Electromagnetic Compatibility of Devices on Hybrid Electromagnetic Components

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Abstract. There is a general tendency to reduce the weight and dimensions, the consumption of conductive and electrical insulating materials, increase the reliability and energy efficiency of electrical devices. In recent years, designers have been actively developing devices based on hybrid electromagnetic components (HEMC) such as inductive-capacitive converters (ICC), voltages pulse generators (VPG), secondary power supplies (SPS), capacitive storage devices (CSD), induction heating systems (IHS). Sources of power supplies of similar electrical devices contain, as a rule, links of increased frequency and function in key (pulse) modes, which leads to an increase in electromagnetic interference (EMI). Nonlinear and periodic (impulse) loads, non-sinusoidal (pulsation) of the electromotive force and nonlinearity of the internal parameters of the source and input circuits of consumers distort the shape of the input voltage lead to an increase in thermal losses from the higher harmonic currents, aging of the insulation, increase in the weight of the power supply filter units, resonance at higher harmonics. The most important task is to analyze the operation of electrotechnical devices based on HEMC from the point of view of creating EMIs and assessing their electromagnetic compatibility (EMC) with power supply systems (PSS). The article presents the results of research on the operation of an IHS, the operation principle of a secondary power supply source of which is based on the operation of a half-bridge autonomous inverter, the switching circuit of which is made in the form of a HEMC, called the «multifunctional integrated electromagnetic component» (MIEC).

1. Introduction

There is a general tendency to reduce the weight and dimensions, the consumption of conductive and electrical insulating materials, increase the reliability and energy efficiency of electrical devices [1, 2]. In recent years, designers have been actively developing devices based on hybrid electromagnetic components (HEMC) such as inductive-capacitive converters (ICC), voltages pulse generators (VPG), secondary power supplies (SPS), capacitive storage devices (CSD), induction heating systems (IHS) [3–5]. Sources of power supplies of similar electrical devices contain, as a rule, links of increased frequency and function in key (pulse) modes, which leads to an increase in electromagnetic interference (EMI) [6–8]. Nonlinear and periodic (impulse) loads, non-sinusoidal (pulsation) of the electromotive force and nonlinearity of the internal parameters of the source and input circuits of consumers distort the shape of the input voltage lead to an increase in thermal losses from the higher harmonic currents, aging of the insulation, increase in the weight of the power supply filter units,
resonance at higher harmonics [9–11].

2. Problem statement
The most important task is to analyze the operation of electrotechnical devices based on HEMC from the point of view of creating EMIs and assessing their electromagnetic compatibility (EMC) with power supply systems (PSS) [12, 13]. The article presents the results of research on the operation of an IHS, the operation principle of a secondary power supply source of which is based on the operation of a half-bridge autonomous inverter, the switching circuit of which is made in the form of a HEMC, called the «multifunctional integrated electromagnetic component» (MIEC) [14, 15]. The implementation of the IHS based on the MIEC allows to reduce the mass, reduce the dimensions of the PSS, and also to ensure the improvement of the quality of electric energy due to a decrease in the EMI level and the non-sinusoidal coefficient [16]. In this article, we present the results of an experimental study confirming this assertion.

With this study, the following tasks were accomplished:
– the energy quality indicators (non-sinusoidal coefficient, power factor) were analyzed for HEMC operation;
– the parameters of the operating modes of these components are determined;
– an estimation of its EC and influence on the network, including an estimation of the level of the higher harmonics, the ratio of the actual and normative values;
– experimental data on the functioning of a HEMC in an autonomous inverter are obtained.

3. Theory
Disadvantages of electrical devices on discrete elements are a low power factor and the presence of modulation of the active power consumed [17]. The functional integration of electromagnetic elements allows to eliminate of these disadvantages [18, 19].

Consider the circuit of the secondary power supply source (PSS) of IHS, which should also ensure the preservation of the power quality of the supply network (Figure 1).

![Figure 1. Half-bridge circuit of PSS with ICC on a hybrid component.](image)

The secondary power source consists of the following main units:
– diode bridge providing rectification of alternating voltage;
– transistor half-bridge inverter;
– control system that provides alternate key switching and does not allow simultaneous stay in the open state;
– matching transformer, providing a softer mode of operation of the switches.

The switching circuit is made in the form of a MIEC transformer connected to the secondary winding, which performs the function of local heating.

4. Results of the experiment
Experiments were carried out to study the functioning of the device on a HEMC (IHS) and an EMC estimate of this IHS from SES, the influence of IHS based on the component on the network and the quality of electrical energy. In particular, the level of higher harmonics is determined using the
instrument «RESURS-UF2M».

The experiments are performed for four electromagnetic components, the parameters of which are given in Table 1, working separately and in a system consisting of four MIECs connected in series.

| MIEC model | R, mΩ | L, μH | C, μF | α, turns | fres, kHz |
|------------|-------|-------|-------|----------|-----------|
| MIEC 10    | 150   | 12.8  | 0.245 | 23       | 90        |
| MIEC 11    | 150   | 13.7  | 0.185 | 22       | 100       |
| MIEC 12    | 150   | 12.8  | 0.18  | 22       | 105       |
| MIEC 24    | 150   | 12    | 0.174 | 20       | 110       |
| System     | 600   | 19.7  | 0.076 | 87       | 130       |

The results of the research are data on the indicators of the quality of electrical energy (harmonic amplitude and non-sinusoidal coefficient) and energy parameters (power factor and active power value), presented in Figures 2 – 7.

Figure 2 shows the amplitudes of even harmonics (k = 2, 4, 6, 8, 10, 12, 14, 16) for a system of four MIEKs connected in series at different frequencies; on each of the harmonics, the columns are indicated by colors corresponding to different frequency values.

Figure 3 shows the amplitudes of odd harmonics (k = 3, 5, 7, 9, 11, 13, 15, 17) for a system of four MIECs connected in series, operating in resonance mode; on each of the harmonics, the column to the

Figure 4 shows the amplitudes of odd harmonics (k = 3, 5, 7, 9, 11, 13, 15, 17) for a system of four MIECs connected in series, operating in resonance mode; on each of the harmonics, the column to the
left shows the normative value, the shaded column in the middle corresponds to the mode under load, the column to the right reflects the amplitude of the harmonics in the system of four MIECs connected in series, operating without load.

![Graph showing amplitude of odd harmonics at resonance](image)

**Figure 4.** Amplitude of odd harmonics at resonance.

Figure 5 shows a plot of the non-sinusoid coefficients of phase voltages versus frequency. The column to the left shows the non-sinusoidal coefficient when the MIECs are connected in series, the column in the middle, when «MIEC 10» is working separately, the column to the right reflects the non-sinusoidal coefficient in the separate work of «MIEC 24».

![Graph showing dependence of non-sinusoidal coefficients on frequency](image)

**Figure 5.** Graph of dependence of non-sinusoidal coefficients on frequency.

Figure 6 shows the dependence of the active power on frequency. The column on the left shows the active capacity of «MIEC 10», the column in the middle corresponds to the work of the MIECs connected in series, the column on the right reflects the active capacity for «MIEC 24».

![Graph showing dependence of active power on frequency](image)
Figure 6. Dependence of active power on frequency.

Figure 7 shows the power factor versus frequency. Figure 6 shows the power factor versus frequency. The column to the left shows the power factor of «MIEC 10», the column in the middle corresponds to the work of the MIECs connected in series, the column to the right reflects the power factor for «MIEK 24».

![Figure 6](image1)

Figure 7. Power factor versus frequency.

Figure 8 shows the dependence of the active and reactive powers on frequency. The columns on top show the active capacity of MIEK 10 and MIEK 24, respectively, the columns from below show the reactive power of MIEK 10 and MIEK 24, respectively.

![Figure 8](image2)

Figure 8. Dependence of active and reactive power on frequency.

5. Discussion

Even harmonic components are practically absent (Figure 2).

At the individual MIEC, the fifth harmonic is maximal, the other odd harmonics gradually decrease. In the system of four connected MIECs working together, the third harmonic is maximum, while the other odd harmonics are much lower (Figures 3 and 4).

The non-sinusoidal coefficient is below the normative value equal to 8 %, while in the case of the system from the MIEC connected in series, it is lower than for the individual MIECs (Figure 5).

The maximum power of «MIEC 10» is achieved at a resonance frequency of 90 kHz, the maximum power of «MIEC 24» is achieved at a resonant frequency of 110 kHz, the maximum system power from the series-connected four MIECs is achieved at a resonant frequency of 130 kHz (Figure 6).

The power factor as a whole is not lower than 0.9, for some MIEC at the maximum power the coefficient is closer to 1, while MIEC’s work in the system is on the contrary further (Figure 7).

Reactive power is negative, which indicates the capacitive nature of the load (Figure 8). Multifunctional integrated electromagnetic component acts as a reactive power compensator, provides
compensation of reactive power.

6. Conclusions

According to the results of the study:

– indicators of power quality (PQ), which are the most important for devices on hybrid components;

– we estimated of IHS EMC based on a HEMC from PSS, including the level of higher harmonics, the ratio of actual and normative values.

The operation of the HEMC in resonance mode provides a power factor above 0.9.

The maximum power is achieved at the frequency of free oscillations, both for the system and for individual MIECs.

Integral performance of electromagnetic components operating in resonant mode, provides acceptable levels of EMI (higher harmonics).

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