converters, according to the principle of master and slave, is not effective, and the requests for the current settings are distributed unevenly. While one converter is operating in the range from 60 A to 185 A, the other converter remains unloaded. Connecting a powerful load generates a current of the order of 100 A for a short time interval of 1 s, which brings the converter operation mode to a limit of capabilities of 200 A. Moreover, the current implementation is delayed from the setting by approximately 1 s, which leads to a drop in the battery charge current to 8-10 A. Uneven loading of the converters affects the resource and the thermal mode of their operation, and also does not allow to ensure a stable state of the charging current, which, when the load is connected abruptly, leads to a delay in the operation of the converters, and, as a result, a drop in current on the battery and its short-term discharge [6]. This method can be used in control systems with one DCDC converter, but in systems with two converters it is not very effective.

In this regard, changes were made to the proposed control method and a new control concept for DCDC converters was developed for systems including more than one DCDC converter. It takes into account those factors that each of the converters must be partially loaded, which contributes to a faster response to changes in the load in the system.

The method consists in the fact that it calculates the current balance of the power supply, followed by the determination of the required current limit setting and voltage settings, which vary depending on which temperature and battery charge, how many consumers are on and what the actual load of DCDC converters is.
Calculation of the current is carried out based on what current is required from the DCDC converters to ensure battery charge, what maximum battery charge current is acceptable at current values of charge and temperature, and what current flows in or out of the battery itself. The method for generating the current setpoint for a system of two DCDC converters was presented by other formulas.

7. Calculation of the current setting for DCDC converters balanced by maximum power and load factor of each converter

As experimental studies have shown, loading one of the DCDC converters is most complete, and compensating for the lack of power due to the second or the remaining converters leads to the fact that the first converter is operating at the limit of its capabilities and prematurely produces its useful resource. This is manifested in the fact that with a large number of consumers, a large loss power is released, which goes to heating the converter itself, which leads to the aging of its components under the influence of high temperatures. At the time of heating of the components, the power supplied by the converter itself is limited. And the lack of power is compensated by the remaining converters. Due to the increased load on the first converter with this concept of power distribution, its resource and reliability are reduced. This requires the use of other methods for distributing the requested power between all converters in order to increase the reliability of the entire system.

In order to achieve the maximum efficiency of all converters, it is necessary to evenly distribute the requested power between all converters in proportion to the maximum power of each of them and the current load, which is determined by the thermal mode of operation of the converters. To do this, it is necessary to perform a series of the following calculations, which will allow you to evaluate the current load, the maximum power output taking into account the current load and calculate the current setting for each of the converters.

Initially, it is necessary to calculate the maximum current that a DCDC converter can provide, taking into account its current load and the temperature mode of operation, according to the formula:

\[ I_{\text{max1}} = \frac{I_{\text{DCDC1}} \cdot 100\%}{K_{\text{load.actual}}} \]
where $I_{DCDC1}$ is the current of the DCDC converter at the current time (A), $K_{load.actual}$ is the current load factor of the DCDC converter (%).

In this case, the current is limited by the minimum possible and maximum permissible value of each converter.

$$I_{min1} < I_{DCDC1.max} < I_{max1}$$
$$I_{min2} < I_{DCDC2.max} < I_{max2}$$

Next, you need to calculate the load limit of each converter, based on the total requested current for the two converters and the load factor of each of the converters.

$$I_{DCDC1 Req} = \frac{I_{max1} \cdot (I_{req} \cdot 100\%)}{I_{max1} + I_{max2}}$$
$$I_{DCDC2 Req} = \frac{I_{max2} \cdot (I_{req} \cdot 100\%)}{I_{max1} + I_{max2}}$$

where $I_{req}$ is the current, requested from the converters, taking into account the charging of the on-board battery with a nominal voltage of 12V.

The calculated converter load value is a balanced current request for each converter. This allows you to evenly load each of the converters and helps to improve the thermal mode of operation of each of the converters.

In order to evaluate the adequacy of the work of the proposed calculation, an experiment was performed in which, depending on the current load and battery current, the current of each converter was selected, and taking into account that the power of the converters was different, the optimal balance of the current setting for each converter was calculated by the formula.
Figure 9. Graph of the current settings of the DCDC converters for the current load factor, the value of the system current and charge current of the battery.

1 – SWINve_I_IBS_LvBatCurr - current of the battery when it is charged from DCDC (A);
2 - EEPMve_I_maxDcdc1 - requested current setpoint limitation from DCDC1 (A);
3 - EEPMve_I_maxDcdc2 - requested current setpoint limitation from DCDC2 (A);
4 - EEPMve_I_IDC_iReq1 - calculated limitation of the current setpoint from DCDC1;
5 - EEPMve_I_IDC_iReq2 - calculated limitation of the current setpoint from DCDC2;
6 - EEPMve_I_IDC_iReq - calculated value of the current setting from two converters;
7 - EEPMve_I_MaxCalcCurDc1 - calculated value of the maximum current setting that the DCDC1 converter is capable of working out based on the actual load;
8 - EEPMve_I_MaxCalcCurDc2 - calculated value of the maximum current setting that the DCDC2 converter is capable of working out based on the actual load.

Consider an example with real values. The maximum current that each DCDC converter can provide, taking into account its current load and temperature conditions:

\[ I_{\text{max}1} = \frac{I_{\text{DCDC1}} \cdot 100\%}{K_{\text{load.actual}}} = \frac{64,447 \cdot 100\%}{0,43} = 150\ A \]
\[ I_{\text{max}2} = \frac{I_{\text{DCDC2}} \cdot 100\%}{K_{\text{load.actual}}} = \frac{25,447 \cdot 100\%}{0,1272} = 200\ A \]

where \( I_{\text{DCDC1}} \) is current of the DCDC converter at the current time, \( K_{\text{load.actual}} \) is the current load factor of the DCDC converter.

Limitation of the minimum possible and maximum permissible current value of each converter:

\[ 150\ A > I_{\text{DCDC,max1}} > 0\ A \]
\[ 200\ A > I_{\text{DCDC,max2}} > 0\ A \]

The load limitation of each converter based on the total requested current for two converters and the load factor of the converters:

\[ I_{\text{DCDC1,req}} = \frac{I_{\text{max}1} \cdot (\frac{I_{\text{Req}} \cdot 100\%}{I_{\text{max}1} + I_{\text{max}2}})}{100\%} = \frac{150 \cdot (151,406 \cdot 100\%)}{350} = 64,89\ A \]

\[ \Delta I_{\text{DCDC1,req}} = 0,4525\ A \]

Rated current \( I_{\text{DCDC1,req}} \) = 64,89 A, experimental current \( I_{\text{DCDC1,req}} \) = 64,4375 A.

\[ I_{\text{DCDC2,req}} = \frac{I_{\text{max}2} \cdot (\frac{I_{\text{Req}} \cdot 100\%}{I_{\text{max}1} + I_{\text{max}2}})}{100\%} = \frac{200 \cdot (151,406 \cdot 100\%)}{350} = 86,52\ A \]

Rated current \( I_{\text{DCDC2,req}} \) = 86,52 A, experimental current \( I_{\text{DCDC2,req}} \) = 85,9688 A.

\[ \Delta I_{\text{DCDC2,req}} = 0,5512\ A \]

\( I_{\text{Req}} \) is the current requested from the converters, taking into account the charging of the on-board battery with a nominal voltage of 12V.

The graph shows that the current that is requested on the converters is distributed balanced in relation to the actually requested current and the maximum current that each converter can provide. The current on the battery has an almost linear characteristic, which is due to the fact that all load changes are compensated by the DCDC converters, which perform a damping function, and the battery is charged with current at this moment approximately equal to 8-10% of the nominal battery value of 100 A. The shape of the current curves of the DCDC converter repeats the shape of the curve that describes the current setting for each converter. Thus, the delay in the actual implementation of the current setpoint request tends to zero and is compensated by the battery current, and the uniform distribution of current between the converters minimizes the actual load. The graph shows that the
current of the converters is significantly lower than each of the restrictions, but the percentage of the realized current and the maximum are approximately equal for each converter. This suggests that the thermal mode of operation of each of the converters is optimal and allows long-term operation with connected loads. The deviation of the actual value of the converter current from the setting is not more than 1%, the relative constancy of the charge current indicates that the battery is charging optimally and damps extremely sharp surges due to the instantaneous connection of powerful loads.

The proposed change in the previously obtained model allows us to solve the problem of controlling the converters in optimal temperature conditions and to ensure the relative constancy of the low-voltage battery charge current, which increases the efficiency and reliability of the entire system.

8. Results and conclusions
As a result of the experimental and analytical work, we can come to the following conclusions:

1) The model for diagnosing the condition of the battery is an effective solution that contributes to the timely decision-making on the maintenance of the battery. It allows you to correctly select the charge mode of the battery, which allows you to maintain the battery in a charged state at a time when the dynamics of changes in the current consumption has significant gradients in the characteristics of consumption.

2) The leakage current monitoring model allows detecting and timely servicing those systems that consume electrical energy at a time when their current consumption should be reduced. Monitoring

![Graph of battery charge in balanced mode.](image-url)
leakage currents allows you to more reliably judge the charge and condition of the mains, which is especially true at low temperatures.

3) A method that allows disconnecting powerful consumers is effective and allows you to adjust the current consumption of powerful consumers in the range of 2-80A, which is achieved by reducing the time of their work or by completely disconnecting them from the on-board network of 12V.

4) The model of DCDC converters allows you to maintain battery charge at a given level, which positively affects its operational characteristics. The speed of the original method, where one converter is leading and loaded up to 100%, is small, and delays of up to 2 seconds appear, which, in turn, cause a short-term increase in load up to 100A, which affects the resource characteristics of the battery.

5) An improved balanced control method for DCDC converters is proposed to solve the problem of current delay, which has proved to be much more efficient. The maximum delay in the implementation of the setpoint does not exceed a value of 100 ms, and the temperature regime of each converter becomes optimal, which allows to improve the operational characteristics of the components.

The solution of the tasks was achieved through the implementation of mathematical functions integrated into a single model and implemented in the form of program code as part of the automotive electronic control unit for body electric equipment.

The presented generalized concept for the implementation of the mathematical model for controlling the charge balance of a car battery can be used on various vehicles: in traditional vehicles with a LIN driven generator, in hybrid vehicles, in electric vehicles and electric vehicles, and other vehicles.

It requires an assessment of the applicability of the technology in severe climatic conditions and an assessment of the boundary modes of application.

Testing the model as part of the control unit on the current vehicle model confirms that when it is used, a positive battery charge balance is achieved for standard electronic control systems.

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