Electromagnetic compatibility of functional elements of autonomous power supply systems

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Abstract. Currently, static power converters are used as part of autonomous power supply systems. System developers deal with electromagnetic compatibility of sources, converters and consumers of electricity, due to the switching of power electronic devices that create electromagnetic interference and deteriorate quality of electricity and cause malfunction of electrical equipment. The article discusses causes of electromagnetic interference and ways to eliminate it. The noise level is reduced due to the use of single-phase-three-phase transformers with a rotating magnetic field and universal static converters as part of static converters, which can reduce the number of power electronic devices in the autonomous system - sources of electromagnetic interference. The basic rules of installation of equipment that reduces the electromagnetic interference were analyzed. An effective method for reducing the electromagnetic interference is application of passive reactive filters at the input and output of static converters, as well as protection of equipment from external electromagnetic fields by electrostatic shields. The methods for reducing the electromagnetic interference will increase the level of electromagnetic compatibility of equipment used as part of the autonomous power supply system.

1. Introduction

Currently, an integral part of transport and stationary autonomous power supply systems (APSS) are static power converters (SPCs), which coordinate source parameters and parameters of electricity consumers [1–3]. SPCs perform two functions:

- conversion of the type of electricity (alternating current into direct current and vice versa) and current frequency;
- voltage stabilization.

These functions are independent.

APSS developers deal electromagnetic compatibility of sources, SPC and electricity consumers. SPCs adversely affect electrical devices due to the switching of power electronic devices. This effect deteriorates quality of electricity and electromagnetic interference. The propagation of interference occurs through power electric circuits connecting the converters with sources and consumers, along the control and protection system circuits, as well as directly into the surrounding space. The occurrence of electromagnetic interference can cause the malfunction of power electronic equipment, as well as disruption of local control systems and electrical equipment that is part of the APSS [4–6].

In addition, in order to improve the efficiency of control over enterprises and organizations, the electronic, including microprocessor technology is widely used. Therefore, the issue of
electromagnetic compatibility is crucial. Under the influence of electromagnetic interference, emergency situations can occur in control systems or a false command can be generated for the operation of contactors, circuit breakers and other switching equipment. The electromagnetic compatibility of electrical equipment is violated if the protection against electromagnetic interference arising during normal operation of power electronic devices from the electromagnetic radiation detector is insufficient. This can lead to disruptions in software, relay protection and automation devices, local digital control systems and APSS control systems. False commands can lead to a significant economic damage.

2. Methods
When conducting research, theoretical and empirical methods were used. The analysis and synthesis of static electric power converters with a reduced level of electromagnetic interference were carried out.

At the design stage, it is advisable to consider basic terms and definitions of electromagnetic compatibility regulated by GOST R 50397-2011:

1. Electromagnetic compatibility is the ability of a technical device (sources, converters and consumers of electricity) to function effectively in a specific electromagnetic environment, without creating unacceptable electromagnetic interference to other technical devices.

2. Electromagnetic interference is an electromagnetic phenomenon that impairs quality of the functioning of a technical device.

3. The influence of electromagnetic interference is deterioration of quality of the technical device exposed to interference. As a rule, these indicators include indicators of quality of electricity, the main of which are the coefficient of non-sinusoidality of the output voltage and the input current distortion coefficient.

4. Immunity is the ability of a technical device (sources and converters of electricity) to maintain quality of the technical device exposed to electromagnetic interference.

The article discusses causes of electromagnetic interference and ways to eliminate it, as well as the issues of ensuring electromagnetic compatibility of the main functional elements of the system.

3. Results
In electrical engineering, electromagnetic compatibility means the ability of sources, converters, stabilizers and consumers of electricity to work together so that adverse phenomena (surges in voltage and currents) do not lead to an unacceptable decrease in operational and technical characteristics and quality indicators of the electricity system.

The problem of electromagnetic compatibility should be solved at the design stage of the APSS. It is necessary to carry out a spectral analysis of the electromagnetic interference, i.e., to study electromagnetic processes in the power circuits of the system caused by changes in voltages and currents in the nominal operating mode, value and nature of the load [4, 7].

At the first stage, the following characteristics and dependencies should be obtained:
- static characteristics that determine the main electrical parameters of the source according to the parameters of electricity specified at the input (the SPC are the load);
- determining parameters of power electronic devices (thyristors, transistors, diodes, etc.), reactive elements (capacitors, chokes) that are part of the converters, as well as transformers;
- determining such a combination of electric power parameters at which the electric power sources operate, providing required quality and not affecting the sources and consumers of electric power, as well as parallel converters.

At the second stage, in order to increase the accuracy of the parameter values, the higher harmonics of voltages and currents should be investigated.

At the design stage, which include several SPCs, it is also advisable to analyze the causes of electromagnetic interference influencing the system.

Electromagnetic interference created by power electronic devices can be of two types.
The first type is associated with the principle of operation of converters – the switching of power electronic devices which leads to surges in currents and voltages, as well as pulse-width modulation of the output voltage. The electromagnetic interference occurs during the normal operation of the converters.

The second type is associated with a violation of the algorithm of operation of the control system of the ASPP. As a rule, their consequences are emergency operating modes.

In addition, electromagnetic interference occurs under changing conditions, when exposed to a variety of random disturbances:

- changes in the parameters of electric power sources;
- changes in the value and nature of the load (consumers);
- fluctuations in the parameters of the signals of control systems.

For stationary and transport systems, these changes are different.

In transport APSSs, the rotor of an electric power generator is driven by a shaft of diesel or gas piston engines or a high-speed turbine of a gas turbine engine. The electric power generator generates alternating current of industrial or high frequency. Rectifiers, inverters and frequency converters (with direct connection or with an intermediate link of an increased current frequency) can be used as part of the system to supply electricity to various consumers. If they are absent, static stabilizers of electric power parameters can be used.

The first type of electromagnetic interference is associated with random changes in the operating modes of the drive motor and parameters of the electric power at the generator output, as well as random changes in the parameters of electric power consumers.

There are two main operating modes of the drive motor and the electric power generator: with large and small changes in shaft speed and frequency of the generated voltage.

With changes in the frequency of rotation of the drive motor shaft, non-contact electric machines are used as an electric power generator. In the onboard APSS, the turbine rotational speed exceeds 12000 rpm and, accordingly, the frequency of the generated voltage exceeds 1200 Hz. Transient time does not exceed 0.42 ms and, surges in voltages and currents will not affect the electromagnetic compatibility of the equipment.

Small changes in the rotational speed of the drive engine (90-110% of the nominal value) occur when diesel or gas piston engines are used as drive engines. These changes occur due to the constant movement of the transport system, as well as changes in the value and nature of the load.

There are large and small changes in the parameters of electricity consumers.

Large changes in occur when the current changes by 50-100% of the nominal value. With such changes, the voltage decreases by more than 20%. The voltage regulator of the generator restores it within a few seconds. The changes in the parameters of electricity consumers are rare.

Small voltage changes are continuous. They are associated with the "imperfect" reaction of the voltage regulator to fluctuations in the parameters of electricity that occur in the load, as well as the rotational speed of the drive motor shaft. The limits of voltage changes are 2-10% of the nominal value. Small changes in voltage lead to a change in its shape in low power generators. In addition, it differs significantly from the sinusoidal shape. The coefficient of nonlinear distortion can be 16%.

Random changes in the parameters of electric power affect the choice of power electronic devices and the parameters of input and output filters of the converters.

Thus, it is possible to increase the level of electromagnetic compatibility of different types of sources and converters of electric power of the autonomous system, as well as its consumers, by reducing the level of electromagnetic interference created by power electronic devices [8, 9].

One of the ways to reduce the level of electromagnetic interference is to use single-three-phase transformers with a rotating magnetic field (TRMF). These transformers can be made on the basis of an asynchronous motor with a phase rotor. Two primary windings are placed on the stator, shifted in space relative to each other by 90° and connected to each other through a phase-shifting capacitor. In the secondary winding, they are placed on the rotor with a spatial offset of 120° between each other. The rotor is rigidly fixed and stationary. When current flows through the primary windings, a rotating
magnetic field is formed, and at the terminals of the secondary windings a three-phase symmetrical voltage system is formed. To increase the efficiency of a single-three-phase transformer, the air gap has minimum values allowed only for installation.

The use of a single-phase-three-phase TVMP as part of the ESP will reduce the number of power electronic devices of converters (a large effect is achieved by replacing the three-phase power circuit of the inverter with a single-phase one), simplify the control system and, as a result, increase the efficiency, reliability and performance characteristics of the ASE in the complex [7, 10].

The second effective way to reduce the level of electromagnetic interference is to use universal static converters (USC) of electric power. They are a three-phase power circuit containing three blocks parallel connected to each other, in which two power electronic devices are connected in series. The USC control system can operate according to several algorithms, including the rectifier mode and the invert mode. To operate in a converter mode, two USCs are connected to each other in series, and in the direct frequency converter mode, power electronic units are connected to each other in parallel. In addition to converting electricity, the USCs stabilize its parameters and are able to pass energy flows through them in both directions. In one direction, they can operate in a rectifier mode, and in the other one - in an inverter mode [7, 10].

The solar photovoltaic device is connected to a DC bus, from which the batteries are charged, and the USC is connected to it, which converts DC voltage to AC voltage applied to the power supply bus. In this case, the USC operates in an inverter mode. Batteries can be charged from the AC bus, but the USC will operate in a rectifier mode. The control system changes the operation algorithm of the power electronic devices of the converter and switches the power transformer.

Thus, the use of one USC reduces the number of power electronic devices and increases the level of electromagnetic compatibility of the main functional elements of the system.

Since electromagnetic interference propagates through the power wires, diversity and orientation of power circuits between themselves and control and protection system circuits are used to reduce their level.

In order to reduce the level of electromagnetic interference whose sources are APSSs and their effects, it is necessary to follow the installation rules:

1. The wires of the three-phase (three-wire and four-wire) system, the neutral and phase wires of the single-phase AC system, as well as the wires of the DC circuits must be in a single bundle.
2. The interconnection of power electronic devices as part of the APSS, as well as the direct connection of inputs of the converters with electric power sources (electric machine generators, solar and rechargeable batteries) and outputs with a bus to which electric power consumers are connected, must be carried out with a minimum cable length (according to design opportunities);
3. It is necessary to separate power wires and wires of the control circuits (place them in different boxes);
4. The intersection of power wires and wires of control and protection systems circuits should be carried out at right angles.
5. It is necessary to separate wires through which the alternating current and direct current flow;
6. Wires that transmit signals from sensors to amplifiers of control and protection systems and measuring devices and other highly sensitive nodes, must be made in the form of twisted pairs of wires.

Another effective way to reduce the level of electromagnetic interference is to protect equipment by electrostatic screens.

The electrostatic screen is made of copper foil. It is surrounded by a source of electromagnetic interference (blocks of power electronic devices). The metal shell of the screen closes the electric field of the wire, limiting its distribution into the environment.

The main method for suppressing electromagnetic interference is the use of passive filters made using capacitors and chokes at their input and output. The blocks in which the reactive elements of the filters are located must be placed in the screen.
In addition to these methods for reducing the level of electromagnetic interference and increasing the electromagnetic compatibility of electrical equipment, some other methods are used.

1. Organizational decisions aimed at developing regulatory and technical documents reducing electromagnetic interference caused by switching elements of the ASE.

2. An experimental and (or) theoretical study on the subject of assessing the electromagnetic compatibility of the main functional elements taking into account possible operation modes.

3. New technical solutions and (or) modernization of well-known technical solutions of electrical equipment aimed at increasing the level of electromagnetic compatibility of the main functional elements of the APSS.

4. Certification of electrical equipment for compliance with the requirements of electromagnetic compatibility includes measures that verify the compliance of a certain type of electrical device, including sources and converters of electricity, with the requirements of state and international regulatory and technical documents governing the characteristics of electromagnetic compatibility, by issuing a certificate to the APSS developer. A certificate is issued on the basis of tests conducted by employees of accredited enterprises. Tests involve checking the immunity of electrical equipment to electromagnetic interference with standard parameters for acceptable levels of electromagnetic interference.

4. Conclusion

An effective tool for studying the electromagnetic compatibility of the main functional elements of a system is mathematical modeling of physical processes that occur in power circuits.

The causes of electromagnetic interference in the APSS as well as ways to reduce them will create high-performance mathematical models for the joint operation of the main functional elements of the system in normal and emergency modes. This will increase the efficiency of pre-project work on the development of systems with the lowest level of electromagnetic interference generated by the SPC and electromagnetic compatibility of sources, converters and consumers of electricity.

References

[1] Goncharenko I V 2018 Electromagnetic compatibility (Moscow: Radiosoft) p 400
[2] Grigorash O V 2018 The new element base of renewable energy sources (Krasnodar: KubSAU) p 202
[3] Grigorash O V 2011 Static converters and stabilizers of autonomous power supply systems (Krasnodar: KubSAU) p 188
[4] Dovbysh V N 2009 Electromagnetic safety of the elements of energy systems (Samara: Sodruzhestvo) p 198
[5] Dyakov A F 2016 Electromagnetic compatibility and lightning protection in the electric power industry: a textbook for high schools (Moscow: MPEI)
[6] Zhezhelenko I V 2012 Electromagnetic compatibility of consumers (Moscow: Mechanical Engineering) p 351
[7] Kharlov N N 2007 Electromagnetic compatibility in the electric power industry (Tomsk: TPU) p 207
[8] Gordeev A S 2014 Energy conservation in agriculture (St. Petersburg: Lan) p 400
[9] Shergin V 2011 Static converters for advanced power supply systems (Lambert Academic Publishing) p 192
[10] Tregubov S I 2008 Fundamentals of the design of electronic tools (Krasnoyarsk: SFU) p 448