UNIVERSAL THREE-PHASE FERRORESONANCE STABILIZERS

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Abstract: A comparative analysis has been carried out on two options of three-phase parametric current sources (inductive-capacitive stabilizers). Their capacities to operate in voltage stabilizer mode have been studied. Such capacities were proven and their conditions were defined. Theoretical results were experimentally checked and confirmed with satisfactory accuracy. Based on theoretical and experimental studies it was proven that the considered systems can operate in both modes – as current and voltage stabilizers.

Keywords: current stabilizer, voltage stabilizer, parametric current source, inductive-capacitive stabilizer.

1. INTRODUCTION

It is known that capacitive elements in electric circuits can exchange reactive power and resonate not only with inductances but also ferromagnetic elements (magnetic resistances). Ferroresonance stabilizers are built up based on such resonance phenomena. Their varieties are the parametric current sources (PCS) [1, 2]. Indeed, they are based on the theory of the so-called inductive-capacitive current stabilizers (ICS) [2, 3]. They are alternatives of the electronic current stabilizers and excel over them in terms of qualities in the environment of power electronics. This is why their main applications are in this area (welding current supply, laser systems power supply, etc.) [1, 2, 3].

Object of the study

Since matching transformers often need to be applied in high voltage electronics, there is such transformer constructively built in PCS. It is integrated with a ferromagnetic throttle which according to the ICS principle resonates with the capacitor in the system. This integration results into better mass-dimensional and other value indices. Apart from the presumptive regulatory functions of the matching transformer, in arc welding it separates the high voltages of the arc from the power supply network and limits the idle voltage. It has also a technological function justified by its appropriate (with increased curve steepness) external characteristic [1, 4] which favors the arc burning and improves welding technological process.

It is not necessary to consider the technological improvements of the welding process followed by increased arc elasticity. The results from them are expressed in a reduced quantity of welding sputters (thus lower metal consumption and better quality of the weld) and fewer pores [1].

An additional but not negligible advantage of this type of current sources is their better power factor compared to the classic welding transformers. It is significant especially in idle modes and it is easily explainable with the availability of capacitive elements as an important part of inductive-capacitive stabilizers. Thus, in certain operation modes a capacitive power factor can be achieved which leads to compensation of reactive power and

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improvement of $\cos\varphi$. The stated properties of PCS are thoroughly studied in single-phase applications and less studied in three-phase applications.

The aim of this paper is to study and prove a new possibility for PCS, i.e. that they could also play the role of voltage stabilizers in a three-phase application.

This would make them universal stabilizers (both current and voltage) for three-phase high voltage circuits. Two principle constructive options [5] are known which can be used for implementing three-phase inductive-capacitive current stabilization. They can be conditionally called symmetric and asymmetric options. There is symmetry with regards to the power supply network. Circuit solutions are shown in Figure 1 and Figure 2.

A drawback of the first option is its mass-dimensional indices. For each separate phase transformers with magnetic shunt are independent or they lack completely or partially their integrated parts and logically total mass and weight are higher. However, this option (Figure 1) has two advantages. The first one is that the dimensions and weight of each of the three individual transformers are smaller versus the three-phase integrated option. This facilitates the transformers installation and relocation, if needed. The second advantage is expressed in the smaller so called standby (if needed) or in the fact that in case of a failure almost always only one of the three transformers of the system needs to be replaced (repaired).

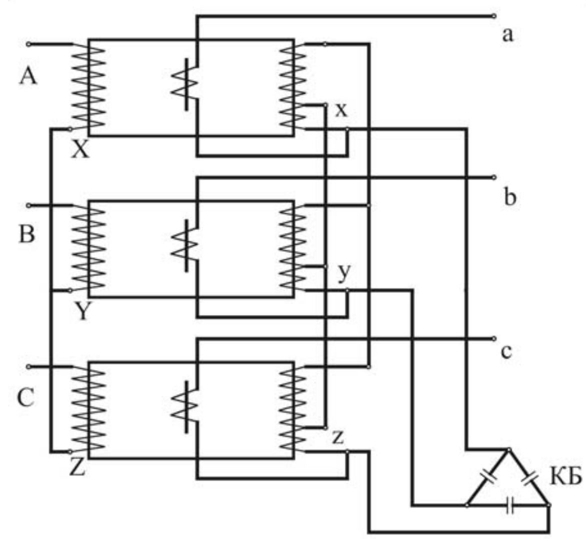

Fig. 1. Circuit schematic of a three-phase inductive-capacitive current stabilizer - symmetric option.

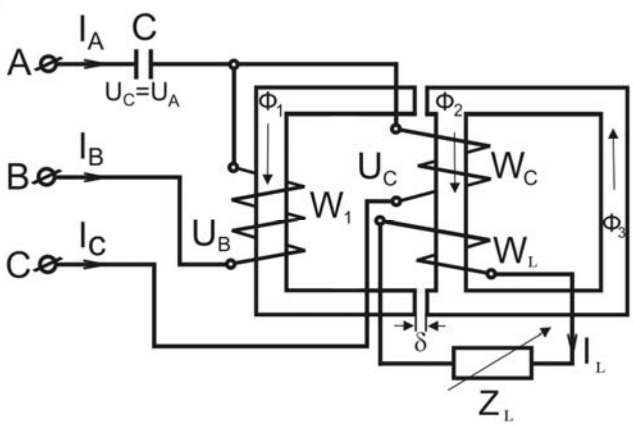

Fig. 2. Circuit schematic of a three-phase inductive-capacitive current stabilizer - asymmetric option.

There are studies [2, 5] which determine PCS as a current stabilizer. The purpose of this paper is to study and prove a possibility for three-phase system PCS to play the role of voltage stabilizers.

2. ANALYTICAL STUDIES

In order to determine the capacities of the two circuit options for voltage stabilization, it is necessary to define their analytical functional relations of the mentioned voltage. The symmetry in the first option allows that it could be analyzed just for one phase. An electromagnetic circuit just for one of the phases for the symmetric PCS is shown in Figure 3.

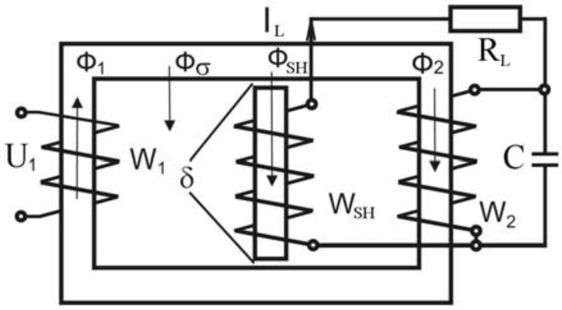

Fig. 3. Electromagnetic circuit for one of the phases for the symmetric PCS.

The complex method allows that a generalized complex system of equations be worked out, which describes this circuit (1). Being initial equations, the latter report a maximal number of factors (parameters) of the system. Subsequently, some of them can be ignored.

$$\left|\begin{array}{l} \dot{\Phi}_{m1} = \dfrac{\dot{U}_1\sqrt{2}}{j\omega W_1} \\ \dot{\Phi}_{m1} = \dot{\Phi}_{m_\sigma} + \dot{\Phi}_{m_{SH}} + \dot{\Phi}_{m2} \\ \dot{F}_{m1} - \dot{\Phi}_{m1}\dot{Z}_{\mu 1} = \dot{\Phi}_{m2}\left(\dot{Z}_{\mu c} + \dot{Z}_{\mu 2}\right) + \dot{F}_{m2} \\ \dot{\Phi}_{m_{SH}}\left(\dot{Z}_{\mu_{SH}} + R_{\mu\delta}\right) \pm \dot{F}_{m_{SH}} = \dot{\Phi}_{m_\sigma} R_{\mu\delta} \\ \dot{\Phi}_{m_2}\left(\dot{Z}_{\mu_2} + \dot{Z}_{\mu c}\right) + \dot{F}_{m2} = \dot{\Phi}_{m_\sigma} R_{\mu\delta} \\ \dot{I}_L = -\dfrac{j\omega}{\sqrt{2}\,\dot{R}_L}\left(W_2\dot{\Phi}_{m2} - W_{SH}\dot{\Phi}_{m_{SH}}\right) \end{array}\right. \qquad (1)$$

The symbols used above are according to Figure 3 and mean the following:

Φ_m – maximal values of magnetic fluxes through the circuit sections;

F_m – maximal values of the magnetomotive voltages created by the respective coils;

Z_μ - equivalent magnetic resistances of the respective electrical ones (of the three coils and of the condenser);

R_μ - active magnetic resistances of the respective sections of the magnetic circuit (the parts of the magnetic core and dissipated magnetic flux) according to Figure 3;

$X_{\delta 2}$, $X_{\sigma 2}$ – adjusted to the secondary coil reactive electric resistances equivalent to the respective magnetic ones ($R\mu\delta$ and $R\mu\sigma$);

$$a = \sqrt{\frac{X_{\delta 2} + X_{\sigma 2}}{X_{\delta 2}}}$$

W is number of windings of the respective coils;
I_L, R_L – current and resistance of the load;
ω – circular frequency of the sinusoidal values;
j – complex imaginary unit.

It should be also noted that there are two possible ways to connect the shunt (W_L) and secondary (W_2) coils – in the same and opposite direction. This is why the fourth equation of (1) contains two signs "+" and "–". Previous studies have shown that connection in the opposite direction is compulsory for current stabilization. The present studies showed that the voltage stabilization is possible in both ways but it is better when connected in the same direction. This means that the "+" sign is preferred and it will be used hereinafter.

3. RESULTS FROM THE ANALYTICAL STUDIES

Considering the complexity and volume of the expressions which are obtained when the equations are fully solved, it is expedient to make simplifying assumptions ignoring the active resistances of the materials for the condenser and magnetic core since they have the lowest impact. The solution of (1) allows defining the main values for the system. In view of the set objective, the expressions for the load current and the voltage upon the load are most significant. If there are requirements for current stabilization [1, 2, 4], i.e. that the system has to be PCS, it is needed to comply with the following condition:

$$X_{C2} = \frac{1}{\omega C} = X_{\delta 2} + X_{\sigma 2} \tag{2}$$

It is called resonance condition since ferroresonance phenomena occur which lie in the grounds of current stabilization.
Then, the stabilized current is defined as:

$$I_L = \frac{U_1.W_2}{W_1} \cdot \frac{1}{(\alpha + 1).X_\delta + X_\sigma} = \frac{U_1.W_2}{W_1.X} \tag{3}$$

In order to study the capacities of the system to operate in voltage stabilization mode, it is logical to ignore (2). The simplifying assumptions made above remain valid when reporting the resistance of the secondary branch. In this case, it is easy to prove that if the following inequality is true:

$$r_L^2 \geq\geq \frac{\left\{X_\delta.X_2.X_C.(\alpha + 1) + X_\sigma.\left[X_2.X_C + \alpha^2.X_\delta(X_C - X_2)\right]\right\}^2}{\left[X_2.(X_C - X_\delta - X_\sigma) - X_\sigma.X_C\right]^2} \tag{4}$$

the expressions for the current through the load and for the voltage are as follows:

$$I_L = \frac{U_1.W_2}{W_1} \cdot \frac{\alpha.X_\delta(X_2 + X_C) + X_2.X_C}{r_L\left[(X_2 + X_C)(X_\sigma + X_\delta) + X_2.X_C\right]} \tag{5}$$

$$U_L = I_L.r_L = \frac{U_1.W_2}{W_1}.\frac{\alpha.X_\delta(X_2 + X_C) + X_2.X_C}{[(X_2 + X_C)(X_\sigma + X_\delta) + X_2.X_C]} \quad (6)$$

It becomes apparent that voltage is not dependent on the load. The analysis of (4) show that X_2 has much lower values than X_δ , X_σ , X_C . Then, the terms which contain X_2 can be ignored and (4) is reduced to: $r_L^2 \geq\geq \alpha^4.X_\delta^2$. Since the value of α is close to 1 and X_δ is much smaller than 1 (since the magnetic resistance of the aerial gap is large) i.e. it is like 0.2 – 0.3, it becomes clear that this inequality is true when the values of r_L are larger than 1. It is obvious that in this case the system will act as a voltage stabilizer.

Considering the obtained so far results, we can focus on the asymmetric three-phase system in Figure 2. Analyses have to be made for the overall electromagnetic circuit but not just for one phase. The general complex equations which describe it are (7).

$$\left| \begin{array}{l} \Phi_1 + \Phi_2 + \Phi_3 = 0 \\ I_A + I_B + I_C = 0 \\ I_L.Z_L + \frac{j\omega}{\sqrt{2}} W_L \Phi_2 = 0 \\ I_C W_C + I_L W_L = 0 \\ \frac{j\omega}{\sqrt{2}} W_1 \Phi_1 - \frac{j\omega}{\sqrt{2}} W_C \Phi_2 = U_{LIN} \\ \frac{j\omega}{\sqrt{2}} W_1 \Phi_1 + \frac{j}{\omega C} I_A = U_{LIN} \\ \sqrt{2}.I_1.W_1 - \Phi_1.R_\delta = 0 \end{array} \right. \quad (7)$$

Their solution gives an expected result which is analogical to the above one that when the ferroresonance condition is met:

$$X_\delta = \frac{R_{\mu\delta}}{\omega.W_1^2} = X_C = \frac{1}{\omega.C} = X , \quad (8)$$

stabilized load current is achieved:

$$I_L = \frac{U_{LIN}.W_L}{W_C.X} \quad (9)$$

Were U_{LIN} represent linear voltage.

When we look for stabilization of the voltage upon the load making analogy with the symmetric case above, we ignore condition (8) and obtain that when the values of the load resistance are higher than $1\,\Omega$, the system allows voltage stabilization.

4. EXPERIMENTAL CHECK

In order to check the studies made, tests were carried out in experimental plant with the following parameters:

A (symmetric)

$$W_1 = 240$$
$$W_2 = 34$$
$$W_{SH} = 36$$
$$\delta = 3.10^{-3}, m$$
$$C = 100...200, \mu F$$
$$S_\mu = 54.10^{-4}, m^2$$

B (asymmetric)

$$W_S = 732$$
$$W_C = 1300$$
$$W_L = 28$$
$$C = 30...45, \mu F$$
$$\delta = 4.10^{-3}, m$$
$$S_\mu = 28.10^{-4}, m^2$$

The experimental results from the tests are shown respectively in Figure 4.a and Figure 4.b.

It should be noted that in order to study thoroughly the capacities of the systems, a multitude of tests for different values of the parameters of both systems (C, δ, W_i) were carried out when the coils were connected in the same direction and in the opposite one (W_2 and W_{SH}). W_i - number of windings of the respective coils. Many of them are subject to other papers. We have selected just one characteristic for each of both studied systems which clearly prove that the properties which stabilize load voltage of both circuits. Since current stabilization (only when W_2 and W_{SH} are connected in the opposite direction) was studied and proven long ago [1, 6], the results from the current studies are a complement to the properties of the three-phase PCS. It enables us to talk about universal three-phase ferroresonance current and voltage stabilizers connected in circuits as in Figure 1 and Figure 2.

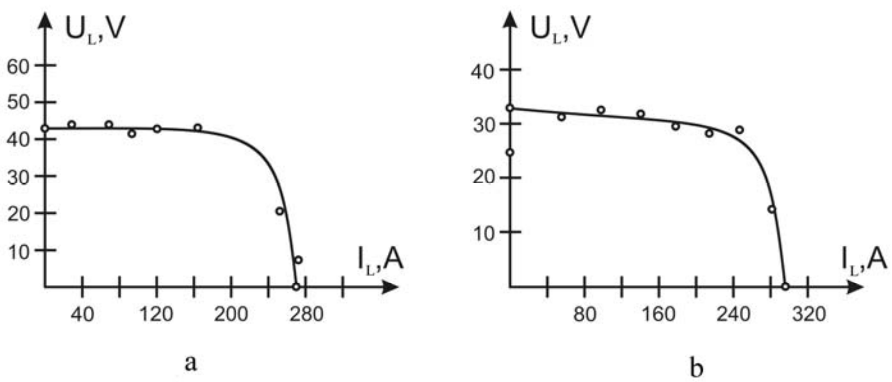

Fig. 4. Experimental results from the tests for symmetric and asymmetric options of a three-phase inductive-capacitive current stabilizer.

5. CONCLUSIONS

As a result from the carried out studies, a possibility for the systems presumptively known as current stabilizers which are called in general inductive-capacitive current stabilizers and in particular parametric current stabilizers to expand their capacities.

When the compulsory conditions for current stabilization are ignored and replaced with others, the same circuit solutions become capable of stabilizing voltage upon the load. Thus, the thesis for obtaining universal three-phase current and voltage stabilizers is justified.

The systems considered herein are appropriate for use in high voltage and power circuits where their advantages are most outstanding versus the electronic stabilizing circuits.

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