In this study, an analytical model is represented for evaluation of remaining charge state of commercial automotive-grade lithium batteries. The model is elaborated for evaluation of battery remaining charge state under dynamic loads and various temperature conditions, which is typical for operation of batteries being parts of electric or hybrid electric vehicles. It is proved that use of the Peukert equation as a part of an analytical model leads to a restriction of field-of-use for those models as the Peukert equation is not applicable under small discharge rates. It has been also shown that in modern analytical models, the usually used temperature dependencies are not applicable at extremely low and extremely high temperatures of battery discharge. The reason is that they do not take into account neither the presence of a negative thermal critical point, under which the battery capacity output becomes equal to zero, nor a limitation of a capacity growth in conditions of a temperature increase. The represented analytical model solves such problems to a large extent and provides with a good prediction accuracy for battery remaining state of charge (relative error is not more than 4%).

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In the article\textsuperscript{13} for battery remaining capacity evaluation, the analytical model is proposed, which takes changes into account both of currentis and battery temperatures in the course of discharging.

\begin{equation}
C_t = C_m - \sum_{i=0}^{\infty} f(i, T_t) \frac{\Delta t}{I_{ref}},
\end{equation}

\begin{equation}
f(i, T_t) = f_1(i) f_2(T_t) = \gamma \left( \frac{i}{I_{ref}} \right)^{\alpha} \left( \frac{T_{ref}}{T_t} \right)^{\beta},
\end{equation}

where $C_m$ is an absolute capacity of a fully charged battery; $C_t$, $i$, $T_t$ are battery remaining capacity, current and temperature in an instant of time $t$; $I_{ref}$, $T_{ref}$, $t_{ref}$ are reference current, temperature and time for an investigated battery; $\Delta t$ is summation interval; $\alpha$, $\beta$, $\gamma$ are empirical constants.

In this work the following values were used:

\begin{equation}
I_{ref} = 1 \text{ A}, \quad T_{ref} = 298 \text{ K}, \quad t_{ref} = 1 \text{ s}, \quad \Delta t = 1 \text{ s}.
\end{equation}

The model was tested for commercial automotive-grade lithium batteries. The maximal relative error received under diverse discharge dynamical modes did not exceed 5%.

In this article let us analyze the model (Eq. 1) on the basis of other most well-known analytical models and in view of new experimental data. This work appears to be a continuation of works\textsuperscript{14-16} devoted to analytical modeling of accumulators’ various operational modes.

Analysis of Empirical Correlations

Providing that in terms of the model (Eq. 1), a discharge is going on under a constant current and temperature until minimum allowable voltage for this particular battery, the value of $C_t = 0$. Along with this, for the capacity released by the battery $C = it$ from (Eq. 1) we receive the equation

\begin{equation}
C = \frac{C_m \gamma}{\Delta t} \left( \frac{T}{T_{ref}} \right)^{\beta}.
\end{equation}

When $T = T_{ref}$ from (Eq. 3) we receive Peukert equation.\textsuperscript{17} So the analytical model (Eq. 1) rests on the Peukert equation. This fact was repeatedly noted in the article\textsuperscript{11} though was not expressed explicitly.

If to consider the function $f(i, T/t_{ref})$ in the model (Eq. 1) as a pseudo-effective current $I_{eff}(i, T)$,\textsuperscript{18,19} then in a general case from

\begin{equation}
I_{eff}(i, T) = \frac{I_{ref}}{\left( \frac{T_{ref}}{T} \right)^{\alpha}}.
\end{equation}
(Eq. 1) for the capacity released by the battery under a constant current of discharge, we receive the equation:

\[ C = \frac{C_m}{I_{eff}(i, T)/i} \]  

[4]

The Peukert Equation 3 is inapplicable at very low discharge currents as at \( i \to 0, C \to \infty \), which is devoid of physical sense. So the Peukert equation is not the best basis for a battery analytical model elaboration as it is not applicable throughout the entire interval of discharge currents changes. In connection with this, let us analyze also other most known empirical correlations. The analysis will allow highlighting the most common empirical correlations being correct within the entire interval of discharge currents changes and reflecting to the fullest extent the electrochemical processes taking place in the course of the batteries discharge.

In all probability, the following correlations may be attributed to the most frequently used and verified empiric correlations for the calculation of capacity released by a battery at different discharge currents:

- Peukert’s17
  
  \[ C = \frac{A}{i^{a-1}} \]  

[5]

- Liebenow’s20
  
  \[ C = \frac{A}{1 + B \cdot i} \]  

[6]

- generalized Peukert’s equations21
  
  \[ C = a_0 + \frac{a_1}{i} + \frac{a_2}{i^2} + \ldots \]  

[7]

\[ C = \frac{A}{i^n} \left( \frac{i^n}{B} \right) \]  

[8]

where \( C \) is released capacity; \( i \) is discharge current; \( A, B, a, a_0, a_1 \) and \( a_2 \) are empiric constants. The Equations 5–7 were originally derived for the lead-acid batteries but presently they are also applied for capacity determining of batteries and other electrochemical systems.13,22

Let us generalize Peukert equation in such a way that it would not lead to a contradiction at small discharge currents. Hence we obtain the correlation:14

\[ C = \frac{A}{1 + B \cdot i^n} \quad (n = a - 1) \]  

[9]

From Equation 9 at different values of the constants \( B, n \), it is possible to derive the Equations 5 and 6. The empiric Equation 8 is also one of generalizations of Peukert equation, as at high discharge currents, it is transformed into Peukert equation; whereas at low currents, it tends to a constant.

The Equations 5–9 are the most frequently used ones for determining of the capacity released by batteries, though there are many other formulas and methods of calculation of released capacity that are less frequently used.12,23–24

The process of batteries discharge is a phase transition, meanwhile phase transitions are often described by the probability integral.25

\[ C = \frac{A}{2} \cdot \text{erfc} \left( \frac{i - i_0}{\sigma} \right) \]  

[10]

That is why we shall also analyze this dependency.

In the articles,26,27 during studying the distribution of current in the depth of a porous electrode, it was demonstrated that one of the reasons for the decrease in the capacity released by a battery at an increase of discharge current is the decrease of depth of electrochemical process penetration into the depth of the porous electrode. Thus, the higher the discharge current, the steeper is the decline of the discharge current along the depth of a porous electrode, and the smaller portion of active substance of the electrode takes part in the process of discharge. It means that the discharge electrochemical process is concentrated more and more in electrode surface layers. The capacity released by the battery decreases according to the following law:

\[ C = \frac{C_m(1 - Ai^n)}{1 + B \cdot H(i)} \]  

[11]

\[ H(i) = \exp \left( \frac{-D}{T} \right) + \sqrt{\pi \sigma} \text{erfc} \left( \sqrt{\frac{D}{i}} \right) \]

where \( A, B, D \) and \( n \) are empiric constants, and \( C_m \) is the maximal battery capacity. It should be noted that in all the Equations 5–11, all the empiric constants are considered as being greater than zero.

According to the accumulated experimental data,21,28,29 it is fair to say that for batteries of any electrochemical system along with growth of discharge current, capacity released by a battery \( C(i) \) decreases and under extremely high discharge currents it is close to zero, i.e.:

\[ \lim_{i \to \infty} C(i) = 0 \]  

[12]

Also for batteries of almost all electrochemical systems, at small discharge currents, the capacity released by a battery is maximal and practically does not change with the discharge current growth up to some value \( I_k \). Namely gratifying to this feature, batteries are used in diverse systems and devices and along with it the discharge current range from zero to \( I_k \) is the working range of the battery discharge currents. The discharge current working range width depends on an electrochemical system of a battery, on its constructive features, on electrodes type, etc. So for batteries belonging to any electrochemical system, the following correlation must be fair:

\[ \lim_{i \to 0} \frac{dC(i)}{di} \approx 0 \]  

[13]

This is true with exception of only rather small quantity of batteries, which are unable to discharge at very low currents in many reasons.21,28,29 Though even for those batteries, the Equation 13 is fair, if not to take into consideration currents being smaller than some critical value \( I_{\omega} \ll I_k \). So any correlations \( C(i) \) being fair within all the discharge currents range must meet criteria (Eq. 12) and (Eq. 13). Based on these criteria, one may state that for batteries of any electrochemical systems, the function \( C(i) \) must take the following qualitative form (Fig. 1).

All the empirical Equations 5–11 meet the criterion (Eq. 12). Although the empirical Equations 5,7 do not meet the criterion (Eq. 13) and hence cannot be used within the entire discharge currents changes range. The Liebenow correlation is concave within the entire discharge currents changes range. Hence it cannot take the form shown in the Fig. 1. That is why it cannot be used within the entire discharge

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Qualitative dependency of batteries released capacity on a discharge current: \( C_m \) is maximum possible capacity of an accumulator; \( I_0 \) is discharge current, at which the battery releases capacity twice as small as the maximum capacity of the battery.
currents changes range. Application area for those equations will be pointed out below.

For the correlation (Eq. 8) the criterion (Eq. 13) will take the form:

$$\lim_{i \to 0} \frac{dC(i)}{di} = \lim_{i \to 0} \left(-nABi^{n-1} \frac{(1 + B i^2)}{D} \right) = \begin{cases} 0 & n \leq 0.5 \\ -\infty & 0 < n < 0.5 \\ -\frac{n}{B} & n = 0.5 \end{cases}$$

Hence, for $n \geq 0.5$ generalized Peukert Equation 8 can be used for evaluation of released capacity throughout the entire interval of the discharge currents.

For the correlation (Eq. 9) the criterion (Eq. 13) will take the form

$$\lim_{i \to 0} \frac{dC(i)}{di} = \lim_{i \to 0} \left(-nABi^{n-1} \frac{(1 + B i^2)}{D} \right) = \begin{cases} 0 & n > 1 \\ -\infty & 0 < n < 1 \\ -AB & n = 1 \end{cases}$$

Hence, for $n \geq 1$ the generalized Peukert Equation 9 can be used for evaluation of released capacity throughout the entire interval of the discharge currents.

For the correlation (Eq. 10) the criterion (Eq. 13) will take the form

$$\lim_{i \to 0} \frac{dC(i)}{di} = \frac{A}{\sqrt{n}} \exp \left( \frac{i_0^2}{\sigma^2} \right).$$

i.e. for a reasonably large value of the parameter $i_0^2/\sigma^2$, the correlation (Eq. 10) will properly meet the criterion (Eq. 13).

For the correlation (Eq. 11) the criterion (Eq. 13) will take the form

$$\lim_{i \to 0} \frac{dC(i)}{di} = \begin{cases} 0 & n > 1 \\ Q & n = 1 \\ \infty & n < 1 \end{cases}$$

Hence, for the dependency (Eq. 11) at $n > 1$, the criteria (Eq. 12) and (Eq. 13) are realized at any values of the empirical constants $A, B, D, Q$ being more than zero.

In order to get a reliable evaluation of the application area of the correlations (Eqs. 5–11), experimental data availability is needed for $C(i)$ at currents in the range from zero to current values, at which the capacity released by battery will be close to zero.

For commercial automotive-grade lithium batteries, which are generally of interest for us, such experimental data in the scientific literature are practically absent. Because, lithium-based batteries demonstrate higher ion transport between an electrode and an electrolyte as compared to other battery technologies, such as lead-acid ones, this rate increase allows lithium-based batteries to be discharged at relatively higher rates. So in order to receive the necessary experimental data, one needs to discharge the commercial automotive-grade lithium batteries in the currents range from zero to current values much greater than 12C (where C is nominal battery capacity). A work with such currents is extremely dangerous for accumulators themselves and sophisticated from a technical point of view.

Although, as it was shown earlier, batteries of any electrochemical systems show qualitatively the same dependency $C(i)$ (Fig. 1). That is why the evaluation of the application area of the correlations (Eqs. 5–11) can be done with use of equations of any electrochemical systems. Of course, the empirical parameters in the correlations (Eqs. 5–11) will depend on an electrochemical system of a battery.

In the work, while investigating discharge characteristics of Ni-Cd batteries (with different capacity and at different modes of the discharge (High, Medium, Long), it was proved by experimental way that Equations 8–11 describe a capacity released by batteries correctly at any possible discharge currents. Along with it, the equations data will take the following forms:

**Generalized Peukert Equation 8**

$$C(i) = C_m \left( \frac{A}{(i/I_0)^a} \right) \exp \left( \frac{(i/I_0)^b}{B} \right).$$

$A = 0.464, \quad B = 0.477, \quad n = 2.336; \quad [18]$ 

**Probability integral (Eq. 10)**

$$C(i) = \frac{A}{2} \exp \left( \frac{(i/I_0 - i_0)}{\sigma} \right),$$

$A \approx 1, \quad \sigma = 1, \quad i_0 = 0.715; \quad [19]$ 

**Porous electrode Equation 11**

$$C(i) = \frac{C_m (1 - A (i/I_0)^a)}{1 + B \cdot H(i/I_0)},$$

$A = 0.246, \quad B = 27.166, \quad D = 4.172, \quad n = 1.28,$

where

$$H(i) = \exp \left( \frac{-D}{i} \right) + \sqrt{\frac{\pi D}{i}} \exp \left( \frac{-D}{i} \right).$$

**Generalized Peukert Equation 9**

$$C(i) = \frac{C_m A}{1 + B \cdot (i/I_0)^a}, \quad A \approx 1, \quad B \approx 1, \quad n = 3.636, \quad [20]$$

where $C_m$ is maximum possible capacity of an accumulator (it was obtained at the discharge current value 0.1C). $I_0$ is discharge current, at which the battery releases capacity twice as small as the maximum capacity of the battery; $A, B, D, n, \sigma, i_0$ are empirical constants.

In the work there was proved by experiments that the above equations are applicable for the batteries of any capacity and at any discharge mode (at the same values of the empirical constants). The generalized Peukert Equation 21 is the most preferable among correlations (Eqs. 18–21) for practical purposes. On one hand, it is the simplest correlation in terms of the structure and the number of the parameters used. On the other hand, it gives the smallest relative error among all the correlations (Eqs. 18–21). Thus, this correlation is the best for description of the electrochemical processes. It worth to be observed that in the Equation 21 for batteries of any electrochemical systems, the condition $A = B = 1$ must be met inasmuch as $C(i_0) = C_m/2$ according to meaning of the parameter $I_0$. For batteries of any electrochemical systems, the Equation 21 takes the form

$$C(i) = \frac{C_m}{1 + (i/I_0)^a} \quad [22]$$

For batteries of other electrochemical systems, the empirical constants in the Equations 18–22, of course, will be different. Although, as it was shown earlier, batteries of any electrochemical systems show qualitatively the same dependency $C(i)$ (Fig. 1).

The correlations (Eqs. 5–7) cannot describe the experimental curve of Fig. 1 throughout the entire interval of discharge current changing. For Peukert Equation 5 and Equation 7, the capacity released by a battery tends to infinity at decreasing discharge current, which is devoid of physical sense. Besides, the experimental curves are convex when they are close to zero, but the correlations (Eqs. 5–7) give only concave curves (at positive values of all constants). In the work it was proved by experiments that the Peukert Equation 5 and the Equation 7 are true only starting from the point of inflection of the experimental curve $C(i)$ and up to infinity (Fig. 1). The Liebenow’s equation can be used only within a small range of discharge currents close to the curve inflection point $C(i)$.}

**Improved Analytical Model**

Based on above investigations, it may be concluded that the use of the Peukert Equation 3 as a basis for an analytical model of the battery discharge (Eq. 1) is a bad solution as the Peukert Equation 3 is not applicable throughout all the range of discharge current changing. For
this purpose the Equations 8–11 fit much better as they are applicable at any discharge currents. Let us use the Equation 9 (in the form (Eq. 22)) as a basis for elaboration of the battery discharge analytical model (Eq. 1). Then instead of the Equation 3 we’ll get the equation

\[ C = \frac{C_m}{\frac{\gamma}{\frac{T}{T_{ref}}} + \left(1 + \left(\frac{i}{I_0}\right)^n\right)^\gamma} \left(\frac{T}{T_{ref}}\right)^6, \]  

[23]

where \( C_m \) is maximum capacity released by a battery, \( I_0 \) is a current, at which a capacity released by an accumulator will be twice as small as the maximum capacity and \( \gamma \) is the empirical constant.

Then based on the Equations 4 for the function \( f(i, T) \) (Eq. 1) we’ll receive the expression

\[ f(i, T) = \gamma \left(1 + \left(\frac{i}{I_0}\right)^n\right)^\gamma \frac{T_{ref}}{T} \left(\frac{T}{T_{ref}}\right)^6. \]  

[24]

It will be observed that the dependency of a capacity released by a battery on discharge temperature in the Equations 3 and 23 is not optimal one.

From this dependency it follows that the capacity \( C \) reduces to zero at \( T = 0 \) (Eq. 3). Though from electrochemical point of view, it is understandable that the capacity \( C \) released by the battery reduces to zero much earlier. As the battery temperature decreases, the available capacity decreases due to increase of internal resistance of the battery and retardation of the chemical metabolism of the batteries effectively hindering the chemical reaction.

Nevertheless it is evident that the capacity cannot increase constantly under reasonable conditions. At reasonably large temperatures, active materials of electrodes start degrading and so does an electrolyte. Hence there must exist such maximum temperature limit \( T_F \) that upper it the capacity released by a battery stops increasing. This can be taken into account with use of the expression

\[ C = \frac{C_{m}}{\frac{\gamma}{\frac{T}{T_{ref}}} + \left(1 + \left(\frac{i}{I_0}\right)^n\right)^\gamma} \left(\frac{T - T_k}{T_{ref} - T_k}\right)^6. \]  

[25]

As the battery temperature increases, the internal resistance of the battery decreases and the chemical metabolism of the battery grows and in so doing effectively increases the capacity of the battery. Nevertheless it is evident that the capacity cannot increase constantly with temperature growth. At reasonably large temperatures, active materials of electrodes start degrading and so does an electrolyte. Hence there must exist such maximum temperature limit \( T_F \) that upper it the capacity released by a battery stops increasing. This can be taken into account with use of the expression

\[ C = \frac{C_{m}}{\left(\frac{T}{T_{ref}}\right)^6} \left(\frac{T - T_k}{T_{ref} - T_k}\right)^6. \]  

[26]

where \( C_{m} \) is maximum capacity released by a battery at temperature \( T_{ref} \).

From (Eq. 26) it follows that at \( T = T_{ref} \), the thermal multiplier is equal to 1; that is it has no influence on a battery capacity. At large temperature values, the thermal multiplier is approximately equal to \( K \). So the parameter \( K \) shows how many times maximum the capacity can be enlarged along with the battery temperature increase. Finally based on (Eq. 26) and (Eq. 4), the improved function \( f(i, T) \) for the analytical model of the accumulator discharge (Eq. 1) will take the form

\[ f(i, T) = \gamma \left(1 + \left(\frac{i}{I_0}\right)^n\right)^\gamma \frac{T_{ref}}{T} \left(\frac{T}{T_{ref}}\right)^6 \left(K - 1\right), \]  

[27]

Cm = CmK.

**Experimental**

In this section let us check and compare a quality of the analytical model (Eq. 1) and the same of the improved analytical model (Eq. 27).
The parameters of the models (1) and (Eq. 27) were found with use of the method of least squares and Levenberg–Marquardt’s optimization procedure. Upon that experimental data was used received for two batteries of each type (as in the work13) in order to receive parameters for a specific battery type instead of ones for a specific accumulator. The optimization results are represented in Tables II and III.

Let us compare the parameters received by us in the course of model (Eq. 1) application and shown in the Table II on one hand and the similar parameters corresponding to the same model received in model (Eq.1) application and shown in the Table II on one hand and shown in the Table II on the other hand. For example, if to use discharge currents 0.1C, 0.5C and 2.6C (i.e. 0.4C), then the values of the discharge currents range leads to changing of relevant parameters.

The parameters of the model (Eq. 1) are also very sensitive to the accumulators’ thermal parameters show a great statistical dispersion. That is why the model (Eq. 1) needs to be calibrated every time with use of specific accumulators.

The parameters of the model (Eq. 1) are also very sensitive to a discharge currents range used and to a temperature interval used. For example, if to use discharge currents 0.1C, 0.5C and 2.6C (i.e. to shift the discharge currents range on 0.4C), then the values of the parameters α and Cm will be changed more than by 15%. This is indicative of the fact that the temperature dependency used in the model (Eq. 1) describes accumulators’ true dependency in a wrong way between the accumulators capacity and discharge currents throughout the entire range of discharge currents changing. This is precisely why an approximation made by use of the Peukert Equation3, 5 on diverse parts of true dependency gives different parameters values. This problem was investigated in the work16 in detail. For the model (Eq. 27) the similar shift of the discharge currents range leads to changing of relevant parameters n and Cm less than by 2%, which stays in limits of a statistical error.

Similarly, if to shift the temperature interval used on five degrees lower, then the parameter β in the model (Eq. 1) will be changed by 15–50%. Especially considerably it changes in the case of the accumulators Kokam. This is indicative of the fact that the temperature dependency used in the model (Eq. 1) describes accumulators’ true dependency in a wrong way. As for the model (Eq. 27), the similar thermal shift leads to changing the parameter β in limits of statistical discrepancy.

In the end let us make accuracy evaluation of models (Eq. 1) and (Eq. 27) in accordance with the methodic outlined in the work.13 The investigation of the overall accuracy of the model included calculated dependency in a wrong way between the accumulators capacity and discharge currents throughout the entire range of discharge currents changing. This is precisely why an approximation made by use of the Peukert Equation 3, 5 on diverse parts of true dependency $C(i)$ gives different parameters values. This problem was investigated in the work16 in detail. For the model (Eq. 27) the similar shift of the discharge currents range leads to changing of relevant parameters $n$ and $Cm$ less than by 2%, which stays in limits of a statistical error.

Similarly, if to shift the temperature interval used on five degrees lower, then the parameter $\beta$ in the model (Eq. 1) will be changed by 15–50%. Especially considerably it changes in the case of the accumulators Kokam. This is indicative of the fact that the temperature dependency used in the model (Eq. 1) describes accumulators’ true dependency in a wrong way. As for the model (Eq. 27), the similar thermal shift leads to changing the parameter $\beta$ in limits of statistical discrepancy.

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deviations between the predicted state of charge (SOC) for the model and the actual experiment. The experimental SOC for the test was calculated as a percentage of the measured energy removed from the battery during the test.

For each discharge mode (for each battery) there were fulfilled five tests. While analyzing the tests results, maximum relative difference in percents was found between the actual SOC and the model’s prediction (y-axis). And also the average relative difference in percents was found between the actual SOC and the model’s prediction (x-axis). The tests results for the model (Eq. 1) are represented in the Fig. 2 and for the model (Eq. 27) in the Fig. 3. Representation of the plots in this manner illustrates results from all tests in an easy to digest format (as in the work13).

Generally the results obtained by us (Fig. 2) correspond to the results received in the work. A prediction error of batteries charge remaining state, which was found with use of the model (Eq. 1) on one hand and in our experiments on the other hand, does not exceed 5% except for one test. Though the tests number, for which the prediction error of the model (Eq. 1) is less than 3%, makes only 55%, in our experiments (Fig. 2), while in the work13 such tests number makes 80%. So based on our experimental results, it follows that the prediction accuracy of the model (Eq. 1) is somewhat lower than it was established in the work.13

From the Fig. 3 it is seen that the prediction error of the remaining state of charge of batteries with use of the model (Eq. 27) does not exceed 4%. Notably that the tests number, for which the prediction error of the model (Eq. 27) is less than 3%, makes 87.5% of tests. So the model (Eq. 27) allows making more accurate predictions than the model (Eq. 1).

Conclusions

Current methods for state of charge modeling use a combination of Coulomb counting (measuring the current at each time step and summing the values to achieve capacity) and voltage profiles to achieve a state of charge profile. However, this method makes accounting for losses difficult and has known accuracy issues.31 In addition, this method make quantifying battery temperature effects difficult or non-existent.

The analytical method of evaluation of remaining state of charge of batteries (model (Eq. 1)) proposed in the work13 solves these problems in many ways. Nevertheless it contains a number of shortages. Firstly, in order to take battery capacity dependency on discharge currents into account, the Peukert equation is used. But this equation is not applicable throughout the entire possible range of the discharge current changing.16 Secondly, the thermal dependency of accumulators’ capacity used in the model (Eq. 1) is not applicable both at very low and very high temperatures. For example, from the thermal dependency of the model (Eq. 1) it follows that the batteries capacity reduces to zero at T = 0, while it is evident that the battery capacity reduces to zero close to electrolyte point of congelation. Those shortages lead to the situation that the model (Eq. 1) is applicable only within some certain quite narrow intervals of discharge currents changing range as well as within quite narrow intervals of...
temperature changing in the course of batteries operation. A shift of these operational intervals leads to considerable changing of the model’s parameters (by 15–50%). Meanwhile, the operational intervals broadening leads to considerable reduction of the model (Eq. 1) accuracy. So the model (Eq. 1) has got just a local pattern of application. The proposed model (Eq. 27) eliminates those shortages to a large extent. The model (Eq. 27) parameters do not change throughout the entire possible range of discharge current changing and thermal interval used in accumulators operation. So the model (Eq. 27) has a more general, global way of application.

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