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HOUSEHOLD VOLTAGE STABILIZER CONTROL SYSTEM

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Abstract**—***This article is devoted to the definition of control features of discrete voltage stabilizers. The article analyzes the features of the operation of these stabilizers, defines the requirements for control devices of such systems. Obtained results were confirmed with a use of the virtual model based analysis of the system.*

Index Terms—Discrete voltage stabilizer; microcontroller system; virtual modeling.

I. INTRODUCTION

To date, the problem of power quality in distribution networks is becoming increasingly important. This is mainly due to the increase in the number of electricity consumers, to which existing networks are not designed [1]. On the other hand, the general deterioration of networks often leads to breaks and poor connections. These factors can lead to either a decrease or an increase in the phase voltages, wherein the deviations from the nominal values can be considerable. Such a change in the supply voltage affects the operation of household appliances and can lead to their failure.

To prevent such undesirable consequences, special devices are used – voltage stabilizers. Today, there is a significant number of different circuit solutions of voltage regulators [2], [3]. One of the simplest solutions are stabilizers with a transformer containing several series-connected windings with taps [4].

The objective of this paper is to study the characteristics of voltage stabilizers, and to define of requirements and approaches to the construction of control systems for such structures.

II. SOLUTION OF PROBLEM

One of the possible structures of this type stabilizers is shown in Fig. 1.

The principle of operation of this stabilizer is that thanks to the switching of the keys it is possible to ensure a consonant and counter connection of the nth number of the series-connected primary windings of the transformer. Consonant connection leads to an increase in the voltage on the secondary winding and, as a consequence, an increase in the output voltage of the stabilizer. A counter-switching leads to a decrease in the output voltage. To ensure that the output voltage is equal to the input voltage, the primary windings of the transformer must be shorted.

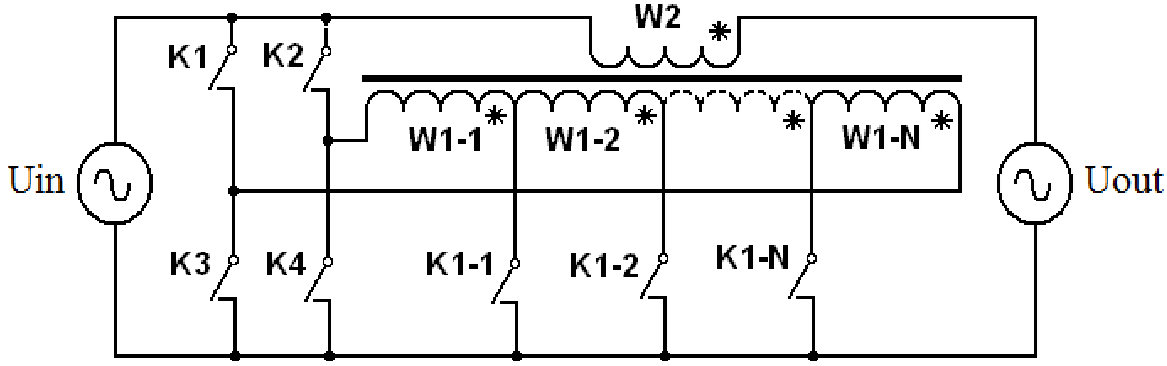


Fig. 1. Structure of the discrete voltage stabilizer

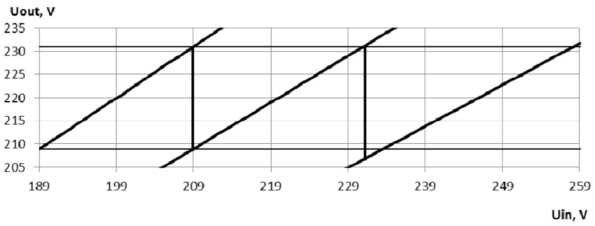
In general, the output voltage of the structure is determined in accordance with the expression:

$$U_{\text{out}} = U_{\text{in}} \pm U_{\text{in}} \frac{W2}{W1-1..N} = U_{\text{in}}\left(1 \pm \frac{W2}{W1-1..N}\right). \quad (1)$$

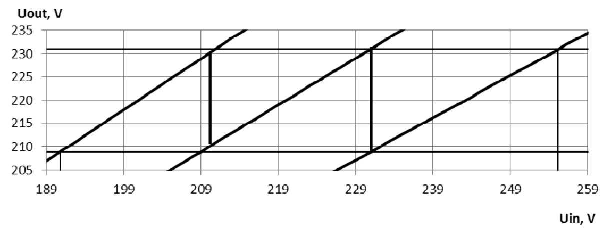
The number of connected windings and polarity determined by a pair of closed switches. So for the consonant connection, the keys K2 and K1-1, K1-2, ... K1-N, K3 must be closed, and for the counter connection K1 and K1-1, K1-2, ... K1-N, K4 must be closed. For short-connect the primary windings, the keys K1 and K2 or K3 and K4 must be closed.

The number of windings determines the total number of operating modes, which in turn determines the maximum input voltage range in which the output voltage will be in a predetermined range. So, if there is only one primary winding, then the number of possible modes of operation will be three: with a shorted primary winding, with consonant connection and with a counter connection. When stabilizing the output voltage at 220 V ± 5%, it is necessary to determine the ratio of the turns of the primary and secondary windings. Considering that the values of the input voltage, for which it is necessary to change the combination of the keys, are known – 220 V + 5% and 220 V – 5%, from the expression (1) it is possible to determine the transformation coefficients that ensure the output of the minimum and maximum values at the switching points. Accordingly $k_{tr1} = 9.5$ and $k_{tr2} = 10.5$.

The graphs of the calculated dependences of the output voltage on the input voltage are shown in Fig. 2.



a



b

Fig. 2. Dependences of the output voltage on the input voltage with different transformation coefficients: (a) – for $k_{tr1} = 9.5$; (b) – for $k_{tr2} = 10.5$)

As follows from the graphs shown, the first value of the transformation ratio does not allow stabilizing the output voltage in the indicated range at an input voltage of 231 V to 234 V. Therefore, for such a stabilizer, it is expedient to use the second value of the coefficient. At the same time, stabilization of the output voltage within the limits of five percent is possible at the values of the input voltage from 191 V (220 V – 13.2%) to 256 V (220 V + 16.3%).

With two primary windings, the number of operating modes will be five and, accordingly, it will improve the quality of output voltage stabilization. Using a similar approach to determining the transformation ratios provides stabilization of the output voltage within five percent for input voltage values from 173 V (220 V – 21.4%) to 280 V (220 V + 27.3%).

The implementation of the control of such a stabilizer involves the formation of unlocking and locking signals, the combination of which depends on the actual value of the input voltage. As switches, it is advisable to use triacs with a driver implementing opto-isolation. The circuit of one such switch is shown in Fig. 3.

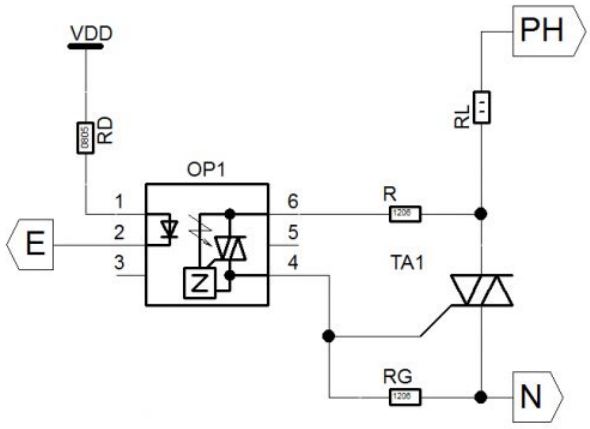


Fig. 3. Schematic realization of the power switch

Accordingly, the change in the signal must be carried out at times corresponding to the current transfer through zero, i.e. at an interval of half a period of the supply voltage. Thus, during one half cycle, the control device must perform the following operations: determination of the actual value of the voltage and the formation of the corresponding combination of control signals.

To build such a control device, it is advisable to use a microcontroller containing a sufficient number of pins for switch management and having a built-in ADC. To calculate the effective or root-mean-square value of the voltage, the formula can be used:

$$U = \sqrt{\frac{2}{T}\int_{0}^{T/2} u^2(t)dt}. \qquad (2)$$

In the case under consideration, in order to determine the value of such an integral, it is necessary to use numerical methods of approximate calculation. In this case, the half-period is divided into n equal intervals, on each of which the instantaneous value of the voltage is determined, and the calculation is carried out as follows:

$$U = \sqrt{\frac{2}{T}\sum_{i=1}^{n}\left(u_i^2 \frac{T}{2n}\right)} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(u_i^2\right)}. \qquad (3)$$

When using microcontrollers, the realization of these tasks involves the use of an interrupt mechanism. Accordingly, to measure instantaneous voltage values, an analog-to-digital converter can be used, which is started using a timer-counter that is set to periodically count the fixed time interval equal to $T/2n$. The timer starts running at the start of the every period of the input voltage. After each measurement, the measured value is squared and added to the variable containing the sum entering the expression (3). After the last measurement at half-cycle (n–1), the active voltage value is calculated, the timer is turned off and a combination of switches is selected, which is sent to the port outputs controlling the stabilizer operation. With the beginning of the next period, the timer is restarted and the procedure for calculating the effective value and selecting a new combination of switches is done anew. Separate requirement for microcontroller is that its performance should be sufficient to calculate the RMS voltage value and selecting a combination of switches during time interval of $T/2n$.

Using this approach, a program was developed for the Atmega16 microcontroller, and in the software environment for simulating the operation of electronic devices Proteus, a virtual stabilizer model was constructed containing two primary windings with transformation ratios of 4.775 and 5.725.

The virtual model of the discrete voltage regulator used for analysis of its operation is shown in Fig. 4.

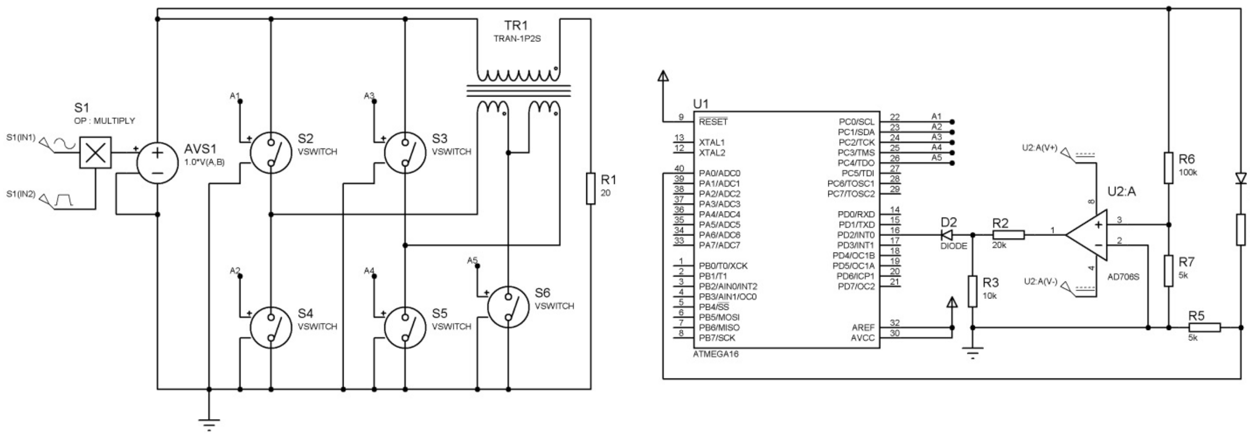


Fig. 4. Virtual model of discrete voltage stabilizer with control system

In this model, the network is modeled by a regulated voltage source AVS1, which generates a voltage equal to the product of the sinusoidal signal by a triangular waveform with a constant component. Thus, a sinusoid with time-varying amplitude is fed to the input of the stabilizer. As the power switches of the stabilizer, ideal controlled keys are used, the state of which is controlled by signals from the port C of the microcontroller: a high level closes the key, and a low one – opens. The comparator, which serves to send the signal to the INT0 input of the microcontroller at the beginning of the period, is implemented on elements: U2:A, R6, R7, R2, R3, D2. A voltage divider consisting of the resistors R4, R5 with a rectifying diode D1 serves to feed a signal to the input of the microcontroller ADC. Resistor R1 serves as a load of the stabilizer.

The results of the simulation of its operation are shown in Fig. 5.

This figure shows the graphs of the input and output voltage of the stabilizer. The input voltage varies within the range of ± 20% of 220 V, and the output voltage does not exceed ± 5% of this value. Variations of the combinations of closed and open stabilizer switches are performed when the input voltage equal to 191 V, 210 V, 231 V, 255 V. The maximum range of the input voltage variation at which the output voltage stabilization is carried out within five percent is from 173 V to 280 V.

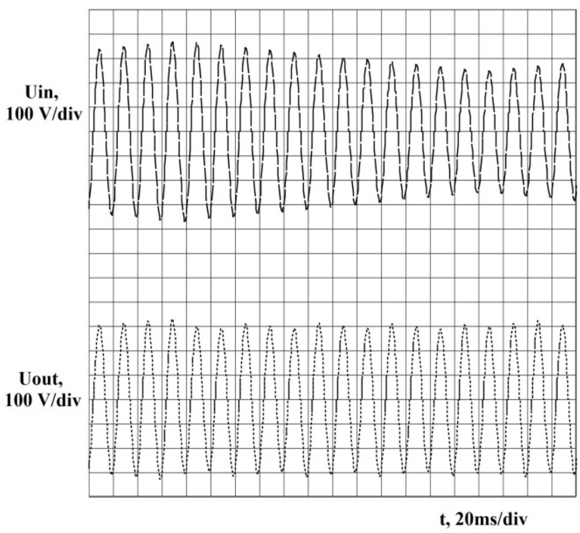


Fig. 5. Time diagrams of the input and output voltages

III. CONCLUSIONS

The paper describes the features of voltage stabilizers containing transformers with multiple primary windings. An approach to the control of such stabilizers using modern microcontrollers is proposed. A model was developed for analyzing the operation of a stabilizer with two primary windings and modeling of the operation of such a system was carried out, which confirmed the correctness of the proposed approach.

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О. В. Стаценко. Система керування побутовим стабілізатором напруги

Визначено особливості керування дискретними стабілізаторами напруги. Проаналізовано особливості роботи цих стабілізаторів, визначено вимоги до керуючих пристроїв такими системами. Отримані результати підтверджено шляхом аналізу роботи системи з використанням віртуальної моделі.

Ключові слова: дискретні стабілізатори напруги; мікроконтролерні системи; віртуальне моделювання.

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А. В. Стаценко. Система управления бытовым стабилизатором напряжения

Определены особенности управления дискретными стабилизаторами напряжения. Проанализированы особенности работы таких стабилизаторов, определены требования к управляющим устройствам такими системами. Полученные результаты подтверждены посредством анализа работы системы с использованием виртуальной модели.

Ключевые слова: дискретный стабилизатор напряжения; микроконтроллерные системы; виртуальное моделирование.

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