Simulation model of dynamic voltage stabilizer for autonomous power supply systems

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Abstract. The article presents a simulation model of a dynamic voltage stabilizer utilized in autonomous power supply systems. The proposed simulation model allows developers to test at the design stage the parameters of a real device for compliance with the requirements of the Interstate standards. Models of individual units of the dynamic voltage stabilizer and their key elements modes of operation are described. Graphs of control pulses and a pulse-width modulation are presented. The device implemented based on the proposed simulation model stabilizes the output voltage of an autonomous generator and corrects its shape bringing it closer to the ideal sine wave with the amplitude and frequency parameters of 220√2V and 50kHz, respectively.

1. Introduction
Where it is impossible to use any stationary power supply from an industrial electrical network, autonomous power sources, such as petrol and diesel generators, are utilized to ensure the uninterrupted operation of various electrical and electronic devices.

At the same time, the consumers’ demand for the uninterrupted operation implies stricter requirements for the electric power quality of the autonomous supply systems, which are regulated by the Interstate standards [1]. This necessitates improving the quality of the autonomous generators output parameters.

It should be noted that when an electromechanical device is used as a source of supply voltage, for example, a petrol generator, the effect on the power supply circuit of higher harmonics of the current and voltage generated by the load switching is more pronounced than in industrial and residential electrical networks [2]. This occurs mainly due to the design feature of such generator, including the presence of inductance and active resistance of the windings.

It should also be noted that the frequency, form and amplitude of the petrol generator output voltage, even running at idle without correction devices, differs from the required parameters.

Besides, load switching due to the increase in current consumption makes the deviation of the generator output voltage even greater than is required for the power supply.

2. Background
As evidenced from practice, devices for voltage regulation and adjustment, such as filter-regulators, filter-compensators, and active and hybrid filters utilized in industrial and residential stationary power supply systems are ineffective when they are used with an autonomous power supply (APS) system [3, 4].
As a rule, the main reason for the incompatibility is that the autonomous generators output voltage has a frequency different from 50 Hz and, therefore, at some points in time, the generator voltage will be in antiphase to the load. As a result, the current consumed by the load will exceed the capacitor charge current of the converter intermediate circuit, which leads to a rapid decrease in the voltage of the direct current (DC) link and to the inability of the device to perform regulatory and corrective functions due to the lack of energy.

The disadvantages of the existing technical solutions improving the quality of electricity supplied by APS systems, such as uninterruptible power supply and output voltage regulator of autonomous power sources, are [5]:

- high cost of the device used;
- high complexity of the required work algorithm implementation on the control system;
- a large number of executive mechanisms, respectively.

To eliminate the mentioned problems of power supply, we proposed to utilize a device for dynamic voltage stabilization [6].

3. Simulation of dynamic voltage stabilizer

To design a dynamic voltage stabilizer with specified technical parameters, it is necessary to develop its simulation model first [7, 8].

Figure 1 presents a simulation model of this device created in the MATLAB Simulink environment.

![Figure 1](image_url)

**Figure 1.** A simulation model of a dynamic output voltage stabilizer for autonomous generators.

Let us consider the components of the presented simulation model.

Figure 2 shows a model of the regulator unit of the dynamic voltage stabilizer.
The purpose of this unit is to stabilize the input signal of the regulator in frequency, so that its output voltage has a frequency of 50 Hz without requirements for its shape and amplitude.

The control pulses of the regulator key elements are presented in Figure 3.

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**Figure 2.** A model of the regulator unit.

**Figure 3.** Control pulses of the key elements and the reference pulse-width modulation (PWM) signal of the regulator unit.
The transistor control pulses are created by comparing triangular pulses with an amplitude of 1V and a frequency of 1kHz with a reference sinusoidal signal with an amplitude of 0.5V and a frequency of 50Hz. If the reference signal is greater than the sequence of triangular pulses, the unlocking pulse is fed to the gate of the transistor VT1, otherwise – to VT2.

As a result, the unit output voltage has a fixed frequency of 50kHz regardless of the frequency of the input signal.

A model of the compensator unit of a dynamic voltage stabilizer is shown in Figure 4.

![Compensator Unit Diagram](image)

**Figure 4.** A model of the compensator unit.

This unit is designed to correct the amplitude and shape of the compensator input signal so that its output voltage, i.e. the voltage applied to the load, most closely approximates a sinusoidal one with an amplitude of 220√2V and a frequency of 50 kHz, respectively.

In the operation of the unit key elements, the following modes of operation can be distinguished:

- overvoltage mode;
- undervoltage mode;
- nominal voltage mode.

The control pulses of the compensator unit key elements are presented in Figure 5.
Figure 5. Control pulses of the key elements and the reference PWM-signals of the compensator unit.

The bottom waveform is:

- signal 1 – the reference signal described as follows:
  \[
  \frac{(U_{in} - U_{\text{sin}})}{U_C}, \text{ where}
  \]
  - \(U_{in}\)- unit input;
  - \(U_{\text{sin}}\)- an ideal sine wave with an amplitude of 220√2V and a frequency of 50Hz;
  - \(U_C\)- DC link capacitor voltage;

- signal 2 - the reverse reference signal defined as:
  \[
  -\frac{(U_{in} - U_{\text{sin}})}{U_C};
  \]

- signal 3 - a sequence of triangular pulses with an amplitude of 1V and a frequency of 15kHz.

The control pulses of the transistors are created by comparison with triangular pulses. Thus, for VT1, VT2 – the direct reference signal, and for VT3, VT4 – the reverse reference signal, respectively.

If the reference signal is larger than a sequence of triangular pulses, the unlocking pulse is fed to VT1, otherwise – to VT2.

If the reverse reference signal is larger than a sequence of triangular pulses, the unlocking pulse is fed to VT3, otherwise – to VT4.

In the overvoltage mode, the reference signal has a negative value \((U_{in} < U_{\text{sin}})\) and the reverse reference signal has a positive value, the transistors VT2, VT3 are open and, as a result, the intermediate circuit capacitor begins to discharge through the primary winding of the booster transformer resulting in the electromotive force (EMF) induction in the secondary winding, which compensates the difference \(U_{in} - U_{\text{sin}}\).

Thus, mathematically, the operation of the compensator can be described by the equation:
\[
U_{out} = U_{in} + U_{\text{comp}}, \text{ where}
\]
$U_{\text{out}}, U_{\text{com}}$ - the voltage after the capacitor and the correction voltage of the compensator, respectively.

In the undervoltage mode, the reference signal has a positive value ($U_{\text{in}} > U_{\text{sin}}$), and the reverse signal has a negative value, the transistors VT1, VT4 are open, and as a result, the intermediate circuit capacitor begins to discharge through the primary winding of the booster transformer, which leads to the EMF induction in the secondary winding compensating the difference $U_{\text{in}} - U_{\text{sin}}$.

In this case, the operation of the compensator is described by following:

$$U_{\text{out}} = U_{\text{in}} - U_{\text{com}}.$$  

Thus, in the over- and undervoltage modes, the resulting value of the voltage applied to the load after the compensator unit, its shape and frequency, is almost identical to the ideal sine wave.

In the nominal voltage mode, the direct and reverse reference signals equal 0. If the sequence of triangular pulses has a positive value, the unlocking pulse is fed to the gates of the transistors VT2, VT4, and if its value is negative, then it is fed to VT1, VT3. In both cases, the primary winding is connected to the same terminal of the capacitor plate, as a result of which there is no voltage on the winding, no current arises, and therefore, no EMF occurs in the secondary winding.

Thus, the constancy of the nominal input voltage of the dynamic stabilizer is ensured.

4. Conclusion

The article describes a simulation model of a dynamic voltage stabilizer for APS systems.

As the analysis of simulation results showed, due to the presence of two converters with separated functions in the structure of the proposed device, the output voltage of an autonomous generator is stabilized in frequency before it is adjusted in shape and amplitude using a separate regulator unit.

This allows us to solve the problem of fast discharge of the intermediate circuit in the antiphase moment of load voltage and generator voltage.

Besides, the device implemented on the basis of the presented simulation model provides the output voltage form that most closely approximates the ideal sine wave with the amplitude and frequency parameters of 220√2V and 50kHz, respectively.

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