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ANALYSIS OF THE EFFICIENCY OF ELECTRICAL ENERGY ACCUMULATION IN A SELF-OSCILLATING CIRCUIT.

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Annotation. The article examines the analysis of electrical energy storage systems (EESS) as a tool for improving the reliability and survivability of electric power systems (EPS), the main approaches to selecting optimal EESS configurations, methods for assessing their impact on power system stability, and improving the quality of power supply to consumers. This makes it possible to draw conclusions about the feasibility of implementing EESS under real operating conditions of energy facilities and to develop recommendations for optimizing the operating modes of power systems.
Keywords: power system, power supply, electrical energy storage system, electric power system, energy efficiency, energy facilities, oscillations, power.

The application of energy storage in power systems for electricity generation, distribution, and consumption is a pressing issue.

In recent decades, distributed generation has been rapidly developing, significantly exacerbating the problem of maintaining active power balance. The fleet of electric vehicles is growing at a rapid pace, and the sector of renewable energy sources (RES) generation in the global energy industry has expanded considerably. Energy storage in specialized devices is becoming one of the key directions for the development of the energy industry, marking a new stage of its evolution.

The global energy system is constantly changing, and industrial energy storage systems are an important component of this growth, as they contribute to increased flexibility and play an increasingly significant role in energy distribution. Long-term energy storage has great potential for a world where wind and solar energy prevail over the addition of new power plants and gradually displace other electricity sources. The utility sector and transportation are striving for a complete transition to electrical energy, leading to a rapid increase in the need for reliable, efficient, and cost-effective energy accumulation and its release during peak loads. Batteries, capacitors, kinetic energy, energy storage in the form of heated or cooled liquids, as well as in the form of hydrogen – all of these are already available and used solutions offering broad possibilities. However, there is no ideal method, and each of the listed technologies has its own advantages depending on the intended subsequent use of the accumulated energy.

As the percentage of continuous carbon-based energy generation in the energy consumption structure gives way to less stable renewable energy production, energy storage represents a means by which intermittent supply can be effectively synchronized with fluctuations in generation and demand throughout any given day. Wind and sun produce energy only at certain times, so they need additional technology to help fill the gaps. In a world where the share of periodic, seasonal, and unpredictable electricity generation is growing and the risk of de-synchronization with consumption increases, storage makes the system more flexible. Storage devices primarily serve as a buffer and simplify the management and integration of renewable energy sources both in grids and in buildings when there is no wind or sun.

The impact of high-power consumers with a sharply variable load profile on the operation of the power system has a number of negative consequences. Due to power fluctuations on transmission lines, active power losses increase, the level of static and dynamic stability of the power system decreases, and the probability of low-frequency oscillations of operating parameters developing increases. The installation of electrical energy storage systems at a load node allows for the neutralization of all undesirable deviations in operating parameters and their stabilization within specified limits.

One of the primary functions of electrical energy storage systems is reactive power control. At the installation nodes of electrical energy storage systems, in addition to performing the main function of active power control, it is advisable to assign them the task of reactive power control, replacing traditional means of control, regulation, and compensation. The fast response of electrical energy storage systems and their ability to both consume and output reactive power allow them to be used not only for regulation under normal operating conditions but also for solving emergency control problems. Electrical energy storage systems protect generating units from sharp load changes. Sharp, abrupt load changes of significant amplitude in autonomous, isolated power systems, as well as those operating in island mode, can lead to emergency disconnections.

In a real electrical oscillating system, there are always energy losses. If oscillations are excited in such a system, they will inevitably decay, and the greater the losses in the system, the faster the amplitude of oscillations will become zero. To prevent oscillations from decaying, portions of energy must be periodically added to the system from an external source to compensate for losses. In this case, forced undamped oscillations, maintained by a constant energy source, are called auto-oscillations. Systems in which auto-oscillations are maintained are called auto-oscillatory.

Any auto-oscillatory system contains the following elements:

- an oscillating system with losses;
- an energy source;
- feedback.

Consider a parallel resonant circuit in which oscillations are excited. The charge on the capacitor plates constantly decreases – at the end of each full period, the capacitor receives a smaller charge compared to the beginning of the period. The total energy of the system decreases, as it is equal to:

$$W_э = \frac{q_m^2}{2C}$$

To compensate for losses, the capacitor must be recharged at the end of each period. This can be done using a DC voltage source and a circuit breaker (key). The key should only be closed at moments when the positively charged plate of the capacitor is connected to the positive terminal of the power source (and the negatively charged plate to the negative terminal). If done the other way around, the capacitor will discharge through the power source (Fig. 1).

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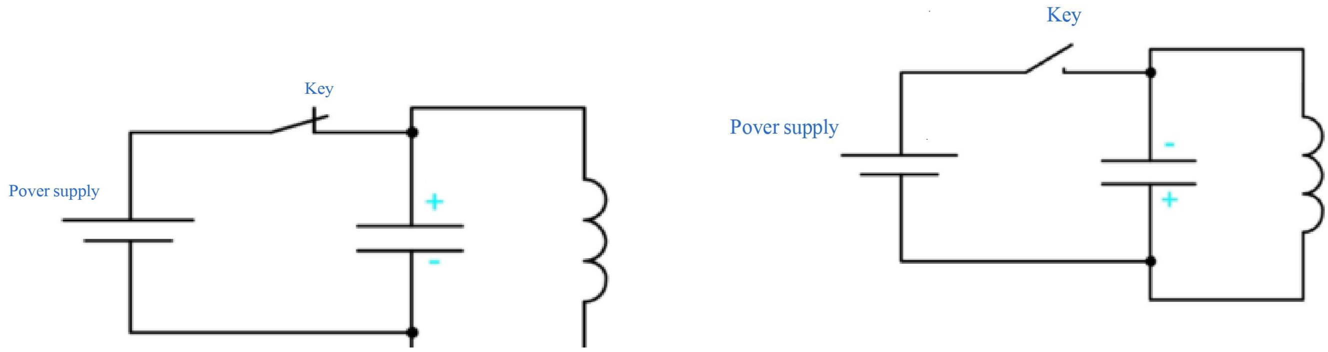

Fig. 1. Electrical auto-oscillatory system

Oscillations in the circuit occur at a very high frequency, making it practically impossible to ensure energy delivery at precisely the right moment manually. It is necessary to arrange for the key to be switched automatically.

By using a bipolar transistor as a switching element, an autogenerator can be built. It contains all the elements of an auto-oscillatory system (Fig. 2):

• the oscillating system is an LC resonant circuit;

• the energy source is a galvanic cell;

• feedback is organized using a coupling coil $L_{\text{св}}$, inductively coupled with coil L, and a bipolar transistor.

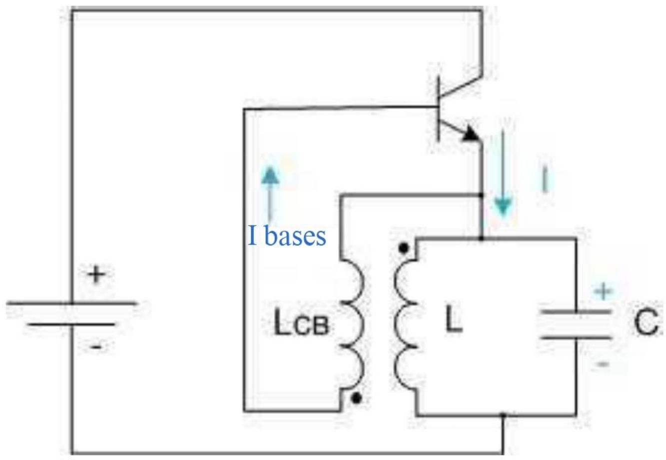

Fig. 2. Auto-oscillatory system with a transistor as a key.

The transistor should open at the moment when the upper plate of the capacitor is charged positively and the lower plate is negatively charged.

At moments of opposite charge, the key should be closed. This condition is met using the phasing of the coil $L_{\text{св}}$. The current required to open the transistor flows in it when the polarity of the connection is correct.

This circuit is somewhat simplified. A real autogenerator has several additional components that set the DC operating mode of the transistor and so on.

The change in current over time, taking into account energy losses, is determined by the formula:

$I(t) = I_0 e^{-\alpha t} \sin(\omega t)$

where:

• $\sin(\omega t)$ — oscillatory process;

• $e^{-\alpha t}$ — amplitude decay;

• α — damping coefficient.

Due to the resistance of the conductors, a portion of the energy:

- is converted into heat;
- is lost;
- the amplitude gradually decreases.

The condition for the emergence of auto-oscillations is determined by the formula:

$A\beta \geq 1$

This is the condition for self-excitation of oscillations.

where:

- A — amplification factor;
- β — feedback coefficient.

The physical meaning of the condition for the emergence of auto-oscillations is as follows. If the amplification compensates for energy losses, the oscillations:

- do not decay;
- are automatically sustained.

This is the basic principle of autogenerator operation. The dependence of quality factor on resistance is as follows.

Determination of the dependence:

$$Q \sim \frac{1}{R}$$

Here, it can be determined that as resistance increases, efficiency drops, and consequently, the quality factor decreases. Also, high resistance causes significant energy losses, rapid decay, and deterioration of energy storage.

In conclusion, the analysis shows that the efficiency of energy storage in an auto-oscillatory circuit is determined by the following factors:

- the magnitude of the quality factor;
- the level of active losses;
- the stability of the resonant frequency;
- the quality of feedback.

High-quality auto-oscillatory circuits ensure minimal losses, stable oscillations, efficient energy storage, and transmission.

Such circuits are widely used in radio engineering devices, high-frequency generators, resonant converters, wireless power transfer systems, and pulsed power engineering.

The study of auto-oscillatory systems plays an important role in understanding rhythmic processes, self-organization, and the stability of dynamic systems.

Auto-oscillations are a phenomenon encountered in various fields of science, from physics and chemistry to biology and medicine, and require analysis considering nonlinear dynamics and stability. Phase portraits and nonlinear equations help researchers explain and predict the behavior of such systems, making the topic of auto-oscillations important for both theoretical and applied research.

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