Influence of the digital data representation error in the linear control contour of a pulse voltage stabilizer

S N Titovskii\textsuperscript{1,2,3}, N V Titovskai\textsuperscript{a1,2} and T S Titovskaya\textsuperscript{2}

\textsuperscript{1}Krasnoyarsk State Agrarian University, 90, Mira ave., 660049 Krasnoyarsk, Russia
\textsuperscript{2}Siberian Federal University, 79 Svobodny ave., 660041 Krasnoyarsk, Russia
\textsuperscript{3}E-mail: sntitovsky@rambler.ru

Abstract. This article assesses the influence of the error in the data representation in the control contour, arising from their limited capacity, on the output voltage of a pulse voltage stabilizer. Also, in this article, an assessment is made for the linear control law. The experimental results of the study of the influence of bit depth analog-to-digital conversion on the stabilizer operation are presented.

1. Introduction
Nowadays, the sources of stabilized voltage are being used almost everywhere. When constructing such sources, developers prefer the pulse voltage stabilizers since, compared to linear stabilizers, they have indisputable and very significant advantages – this is a high efficiency, and, as a result, low heat generation, as well as low weight and small overall dimensions \[1,2\]. The applying of the digital control contour, instead of the analog one, in the pulse stabilizers eliminates the temperature and time drift of parameters, which is typical for analog circuits and is being a modern subject of study \[3-5\].

2. Analytical study
The main task of any voltage stabilizer is to maintain the output voltage (voltage on the load) at a certain level. In pulse voltage stabilizers, this problem is solved by the periodic charge of the inductor, which is subsequently discharged through the load \[6,7\]. In this case, it is believed that the output voltage is directly proportional to the charge accumulated in the inductor, which, in turn, is proportional to the duration of the charge (the duration of the pulse that opens the power switch of the stabilizer), and then

\[ U_{cur} = K T_pul, \] (1)

where \( U_{cur} \) – current value of the output voltage, \( T_{pul} \) – the duration of the pulse that opens the stabilizer power switch, \( K \) – some constant, which depends on the parameters of the stabilizer circuit.

The control device generates this pulse based on the deviation of the current value of the output voltage \( U_{cur} \) from the required (reference – \( U_{et} \)).

The simplest version of the dependence between \( T_{pul} \) and \( U_{cur} \) is the linear law \[6-9\]:

\[ T_{pul} = T_o + C \left( U_{et} - U_{cur} \right), \] (2)

where \( T_o \) and \( C \) – some constants.

In \[10\], it was shown that when organizing a digital stabilizer control contour, errors in the presentation of data appears in (2), arising from the quantization of the values from the formula:

\[ T_{pul} = T_o + C \left( U_{et} - U_{cur} + 2 \Delta_U \right) + 2 \Delta_T. \] (3)
where \( \Delta U - U_{\text{cur}} \) representation error, \( \Delta T - T_{\text{pul}} \) representation error.

It also shows that, under the condition,

\[
N_T \geq N_U,
\]

where \( N_T \) – the number of values \( T_{\text{pul}} \), \( N_U \) – the number of values \( U_{\text{cur}} \),

the error \( \Delta T \) becomes equal to zero, and (3) turns into

\[
T_{\text{pul}} = T_o + C (U_{\text{et}} - U_{\text{cur}} + 2 \Delta U).
\]

Thus, we can assume that the output voltage of the stabilizer is affected only by the error of \( U_{\text{cur}} \) representation, which, in turn, depends on the ratio of the measured voltage values and the number of values used in the \( U_{\text{cur}} \) digital representation, which are the parameters of the used analog-to-digital converter (ADC). These parameters are bit depth and scale (allowable range of input voltages).

The influence of \( \Delta U \) on the output voltage of the stabilizer can be estimated as follows: taking into account (1) and (3), the error of the output voltage can be estimated as

\[
\Delta_{\text{out}} = KC \Delta U,
\]

where \( \Delta_{\text{out}} \) – output voltage error.

The error \( \Delta U \) is a random variable with a distribution range, which is symmetrical to zero

\[
\Delta U = \pm \frac{S_{\text{max}} - S_{\text{min}}}{2^{n+1}},
\]

where \( S_{\text{max}} \) – ADC maximum measured voltage, \( S_{\text{min}} \) – ADC minimum measured voltage, \( n \) – ADC bit depth.

Then \( \Delta_{\text{out}} \) is also a random variable with a distribution range, which is symmetrical to zero and with the same probability distribution. For any symmetric distribution, which is relative to the average value of the range of probability distribution, the expected value is this average value. Therefore, taking into account (4) and (5), we can assume that for a sufficiently long period the average value of \( \Delta_{\text{out}} \) will be zero, and, on average, the necessary voltage will be at the output of the stabilizer. Due to the \( \Delta_{\text{out}} \) randomness the output voltage of the stabilizer will contain random pulsations with an amplitude depending on the ADC parameters.

3. Experimental results

Since there are certain assumptions in the analytical studies that also do not provide information about the required ADC capacity, experimental studies were conducted. In these studies, a prototype model described in [11,12] was used. It uses the ATxmega128A1 microcontroller with a 32 MHz clock frequency and the ADC MAX1308 with \( n = 12 \), a \( \pm 5 \) volts scale and an error of \( \pm 1 \) quantum.

The change of \( \Delta U \) was made by reducing the number of bits used to represent \( U_{\text{cur}} \).

The stabilizer was tested under conditions of a four-fold abrupt change in the load resistance every sixteen periods of the stabilizer operation (key control pulses). Oscillograms of the load current in this mode are shown in figure 1.

![Oscillograms of the load current in 12 and 11 bits](image-url)
Figure 1. Oscillograms of the load current in static mode.

The oscillograms in the lower part show the switching impulses of the stabilizer load, in the middle part – the load current.

Oscillograms (a) - (g) show that reducing the bit depth of the $U_{\text{cur}}$ representation from 12 to 6 has virtually no effect on the stabilizer (they are visually identical).
A noticeable deterioration in the quality of voltage stabilization occurs with a further increase in $\Delta U$: random oscillations appear, the amplitude of which increases with decreasing bit depth of the $U_{cur}$ representation. The duration of transient processes also increases (time to reach the nominal mode when the load changes).

In general, the oscillograms show that the stabilizer behavior corresponds to the statements made in a theoretical study.

Experimental studies also show that the use of high-precision ADCs in voltage stabilizers is optional.

4. Conclusion
The article provides an assessment of the influence of the digital data representation error in the linear control contour of a pulse voltage stabilizer on the quality of its output voltage. It has been experimentally shown that for digital data representation in the control contour, a small ADC bit depth is sufficient. This, in turn, provides an opportunity to reduce hardware costs for its implementation.

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