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Research on Stabilization Properties of Inductive-Capacitive Transducers Based on Hybrid Electromagnetic Elements

S G Konesev¹, R T Khazieva¹, R V Kirillov¹, A A Konev¹

¹ Ufa State Petroleum Technological University, 1, Kosmonavtov Ave., Ufa, 450062, Russia

E-mail: KonesevSG@yandex.ru

Abstract. Some electrical consumers (the charge system of storage capacitor, powerful pulse generators, electrothermal systems, gas-discharge lamps, electric ovens, plasma torches) require constant power consumption, while their resistance changes in the limited range. Current stabilization systems (CSS) with inductive-capacitive transducers (ICT) provide constant power, when the load resistance changes over a wide range and increase the efficiency of high-power loads' power supplies. ICT elements are selected according to the maximum load, which leads to exceeding a predetermined value of capacity. The paper suggests carrying load power by the ICT based on multifunction integrated electromagnetic components (MIEC) to reduce the predetermined capacity of ICT elements and CSS weights and dimensions. The authors developed and patented ICT based on MIEC that reduces the CSS weights and dimensions by reducing components number with the possibility of device's electric energy transformation and resonance frequency changing. An ICT mathematical model was produced. The model determines the width of the load stabilization range. Electromagnetic processes study model was built with the MIEC integral parameters (full inductance of the electrical lead, total capacity, current of electrical lead). It shows independence of the load current from the load resistance for different ways of MIEC connection.

1. Introduction

A lot of electrical consumers, such as charge systems of storage capacitor (CSSC), powerful pulse generators, electrothermal systems, gas-discharge lamps, electric ovens, plasma torches, require constant power consumption, while their resistance changes in the limited range [1].

Current stabilization systems (CSS) with inductive capacitive transducers (ICT) of voltage source into current source provide constant power, when the load resistance changes over a wide range [2]. In addition, CSS increases the energy conversion efficiency of high-power loads' power supplies. ICT in the current stabilization system allows creating an output characteristic, which is required for the consumer supply listed above [3]. While calculating the ICT elements and invertors, considering highest harmonics in the output voltage specter of voltage invertors is needed. When ICT load resistance is low, flowing through the inverter elements current greatly increases. It prevents mutually inductively coupled T-shaped ICT and Wheatstone bridges using that have better energy indicators than Bushero schemes [4]. From the energy conversion efficiency and power coefficient point of view, the most optimal scheme is symmetric ICT. Voltage invertors with Wheatstone bridge, constructed using the ICT, having a T-shaped Bushero scheme with upstream inductance are most



energy efficient [5]. The elements of ICT are selected according to the maximum load that leads to an overestimation of the capacity [6]. The authors propose to power the load with MIEC-based ICT to reduce the capacity of the ICT elements and the weight and dimensions of the CSS.

There are various circuits of ICT performed on the basis of discrete and hybrid electromagnetic elements (EME). Unlike the ICT with discrete EME, designing ICT with hybrid EME has some unsolved problems. There are no engineering calculating methods and constructing algorithms of ICT with hybrid EME. Hybrid EME (MIEC) working modes, electromagnetic and thermal processes are poorly studied. It is the main reason to study ICT for the CSS based on hybrid EME by using mathematical and computer models [7].

Voltage source to current source converters can work with changing loads. Real ICT cannot provide an absolute load current constancy when resistance is changing. ICT parameters are chosen according to the design accuracy of load current stabilization, so that it is required to perform ICT electromagnetic processes calculation. The optimal ICT working mode is a resonant mode when energy conversion efficiency is maximized. The maximum output voltage must be equal to the absolute value of supply voltage to achieve the maximum energy conversion efficiency. It is necessary to determine the optimum load changing range when the efficiency is maximized. Maximum voltage on the capacitance and inductance of the resonant circuit elements is important for ICT elements calculation and reactive power selection [8].

2. Problem statement

The aim of the research is to develop an MIEC-based ICT mathematical model for MIEC electromagnetic processes study, to determine the frequency changing range when stabilization of the load current is within $\pm 7\%$.

3. Theory

Electromagnetic processes of CSS with ICT based on MIEC are investigated by using a mathematical modeling method. The authors developed and patented ICT, based on MIEC (Fig. 1), which can transform the electric energy and change the resonance frequency of device and reduces the weight and dimensions of the CSS by reducing the number of components. A multifunctional integrated electromagnetic component operates as a capacitor and the transformer block. This component consists of the first conductive electrode with electrical leads located throughout the length of the electrode connected to the first switching block and the second conductive electrode formed of several sections with electrical leads which are connected to the second switching block, the current sensor control block, the voltage sensor and the load. The first and second conductive electrodes of MIEC are spiral-rolled and separated with dielectric. The control block sends a signal to the switching blocks that connect conductive electrodes and change the parameters of capacitance and inductance of MIEC to control ICT output current. The necessity of the ICT working scheme in the short circuit mode is reducing the input and contact resistance when frequency increases (with harmonic number increasing). This condition is satisfied in all two-section schemes of MIEC.

The measure of load current stabilization is a stabilization factor when the load resistance changes from zero $Z_L = 0$ to the maximum value $Z_L = Z_{L_{max}}$:

$$\delta = (I_L)^2 \cdot Z_L = 0 / (I_n)^2 \cdot Z_{L_{max}} \leq 1. \quad (1)$$

While powering the ICT by the inverter, the stabilization is possible with constant accuracy only. A stabilization coefficient and energy indicators depend on the ICT Q that is determined with the ICT connection mode and the ratio of resonance circuit's active and reactive resistance. Sharp increasing of the load current leads to a stability loss.

Real converter properties get closer to the ideal converter properties when the resistance value becomes smaller (the larger the quality factor).

$$Q = \omega L / R. \quad (2)$$

With a high quality factor of resonant circuit, the output current of ICT slightly depends on the load resistance and is directly proportional to the supply voltage. Schemes with the transition conductivity equal to zero ($\delta = 0$) and at a frequency equal to zero ($\omega = 0$), for example, ICT, have ideal load current stabilizing properties of an inverter.

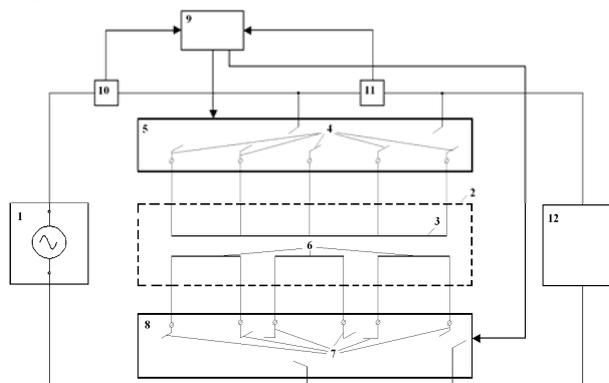


Figure 1. ICT: 1 – EMF source, 2 – MIEC, 3, 6 - conductive electrodes, 4, 7 – electrical leads, 5, 8 – switching blocks, 9 – control block, 10, 11 – current and voltage sensors, 12 – the load

Among the considered two-section MIEC, this condition is satisfied in a scheme with serial-connected sections, diagonal connecting of power supply and the load with the output in the middle of the second electrode. The article [9] describes various schemes of two-section MIEC. The most energy-efficient scheme is the two serial-connected sections, the diagonal connecting of power supply and the load with the output in the middle of the second electrode when it is powered by voltage source with higher harmonics.

However, the higher the quality factor of ICT, the greater its weight and dimensions. The using of MIEC in the ICT can reduce weight, size and cost of the device by reducing the number of components. In addition, we can use MIEC to transform energy and change resonance frequency of device. The advantage of a two-section MIEC is a possibility to connect the sections in different ways. The authors made a frequency characteristics' comparison of two-section MIEC. It was established that two-section MIEC with serial connection of sections, the diagonal connecting of power supply and the load with the output in the middle of the second electrode has the best stabilization properties.

4. Results of the experiment

The authors developed the mathematical model of ICT based on MIEC to determine the width of the load stabilization range. The main feature of the developed mathematical model is that the electromagnetic processes in MIEC are described with linear equations system using the MIEC integral parameters. They are: full inductance of electrodes L , total capacitance C and electrodes' electrical leads current (Fig. 2). The equation system describing the equivalent circuit of MIEC with integral parameters is shown in paper [10].

The mathematical model of two-section MIEC allows determining the width of the load stabilization range. The scheme and the equation system describing the processes in two-section MIEC are discussed in detail in paper [10].

The authors developed the mathematical model ICT based on two-section MIEC and confirmed the independence of the load current to the load resistance for different methods of MIEC electrical leads connection presented in Table 1. It was found that the load current is proportional to the voltage grid and is independent of the load. The results of calculation and the MathCad mathematical model solving are presented in Table 1.

Table 1. Formula for load current for different MIEC connection methods.

№	ICT scheme	Mathematical model of MIEC and formula for load current
1	Two-section MIEC with serial-connected sections and diagonal-connected power supply and load	$\underline{U}_{in} = \underline{U}_{e11} + \underline{U}_{e12} + \underline{U}_2$ $\underline{U}_1 = (\underline{I}_{in} - \underline{I}_1)/(j \cdot \omega \cdot C_1)$ $\underline{U}_2 = (\underline{I}_1 - \underline{I}_L)/(j \cdot \omega \cdot C_2)$ $\underline{U}_{e11} = j \cdot \omega \cdot L_1 \cdot (\underline{I}_{in} + \underline{I}_L)$ $\underline{U}_{e12} = j \cdot \omega \cdot L_2 \cdot (\underline{I}_1 + \underline{I}_2)$ $\underline{U}_1 = \underline{U}_{e11} + \underline{U}_{e12} + \underline{U}_L$ $\underline{I}_1 = (\underline{I}_{in} + \underline{I}_L)/2$ $\underline{I}_2 = (\underline{I}_{in} + \underline{I}_L)/2$ $\underline{I}_L = \omega \cdot C \cdot \underline{U}_{in}/(2 \cdot j)$ $\underline{I}_L = \underline{U}_{in}/(2 \cdot j \cdot \omega \cdot L)$
2	Two-section MIEC with serial-connected sections and the power supply, connected to the first section electrodes' beginnings, and the load, connected to the second section electrodes' endings.	$\underline{U}_{in} = \underline{U}_{e11} + \underline{U}_{e12} + \underline{U}_2$ $\underline{U}_1 = (\underline{I}_{in} - \underline{I}_1)/(j \cdot \omega \cdot C_1)$ $\underline{U}_2 = (\underline{I}_1 - \underline{I}_L)/(j \cdot \omega \cdot C_2)$ $\underline{U}_{e11} = 0$ $\underline{U}_{e12} = j \cdot \omega \cdot L_2 \cdot (\underline{I}_1 - \underline{I}_2)$ $\underline{U}_1 = \underline{U}_{e11} + \underline{U}_{e12} + \underline{U}_L$ $\underline{I}_1 = (\underline{I}_{in} + \underline{I}_L)/2$ $\underline{I}_2 = (\underline{I}_{in} + \underline{I}_L)/2$ $\underline{I}_L = \omega \cdot C \cdot \underline{U}_{in}/(2 \cdot j)$ $\underline{I}_L = \underline{U}_{in}/(2 \cdot j \cdot \omega \cdot L)$
3	Two-section MIEC with serial-connected sections and diagonal-connected power supply and load with the electrical lead in the middle of the second electrode.	$\underline{U}_{in} = \underline{U}_{e11} + \underline{U}_1$ $\underline{U}_1 = (\underline{I}_{in} - \underline{I}_1)/(j \cdot \omega \cdot C_1)$ $\underline{U}_2 = (\underline{I}_1 - \underline{I}_L)/(j \cdot \omega \cdot C_2)$ $\underline{U}_{e11} = j \cdot \omega \cdot L_1 \cdot (\underline{I}_{in} + \underline{I}_L)$ $\underline{U}_1 = \underline{U}_{e11} + \underline{U}_{e12} + \underline{U}_L$ $\underline{I}_1 = \underline{I}_L$ $\underline{I}_L = \omega \cdot C \cdot \underline{U}_{in}/(2 \cdot j)$ $\underline{I}_L = \underline{U}_{in}/(2 \cdot j \cdot \omega \cdot L)$
4	Two-section MIEC with serial-connected primary electrodes and parallel-connected secondary electrodes of both sections and diagonal-connected power supply and load	$\underline{U}_{in} = \underline{U}_{e11} + \underline{U}_{e12} + \underline{U}_2$ $\underline{U}_1 = (\underline{I}_{in} - \underline{I}_1)/(j \cdot \omega \cdot C_1)$ $\underline{U}_2 = (\underline{I}_1 - \underline{I}_L)/(j \cdot \omega \cdot C_2)$ $\underline{U}_{e11} = j \cdot \omega \cdot L_1 \cdot (\underline{I}_{in} - \underline{I}_2)$ $\underline{U}_{e12} = j \cdot \omega \cdot L_2 \cdot (\underline{I}_1 + \underline{I}_2)$ $\underline{U}_1 = \underline{U}_{e11} + \underline{U}_{e12} + \underline{U}_L + \underline{U}_{e11}$ $\underline{I}_1 = (\underline{I}_{in} + \underline{I}_L)/2$ $\underline{I}_2 = (\underline{I}_{in} + \underline{I}_L)/2$ $\underline{I}_L = \omega \cdot C \cdot \underline{U}_{in}/(2 \cdot j)$ $\underline{I}_L = \underline{U}_{in}/(2 \cdot j \cdot \omega \cdot L)$
5	Two-section MIEC with parallel-connected sections and diagonal-connected power	$\underline{U}_{in} = \underline{U}_{e11} + \underline{U}_2$ $\underline{U}_1 = (\underline{I}_{in}/2 - \underline{I}_1)/(j \cdot \omega \cdot C_1)$ $\underline{U}_2 = (\underline{I}_1 - \underline{I}_L)/(2 \cdot j \cdot \omega \cdot C_2)$ $\underline{U}_{e11} = j \cdot \omega \cdot L_1 \cdot (\underline{I}_{in} + \underline{I}_L)/2$ $\underline{U}_{e12} = j \cdot \omega \cdot L_2 \cdot (\underline{I}_{in} + \underline{I}_L)/2$

supply and load	$\underline{U}_1 = \underline{U}_{e11} + \underline{U}_L$ $\underline{I}_1 = \underline{I}_L/2$ $\underline{I}_2 = \underline{I}_{in}/2$ $\underline{I}_L = \omega \cdot C \cdot \underline{U}_{in}/(2 \cdot j)$ $\underline{I}_L = \underline{U}_{in}/(2 \cdot j \cdot \omega \cdot L)$
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The authors produced the calculation of the electromagnetic processes of ICT based on MIEC with different methods of electrical leads connection. We applied integrated parameters which includes the inductance of electrodes (electrodes inductance), total capacitance of MIEC.

Research results along with the mathematical model of ICT, based on MIEC, demonstrate that current stabilization is in the change range of resistance load from 0.1 to 1200 ohms.

The scheme shown in Table 1, p.2 has the best load current stabilization properties. This scheme is the most suitable among the considered circuits that are powered by voltage source with the higher harmonics.

5. Discussion

The experiment confirms that load current does not depend on load impedance when ICT works in the resonance mode.

The MathCad mathematical model allows finding the most effective scheme of ICT for the charge system (CS) of the storage capacitor (SC). According to modeling results, it was concluded, that: CSS, based on IEP, feeds the load with constant input power without additional resistance, reduces the capacity of power supplies. The advantages of this system are particularly important in high-capacity devices, for example, impulse energetics and electrothermal systems.

Analysis of the frequency response of various two-section MIEC, according to the optimal use in electrical devices, confirms that the change of MIEC voltage amplitude allows adjusting the level of constant current in the load when MIEC is powered with the inverter, because the load current in resonance mode of MIEC is directly proportional to the supply voltage. It allows using schemes of MIEC in the charge process of the storage capacitor [10]. The charge process of the storage capacitor (SC) is economical and energy effective at a constant current in order to obtain a linearly increasing voltage. The application of MIEC for charge of the storage capacitor reduces weight and dimensions of the device.

The two-section MIEC-based ICT working scheme was considered when stabilization of the load current is within $\pm 7\%$. Figure 2 shows how load current depends on changing frequency. The needed level of current stabilization in two-section MIEC with the diagonal connecting of the power supply and the load with the electrical lead in the middle of the second electrode can be reached when frequency changes in the range of $0.75 \cdot f_{res.} - 1.35 \cdot f_{res.}$

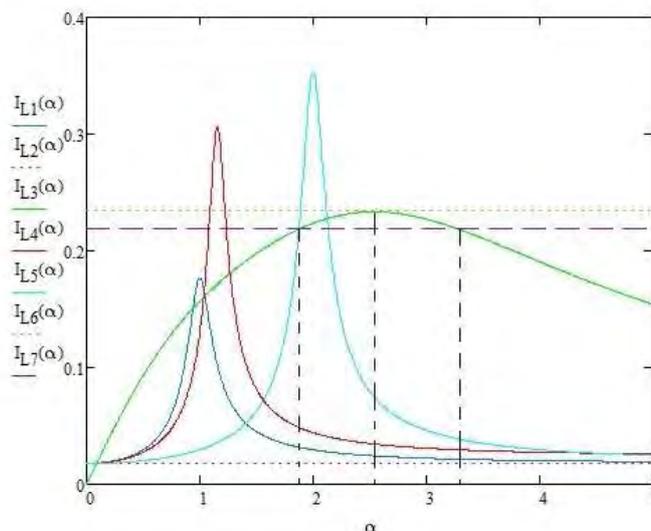


Figure 2. The graphs of load current versus frequency for a variety of power supply and load connection methods.

The authors have developed the charge system (CS) of the storage capacitor (SC) based on researched ICT. Its work is described in detail in [9 - 10]. Using ICT allows rising the voltage on the capacitor linearly and provides a constant current in the load circuit, independently of the state of the storage capacitor. This prevents inrush currents, when the storage capacitor is on charge and causes a linear increase of voltage on the charged capacity that makes maximum energy conversion efficiency.

6. Conclusions

The authors developed and patented ICT based on MIEC that reduces the weight and dimensions of the CSS by reducing components number with the possibility of electric energy transformation and resonance frequency change (control) of the device.

ICT based on the MIEC mathematical model has been designed for finding the width of the load range when the stabilization is carried out. The electromagnetic processes study model was built with the MIEC integral parameters (full inductance of the electrical lead, the total capacity and the current of the electrical lead). The mathematical model shows the independence of the load current from the load resistance for various methods to connect electrical leads of MIEC.

ICT, based on MIEC mathematical model investigation results, shows current stabilization in the resistance load change range of 0.1 to 1200 ohms.

The math model shows that load current is independent of load resistance for different connection methods. The results obtained show that load current is proportional to the mains electricity and is independent of the load value.

Among the considered two-section MIEC, the scheme with series-connected sections, diagonal power supply connection and the load with the electrical lead in the middle of the second electrode has the best stabilization properties and it is best suited while powering by higher harmonics power supply.

The use of the MIEC in ICT can reduce weight, size and cost of the device by reducing the components number when electric energy transformation and resonance frequency change (control) of the device is possible. The advantage of a two-section MIEC is in possibility to connect the sections in different ways. ICT can work at different frequencies by changing power supply and load's connection way without changing the component's structure.

The most effective ICT scheme for the charge system (CS) of the storage capacitor (SC) was identified by means of the developed MathCad mathematical model. As a result of modeling, the

following conclusions were made: CSS based on ICT allows feeding the load for a constant input power without additional resistances, reduces the capacity of power supplies. The advantages of this system are important in high-capacity devices, for example, impulse energetics and electrothermal systems.

Experimental confirmation of the CSS model adequacy was carried out with MIEC laboratory sample.

References

- [1] Musavi F, Eberle W and Dunford W G 2011 *Applied Power Electronics Conf. and Exposition* **26** 821-828
- [2] O'Loughlin M 2007 *Texas Instrument Power Supply Design Sem.* 2007 **5** 5-14
- [3] Kit Sum K 1998 *PCIM Mag.* **24** 42-51
- [4] Morrow K, Karner D and Francfort J 2008 *U.S. Department of Energy - Vehicle Tech. Program* **1**
- [5] Chin, Shaoan A, John T, Milan M J, Raymond B R and Fred C L 1990 *IEEE Applied PowerElectronics Conf. Proc.* 459-466
- [6] Jin J M, Liepa V V 1988 *IEEE Transactions on Antennas and Propagation* **36** 50-54
- [7] Cao Y, Yang X D, Huang X and Sylvester D 2003 *IEEE/ACM International Conference on Computer Aided Design* 848-853
- [8] Robert S B, Philip T K 2013 *IEEE Transactions on Power Electronics* **28** 537-546
- [9] Konesev S G 2016 Multifunctional integrated electromagnetic component *Patent 2585248*
- [10] Konesev S G, Khazieva R T and Kirillov R V 2015 *J. of USATU* 4(70) **19** 66-71