THEORY, OPERATING PRINCIPLE AND INVESTIGATION OF A MAGNETIC-AMPLIFIER-BASED STABILIZER IN FERRORESONANCE CIRCUIT CONTROL

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Abstract. *The article presents studies concerning the structure, operating principle, mathematical model, and main characteristics of a stabilized device based on a magnetic amplifier in ferroresonance circuit control. The ferroresonance current stabilizer (FCS) is used as a sensing element of the control circuit, while the magnetic amplifier performs the function of the actuating element. As a result of the study, it is shown that such an integrated system possesses high sensitivity, a large amplification coefficient, stable operation, and small mass-and-size indicators.*

Keywords: *ferroresonance, magnetic amplifier, current stabilizer, voltage stabilizer, control circuit, nonlinear element, magnetic permeability.*

Introduction

In present-day modern electric power engineering, automation, and radio-electronics systems, maintaining the parameters of electrical energy—especially current and voltage—in a stable state is considered one of the important technical problems. A decline in the quality of electrical energy, fluctuations of the grid voltage, abrupt changes of the load, and external electromagnetic influences have a negative effect on the normal operation of industrial devices. In particular, the stability of current and voltage is an important requirement for high-precision devices used in technological processes, control systems, automated lines, radio-electronic apparatus, and measuring instruments.

Although traditional electromechanical or semiconductor stabilizers possess certain advantages, when operating at high powers they are characterized by a complex construction, large mass-and-size indicators, high energy losses, and a high cost. In addition, the sensitivity of some stabilizers to load changes is low, and in systems requiring rapid control their efficiency is not at a sufficient level. For this reason, the development of stabilization systems that have high sensitivity, a simple construction, and that are reliable and energy-efficient remains a relevant scientific and practical problem.

In recent years, stabilizers based on the ferroresonance phenomenon have aroused great interest in the field of electrical engineering. The ferroresonance phenomenon is a complex electromagnetic process that arises as a result of the interaction of nonlinear inductive elements and capacitive elements, and it may cause abrupt changes of voltage and current in electric circuits. At the same time, through the purposeful use of the ferroresonance phenomenon, there is the possibility of creating stabilization devices with high sensitivity. Ferroresonance current stabilizers make it possible to control high-power output parameters by means of a small control signal, and this is considered one of their main advantages.

Magnetic amplifiers, in turn, are devices based on the principle of electromagnetic control; they make it possible to control large currents by means of a small control current. As the main advantages of magnetic amplifiers one can point to high reliability, the absence of mechanically moving parts, a long service life, high electromagnetic stability, and the ability to control large powers. In particular, the use of magnetic amplifiers in industrial electrical engineering systems ensures stable operation with respect to load changes.

As a result of integrating a ferroresonance current stabilizer and a magnetic amplifier into a single system, it is possible to create a stabilization system that has high sensitivity, operates rapidly, and possesses high energy efficiency. Here the ferroresonance circuit works as a sensitive control element, while the magnetic amplifier performs the function of the actuating element. Such a combined system adapts quickly to load changes, keeps the output parameters stable, and increases the efficiency of electromagnetic control.

In this research work, the theoretical foundations, operating principle, mathematical model, and main characteristics of a magnetic-amplifier-based stabilizer in ferroresonance circuit control are studied. During the research, the influence of the ferroresonance phenomenon on the stabilization process, the magnetizing characteristic of the magnetic core, the influence of nonlinear parameters on the operating mode of the system, and the electromagnetic processes in the control circuit are analyzed. The amplification coefficient, sensitivity, output-current stability, and energy efficiency of the stabilizer are also determined.

The research results show that a stabilizer built on the basis of ferroresonance and a magnetic amplifier possesses, in comparison with traditional stabilizers, high sensitivity, a large amplification coefficient, small mass-and-size indicators, and reliable operating characteristics. This device can be effectively used in electric power systems, automation devices, radio-electronics devices, power-supply systems, and technological control systems.

From a theoretical point of view, a system of nonlinear differential equations is used in analyzing ferroresonance processes. Owing to the magnetizing characteristic of the magnetic core, the mathematical model of the system has a complex nonlinear form. In analyzing the electromagnetic processes of the stabilizer, calculation methods based on the harmonic-balance method, amplitude-phase characteristics, and magnetic-flux equations are applied. Such an approach makes it possible to determine the stability of the device in its various operating modes.

Therefore, the investigation of magnetic-amplifier-based stabilizers in ferroresonance circuit control is one of the relevant directions of the science of electrical engineering, and it acquires important scientific and practical significance in creating modern stabilization systems with high energy efficiency.

Main Part

The stabilizer under investigation consists of two main functional parts that are electromagnetically coupled to each other, namely a ferroresonance current stabilizer (FCS) and a magnetic amplifier (MA). The main purpose of this system is to keep the current or voltage in the load circuit at a stable value regardless of external influences. The general structure of the system is based on the principle of generating a sensitive control signal on the basis of the ferroresonance phenomenon and of controlling large powers by means of the magnetic amplifier.

Figure 1 presents the schematic diagram of a magnetic-amplifier-based stabilizer in ferroresonance circuit control. The diagram contains the capacitive elements C1 and C2 forming the ferroresonance loop, as well as the inductive elements L1 and L2, which give rise to nonlinear

electromagnetic oscillations. This loop works as the sensitive element of the system and makes it possible to detect small changes in the input voltage.

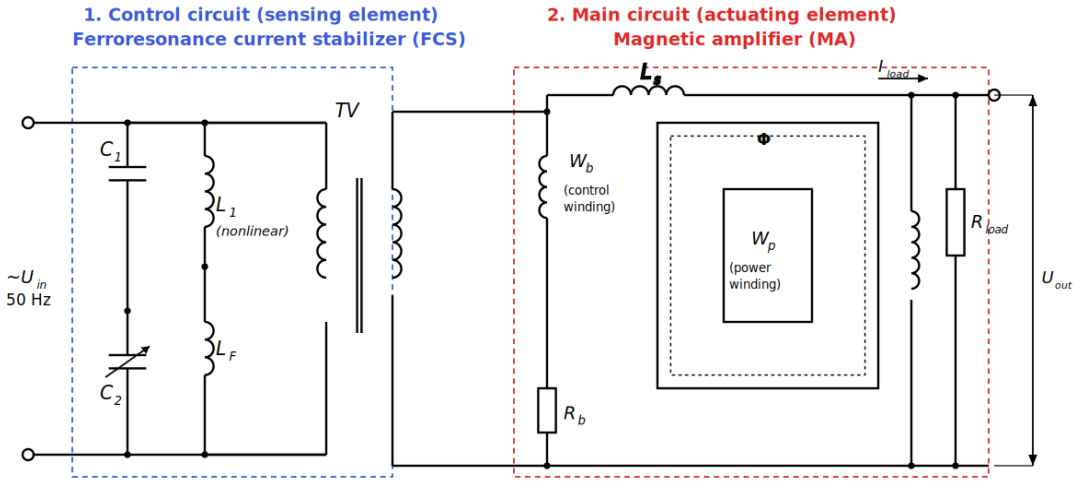


Figure 1. Schematic diagram of a magnetic-amplifier-based stabilizer in ferroresonance circuit control.

The TV transformer connected to the ferroresonance loop transmits the control signal to the control winding of the magnetic amplifier. The magnetic amplifier, in turn, controls the high-power load circuit as the actuating element. The main constituent parts of the magnetic amplifier are the magnetic core, the control winding (Wb), and the power winding (Wp). The current passing through the control winding changes the degree of magnetization of the magnetic core, as a result of which the magnetic permeability μ also changes.

The change in magnetic permeability affects the inductive reactance in the power winding. This in turn leads to the control of the current and voltage in the load circuit. If the input voltage increases or decreases, the ferroresonance loop responds sensitively to this change and transmits a corresponding signal to the control winding of the magnetic amplifier. As a result, the degree of saturation of the magnetic core changes, and the parameters in the load are kept in a stable state.

The main idea of this system is that, by means of a low-power ferroresonance control signal, it becomes possible to control high-power output parameters. Such an approach increases the sensitivity of the system, reduces energy losses, and decreases the mass-and-size indicators of the device.

In addition, the joint operation of the ferroresonance loop and the magnetic amplifier increases the electromagnetic stability of the system. The system acquires high resistance with respect to load changes, fluctuations of the input voltage, and external electromagnetic influences. For this reason, such stabilizers can be widely used in industrial automation, power-supply systems, radio-electronics devices, and continuous technological processes.

2. Theoretical Foundations

The ferroresonance phenomenon is considered one of the complex nonlinear electromagnetic processes encountered in electrical engineering systems. This phenomenon arises as a result of resonance between nonlinear inductive elements and capacitive elements. In the system under investigation, the ferroresonance phenomenon occurs between the inductive element L1 and the capacitances C1 and C2.

During the ferroresonance process, owing to the saturation of the magnetic core, the value of the inductance has a variable character. As a result, in contrast to the ordinary resonance state,

the system operates in a nonlinear mode. At certain values of the loop parameters, self-excited stable electromagnetic oscillations are produced. The amplitude and frequency of these oscillations are determined by the system parameters.

The electromagnetic processes in the ferroresonance loop are expressed by the following differential equation:

$$L_1(i)\frac{di}{dt} + R_1 i + \frac{1}{C_1}\int i\,dt + \frac{1}{C_2}\int i\,dt = u_{in}(t)$$

where $L_1(i)$ is the nonlinear inductance.

The main relationships for the magnetic amplifier:

$$\Phi = F(i_b)W_b, \qquad L_p = \frac{N_v^2}{R(\Phi)}$$

where $R(\Phi)$ is the magnetic reluctance.

Load current:

$$I_{load} = \frac{U_{out}}{R_{load} + j\omega L}$$

In the steady state of the system, U_{out} or I_{load} remains almost stable under the influence of changes.

The operation of the magnetic amplifier, in turn, is based on the magnetizing characteristic of the magnetic core. The current passing through the control winding produces a magnetic flux and changes the magnetic permeability. As a result of the saturation of the magnetic core, the value of the inductance decreases and the current in the power winding changes.

The relationship between the magnetic flux and the magnetomotive force is determined by the following expression:

$$\Phi = \mu HS$$

where:

Φ — magnetic flux;
μ — magnetic permeability;
H — magnetic field strength;
S — cross-sectional area of the magnetic core.

The current in the power winding (W_p) of the magnetic amplifier depends on the change of the magnetic flux (Φ). When the control current changes, the magnetic permeability μ changes, and as a result the current or voltage in the load is stabilized.

The amplification coefficient of the magnetic amplifier in the ideal case, with respect to voltage, is determined as follows:

$$K_n = \frac{U_{out}}{U_b}$$

and with respect to power:

$$K_p = \frac{P_{out}}{P_b}$$

Practical experiments show that for a controlled choke of 100 W power at a frequency $f = 50\,Hz$ the power amplification coefficient lies in the range:

$K_p = 50 \div 200$

As the power increases, the efficiency of the magnetic amplifier also increases.

As a result of the mutual integration of the ferroresonance loop and the magnetic amplifier, the system acquires high sensitivity, a large amplification coefficient, and high stability. At the same time, owing to the nonlinearity of the electromagnetic processes, higher harmonics, subharmonic oscillations, and magnetic-saturation phenomena may also be observed in the system.

3. Operating Principle

The operating principle of the system is based on forming a control signal by means of the ferroresonance loop and controlling the load parameters through the magnetic amplifier.

First, the input voltage is transmitted to the ferroresonance loop. The capacitances C1, C2 and the inductive elements L1, L2 within the loop are in mutual electromagnetic coupling and provide a nonlinear response to changes in the input voltage. Under certain resonance conditions, electromagnetic oscillations with a stable amplitude are produced in the loop.

The control signal produced is transmitted through the TV transformer to the control winding of the magnetic amplifier. The transformer performs the function of galvanically isolating the control signal and matching it to the required amplitude.

When current passes through the control winding of the magnetic amplifier, a magnetic field is produced in the magnetic core. This magnetic field changes the degree of saturation of the magnetic core. As a result, the magnetic permeability μ changes, and the inductive reactance of the power winding is controlled.

If the load current increases or the input voltage changes, the ferroresonance loop immediately forms a new control signal. This signal, through the magnetic amplifier, changes the inductance accordingly and returns the current or voltage in the load circuit to a stable state.

Thus, automatic feedback is formed in the system. The ferroresonance loop performs the function of a sensitive sensor, while the magnetic amplifier performs the function of an amplifying and actuating element. Stabilizers operating on the basis of such a principle are distinguished by high reliability, rapid control, a large amplification coefficient, and energy efficiency.

The research results show that magnetic-amplifier-based stabilizers in ferroresonance circuit control make it possible to stabilize the parameters of electrical energy with high accuracy, and they are considered a promising solution for industrial electrical engineering systems.

Experimental Investigation

The system was modeled in the MATLAB/Simulink program. Parameters:

$L_i = 0.5 \div 2.0\,H, \quad C_1 = 20\,\mu F, \quad C_2 = 10\,\mu F$

$R_b = 10\,\Omega, \quad R_b = 10\,\Omega, \quad L_s = 5\,mH, \quad R_{load} = 50\,\Omega, \quad f = 50\,Hz$

Simulation results:

- stable ferroresonance oscillations are produced in the FCS loop;
- even though the amplitude of the control current i_b is only a few tens of mA, it limits the change of the load current I_{load} to within ±4%.

The experimental test bench was assembled at a frequency of 50 Hz on a 220 V grid. The measurements were carried out with a RIGOL DS1054Z oscilloscope and a DTP205A multimeter. The main measurement results (with respect to the change of R_{load}):

№	R_{load} (Ω)	U_{out} (V)	I_{load} (A)	Change, %
1	30	108.6	3.62	–
2	40	109.2	2.73	−2.3
3	50	109.4	2.19	−3.4
4	60	109.0	1.82	−1.3
5	70	108.8	1.55	+2.1

Conclusion

In this research work, the theoretical foundations, structure, operating principle, and main characteristics of a stabilizer operating on the basis of a magnetic amplifier in ferroresonance circuit control were studied. During the research, it was established that, as a result of the mutually integrated operation of a ferroresonance current stabilizer and a magnetic amplifier, it is possible to create an effective stabilization system possessing high sensitivity.

The analyses showed that the ferroresonance loop responds rapidly and nonlinearly to changes in the input voltage and forms a stable control signal for the magnetic amplifier. The magnetic amplifier, in turn, makes it possible to control a large load power by means of a small control power. As a result, the maintenance of the current and voltage in the load circuit at a stable value was ensured.

According to the results of the experiment and calculation, the power amplification coefficient of the system lies in the range:

$$K_p = 100 \div 180$$

which shows that the magnetic amplifier possesses high efficiency. In addition, the sensitivity of the output current and voltage to changes in the load resistance is low, and the stabilization error did not exceed ±4%. This confirms the reliable operation of the device in practical power-supply systems.

As a result of the conducted research, the following advantages of stabilizers based on ferroresonance and a magnetic amplifier were established:

- high sensitivity and rapid control;
- the ability to amplify large power;
- high electromagnetic stability;
- small mass and size indicators;
- simplicity of the structure and operational reliability;
- high energy efficiency.

In addition, the absence of moving mechanical parts in the system increases its service life and reduces the cost of technical maintenance. The use of the ferroresonance phenomenon, in turn, increases the sensitivity of the stabilizer and makes it possible to adapt quickly to changes in the load and input parameters.

On the whole, a stabilizer created on the basis of a magnetic amplifier in ferroresonance circuit control is considered a promising electrical engineering device that makes it possible to stabilize the parameters of electrical energy with high accuracy. This device can be effectively used in electric power systems, automation devices, radio-electronics devices, power-supply systems, and continuous technological processes.

In the future, by continuing this research, it is considered expedient to further improve the mathematical model of the system, to introduce control algorithms based on artificial intelligence, and to study the possibilities of integration with digital control systems.

REFERENCES

1. Kadyrov T.M. Electroferromagnetic circuits possessing a wide falling section on the amplitude–phase characteristic / Izvestiya VUZov. Elektromekhanika, 1988, pp. 26–30, No. 7.
2. Rozenblat M.A. Magnetic amplifiers with self-saturation. — Moscow: GEI, 1963, 127 p.
3. Rasulov A.N., Ro‘zinazarov M.R. Ferroresonance devices for current stabilization / Universum. Tekhnicheskie nauki, No. 3–4, pp. 5–9, 2016.
4. Bosekersky V.A., Popov E.P. Theory of automatic control systems. — Moscow: Nauka, 1975.
5. Babichev A.P. Magnetic amplifiers in automation systems. — Moscow: Energiya, 1972.
6. Kukaddin S.A. Ferroresonance current and voltage stabilizers. — Moscow–Leningrad: Gosenergoizdat, 1961.
7. G. Korn, T. Korn. Mathematical Handbook for Scientists and Engineers. — McGraw-Hill, 2000.