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ORIGINAL SCIENTIFIC PAPER

Self-sustaining resonant converter of reactive power into active one

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Abstract. The paper proposes is scheme of the self-sustaining resonant converter of the reactive into the active power. It includes a parallel resonant circuit and serial resonant circuit with inductively coupled with each other an auxiliary parallel circuit inductively coupled with each the first parallel circuit. The parallel circuits are excited by a different output elements of an input reactive power source (i. e. its inductance and capacitance). The auxiliary circuit excitates the current resonance in the parallel circuits i.e. the effect of the conditional "negative resistance", thus evoidily the converter import on the reactive power source. The electromagnetic processes are analyzed using the well-known methods of the electric-circuit theory irrespective the resonant phenomena physics. The impact on the processes in the reactive-power source of a current maximum in the converter load is neglected. The calculated scheme element base parameters not only removing losses but even and increase the input power.

Keywords: parallel circuit; power converter; inductive coupling; calculation mode

Samovzdrževalni resonančni pretvornik jalove moči v aktivno

Predlagana je shema samovzdrževalnega resonančnega pretvornika jalove moči v aktivno. Vključuje vzporedno resonančno vezje in serijsko resonančno vezje, ki sta med seboj induktivno sklopljena in tudi pomožno vzporedno vezje, induktivno povezano s prvim vzporednim vezjem. Oba vzporedna vezja vzbujajo različni izhodni elementi vhodnega vira jalove moči (to je njegova induktivnost in kapacitivnost). Imenovanje pomožnega vezja je vzbujanje stroge tokovne resonance v obeh vzporednih tokokrogih (učinek pogojnega "negativnega upora"), kar omogoča izključitev vpliva pretvornika na vir jalove moči v celoti. Analiza tekočih elektromagnetnih procesov je bila izvedena s pomočjo dobro znanih metod teorije električnih tokokrogov brez privlačnosti hipotez o fiziki resonančnih pojavov. Določeni so pogoji, za izpolnjevanje katerih je izključen vpliv na procese v viru jalove energije pri tokovnem maksimumu v obremenitvi pretvornika. Izračunani so bili parametri realne sheme, ki so omogočili na račun izbire elementne baze ne le odstranitve izgub, temveč celo povečanje vhodne moči).

1 INTRODUCTION

The intense public interest, in assuring on effective conversion of the different types energy (solar, windy, thermal, etc.) into the electrical energy is faced mill the problems of the modern scientific policies and technical state of the art. They effect as projects pursuing natural possibilities, their practical use and solution for the power engineering economy.

In 1896, Nikola Tesla patented his apparatus for the production of the electrical currents of a high frequency and potential. The patent was grouted to him represented itself for a "super effective voltage converter". In the special literature, it is referred "Tesla transformer". This invention is the first step taken forwards advanced electric devices of an endless significance [1].

2 A BRIEF LITERATURE REVIEW

The Tesla ideas have been further development by many authors. In [2] his transformer is used in an experimental attempt to generate a super effective resonant converter with a transformation coefficient of k>1000.

[3] optimizes parameters of the Tesla transformer secondary winding, try suppressing the higher harmonics amplitude-frequency spectrum. [4] investigates transient processes in the resonant circuits of his transformer. In the above works, the calculations based on the electric circuit theory methods on mode without any hypotheses about the physical state of the material world. Thus, obtained results and numerical estimates fully agree with the Tesla qualitative conclusions formulated at the beginning of the last century.

[5, 6] present patents granted effective for heat and electricity converters. [5] presents using non-linear dielectrics capacitors, converting their inner energy into electricity a "charge-discharge" cycle. In [6] authors present a further development of their previous work.

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They determine the parameters of the "charge-discharge" cycle to increase the energy conversion.

[7, 8, 9] present different schemes of the resonant converters. They use the electric active-reactive circuits in the "voltage resonance" regime. Unlike in the Tesla transformer, the output element is either the inductance or the capacitance with an equal but opposite directional voltage. Thus receive coefficient of the reactive power increase is k≈33 [9].

The electric resonant amplifiers considerably improve the output parameters levels compared to the known converters of different kinds of energy. However, their deficiency is the output of the reactive power, which poses a problem for a practical use. A solution is a scheme able to converter the reactive into the active power. In [10], the authors therefore propose a circuit of two inductively coupled parallel resonant circuits and a series resonant circuit (the main elements of the proposed circuit), the first of which (i.e. the input of the converter) is connected to the output of the reactive power source (into the inductance or capacitance). The active resistance, i.e. the load of the suggested converter, is connected in the second serial circuit (i.e. the converter output circuit). With an inductive coupling between the circuits, the active power of the excited electric signal is singled out in the converter load. The converter operability is enabled by an additional source voltage in the inductive branch of the input parallel circuit. At appropriate amplitude-phase characteristics, the "current resonance" is excited in the circuit. As the currents in the reactive-power source output on zero, the suggested scheme of the converter does not affect the reactive power source proper. Its deficiency is connecting completely an additional voltage source, which decreases the converter efficiency.

A solution is to introduce an auxiliary parallel RLC-circuit into the converter scheme instead of an additional voltage source. The auxiliary circuit has to be inductively connected to the converter input circuit and excited by a reactive-power source. A converter of such type can be regarded as a “self-sustaining” resonant converter of the reactive into the active power. The aim of the paper is to prove operability of the proposed self-sustaining resonant converter using an auxiliary parallel circuit excited by a reactive-power source.

3 PROBLEM FORMULATION

DEPENDENCIES CALCULATION

To solve of the formulated problem, a comparison is mode between the proposed scheme of the self-sustaining converter and a scheme of the converter with an additional voltage source as suggested in [10].

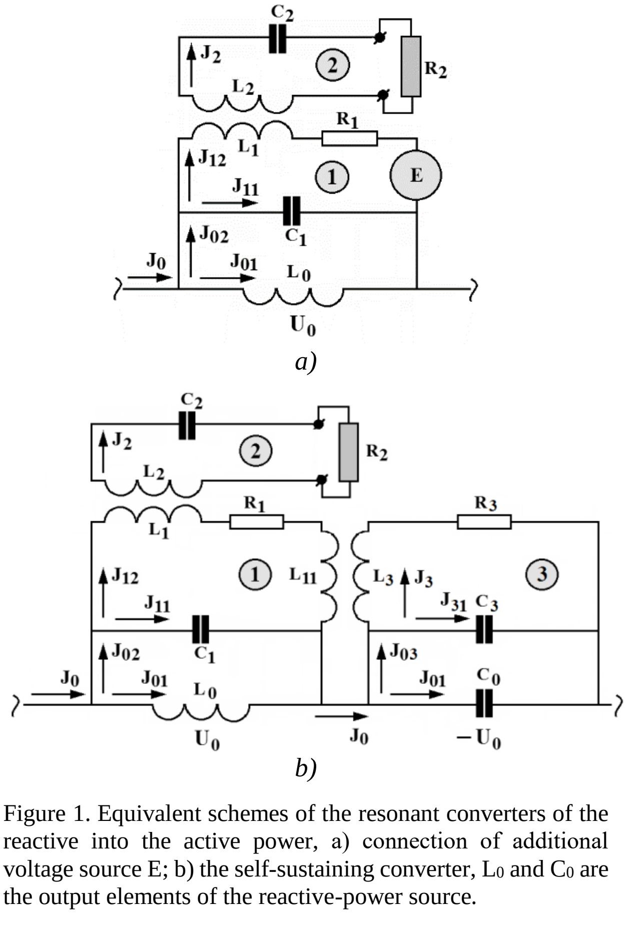
3.1 Electric schemes

Fig.1. shows the equivalent schemes of the resonant converters of the reactive into the active power. A common point of these schemes is two inductively coupled circuits (1 and 2). The first in each of them is excited in the current resonance regime. The second is excited in the voltage resonance regime [11]. The load in the suggested converter schemes is the active resistance (R_2), connected in the second resonant circuit (2). Input current J_0 enters into the output elements of the reactive power source. They are the inductance (L_0) and capacitance (C_0) with the current J_{01} and voltage $\pm U_0$. The variants use different excitation methods of the “current resonance” in circuit 1. In the scheme in Fig.1a, an additional source (E) the corresponding conditions are mode using of the harmonic voltage. In the scheme in Fig.1b, the problem is solved by connecting the auxiliary parallel circuit **3**, which excited by the capacitance output of the reactive power source (C_0).

3.2 Action Principle.

Despite of the differences, the two converter schemes operate in the same way. Parallel circuit **1** in each of them is excited in the regime of the current resonance. Serial circuit **2** is excited in the voltage resonance regime.

The output currents in the s from the reactive power source decrease (J_{02}=0). The voltage on capacitance C_1 equals the voltage of reactive power source $U_0(t)$. Using inductive coupling «L_1- L_2», the electromagnetic energy in parallel circuit **1** transforms into serial circuit 2 with active load R_2, where the active power of the flowing current stands out.



a)

b)

Figure 1. Equivalent schemes of the resonant converters of the reactive into the active power, a) connection of additional voltage source E; b) the self-sustaining converter, L_0 and C_0 are the output elements of the reactive-power source.

The relation between the active power on the converter output and the reactive power on the input is a quantitative index of the transformation of one energy kind into the other of the using the purposed resonant converter scheme.

The general electro-dynamic particularities of the converter proposed scheme should be noted. The first uses a parallel circuit with the "current resonance" to exclude the impact on the reactive-power source. The second use the serial circuit with the "voltage resonance" to maximize the output active power in the converter load.

In Fig.1b, inductive coupling «L_3 – L_{11}» between circuits **2** and **3** is used as a harmonic voltage additional source (Fig.1a). Using appropriate parameters, the inductive coupling does not affect the processes in the reactive-power source by minimizing currents $J_{02} \rightarrow 0$ and $J_{03} \rightarrow 0$.

The main analytical dependencies between the characteristics of the proposed self-sustaining converter scheme will be given below.

3.3 Problem formulation.

- Circuit 1 (a parallel circuit, the converter input circuit) has a branch with two inductances, i.e. L_1 and L_{11}, an active resistance R_1 and a branch with capacitance C_1. The circuit branches of a connected parallel to inductance L_0 that is the first output element of the reactive-power source with harmonic voltage $U_{L_0}(t) = U_{L_0 m} \cdot \sin(\omega \cdot t)$, where $U_{L_0 m}$ is the amplitude, ω is the cyclic frequency and t is the time.
- Circuit 2 (a serial circuit, the converter output circuit) contains inductance L_2 (the winding active resistance is negligibly small), capacitance C_2 and load active resistance R_2.
- Circuit 3 (a parallel circuit, the converter auxiliary circuit) has a branch with the inductance L_3, with active resistance R_3 and a branch with capacitance C_3. The circuit branches are connected in parallel with capacitance C_0 which is the second output element of the reactive-power source with harmonic voltage $U_{C_0}(t) = U_{C_0 m} \cdot \sin(\omega \cdot t)$, where $U_{C_0 m}$ is the amplitude ($U_{L_0 m} \neq U_{C_0 m}$).
- All circuit frequencies are the same so that $\omega_1 = \omega_2 = \omega_3 = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{L_2 C_2}} = \frac{1}{\sqrt{L_3 C_3}} = \omega$ is the converter resonance frequency.
- Relation between the output active power and the input reactive power in first output element L_0 determines the conversion quantitative index of one kind of the electromagnetic energy in another one, by using proposed scheme of the self-sustaining resonant converter.

3.4 Main calculation dependencies.

The calculation dependencies assuring efficiency the proposed converter scheme are based on the physically "transparent" phenomenological statements and on a mathematical approach using the electric circuit theory methods [11].

The next dependencies for the voltages and currents concern the impact equivalence of the additional source shown in Fig.1a and the inductive coupling, shown in the scheme in Fig.1b on the excitation of the resonance regimes in parallel circuits 1 and 3.

a) Circuit 1 [10] and circuit 3 [11],

$$\begin{cases} E_1 = -\,iU_{C_1} \cdot \left(\dfrac{1}{Q_1} + k_{12}^2 \cdot Q_2 \right) = i\omega M_{13} \cdot J_3, \\ J_3 = -iU_{C_3} \cdot \dfrac{1}{Q_3 \cdot R_3}, \end{cases} \qquad (1)$$

where U_{C_1} is the voltage on capacitance C_1 (in current resonance $U_{C_1} = U_{L_0}$); $Q_1 = \frac{\omega L_1}{R_1}$ – is the Q-factor of the circuit 1; L_1 is the inductance of the coupling winding in circuit – 1 with circuit 2; R_1 is the active resistance of circuit 1; $k_{12} \in [0,1]$ is the level index of the electromagnetic coupling between circuits 1 and 2; $Q_2 = \frac{\omega L_2}{R_2}$ is the Q-factor of circuit 2; U_{C_3} is the voltage on capacitance C_3 (in current resonance $U_{C_3} = U_{C_0}$); L_2 is the inductance of the coupling winding in circuit 2 with circuit 1; $M_{13} = k_{13} \cdot \sqrt{L_{11} \cdot L_3}$ is the mutual inductance; $k_{13} \in [0,1]$ is the level index of the electromagnetic coupling between circuits – 1 and 3; L_{11} is the inductance of the coupling winding in circuit 1; L_3 is the inductance of the coupling winding in circuit – 3; $Q_3 = \frac{\omega L_3}{R_3}$ is the Q-factor of circuit 3; R_3 is the active resistance of circuit 3.

b) Circuit 3 and circuit 1 [11],

$$\begin{cases} E_3 = -\,iU_{C_3} \cdot \dfrac{1}{Q_3} = i\omega M_{13} \cdot J_{12}, \\ J_{12} = -iU_{C_1} \cdot \dfrac{1}{Q_1 \cdot R_1}. \end{cases} \qquad (2)$$

Let us find the relation equivalent between voltages $\left(\frac{E_1}{E_3} \right)$. After some substitutions and mathematical transformations, the following dependence is obtain.

$$Q_3\cdot\left(\frac{U_{C_1}}{U_{C_3}}\right)^2=\left(\frac{L_1}{L_3}\right)\cdot\frac{Q_1}{\left(1+k_{12}^2\cdot Q_1Q_2\right)}. \tag{3}$$

The connection between the parameters of the proposed converter scheme is given by Eq. (3), where the currents in the inputs to parallel circuits 1 and 3 vanish and influence of these currents on the reactive power source is being excluded.

In a positively tested resonant amplifier used as a reactive-power source in the scheme of the proposed converter, the below dependence applies for the voltage of the reactive elements output [9]

$$\frac{U_{C_1}}{U_{C_3}}=\frac{U_{L_0}}{U_{C_0}}=\frac{1}{1+\left(\frac{L_{2T}}{L_0}\right)}, \tag{4}$$

where L_{2T} is the inductance of the secondary winding of the coupling transformer of the amplifier output circuit.

Remark. The scheme of the reactive power resonant amplifier contains two inductive serial circuits. The first of them with the source of the amplified power is the input circuit. The second one with reactive elements L_0 and C_0 is the output circuit. The coupling between the circuits is model using a transformer. Its primary winding is input circuit inductance L_{1T}. Secondary winding inductance L_{2T} this is part of the output circuit full inductance ($L_{2T} + L_0$) [9].

Taking into account dependence (4), correlation (3) can be written in a functional connection form between the parameters of the electric scheme proposed converter.

$$\left(Q\cdot L_3\right)=\left(1+\left(\frac{L_{1T}}{L_0}\right)\right)^2\cdot\frac{\left(Q_1\cdot L_1\right)}{\left(1+Q_1\cdot\left(k_{12}^2\cdot Q_2\right)\right)}. \tag{5}$$

It should be noted that dependence (5) is the result of the problem. It proves the operational efficiency of the proposed scheme converting the reactive into the active power.

Using relation (5) excites the resonance in the parallel circuits and nullifies the currents at their input. Eventually, it excludes their impact on the resonant processes in the reactive-power source.

The coefficient of the reactive-power conversion into the active is determined in [10] and with Eq. (6):

$$K_{conv}=\frac{|P_2|}{|P_0|}=\left(\frac{L_0}{L_1}\right)\cdot k_{12}^2\cdot Q_2, \tag{6}$$

where P_2 is the power in the active load, P_0 is the power of the output inductance of the resonant amplifier which is the input reactive power in the proposed converter scheme, k_{12} is the level coefficient of the electromagnetic coupling level between the inductances of circuits – 1 and 2 and Q_2 is the Q-factor of output circuit 2 of the self-sustaining resonant converter.

Taking into account dependence (5), expression (6) for the conversion coefficient of the reactive power into the active one takes the following form:

$$K_{conv}=\left(\frac{L_0}{L_1}\right)\cdot\left(\left(1+\left(\frac{L_{1T}}{L_0}\right)\right)^2\cdot\left(\frac{L_1}{Q_3\cdot L_3}\right)-\frac{1}{Q_1}\right). \tag{7}$$

3.5 *Analysis and numerical estimates*

The numerical estimates are made for the resonant amplifier of the reactive power given in [9]. The characteristics of the self-sustaining converter circuits' are accepted in accordance with [10].

1. The reactive-power source (the resonance amplifier).

a) The working frequency ω=2π·25000 Hz.

b) The inductances $L_{1T}=14.8\cdot10^{-6}$ H, $L_0=169\cdot10^{-6}$ H.

2. The converter.

a) Circuit 1: $Q_1=\frac{\omega L_1}{R_1}\approx 26.7$, $R_1=\frac{\omega L_1}{Q_1}\approx 0.087$ Om, L_1=14,8 H.

b) Circuit 2: $Q_2=\frac{\omega L_2}{R_2}\approx 10.0$, $L_0=169\cdot10^{-6}$ H, load active resistance $R_2=\frac{\omega L_2}{Q_2}\approx 2.7$ Om.

c) Circuit 3: its characteristic assure of the proposed scheme converting of the reactive into the active power (according to dependence (5)).

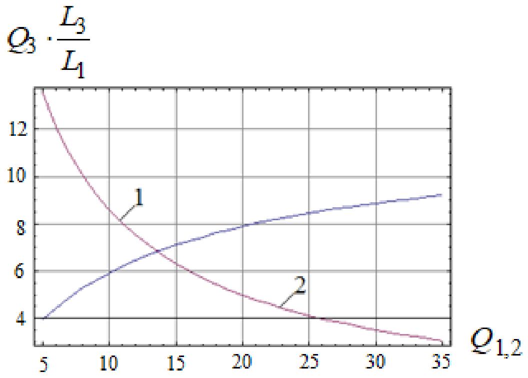


Figure 2. Main characteristics of the self-sustaining converter, 1 – Q_2 = var if Q_1=26,7 [10]; 2 – Q_1 = var if Q_2=10 [10].

A practical application of the proposed scheme shows good results and meets expectancies of the estimates for the self-sustaining resonant converter experimental model.

When the Q-factors of the parallel circuits are the same, $Q_3=Q_1$, expression (5) gives the following result.

$$\frac{L_3}{L_1}=\frac{\left(1+\left(\frac{L_{1T}}{L_0}\right)\right)^2}{\left(1+k_{12}^2\cdot Q_1 Q_2\right)}. \qquad (8)$$

Using (8) and the known value Q-factor ($Q_3=Q_1\approx 26.7$), the inductance and active resistance of the additional parallel circuit get $R_3\approx 0.028$ Om, $L_3=4.77\cdot 10^{-6}$ H. Further, $K_{conv}\approx 1.14>1.0$ (7). It means that besides the conversion the input electric power also increase.

Following the above, our calculations provide enough high output characteristics of the conversion of the reactive into the active power using the corresponding parameters of the suggested self-sustaining converter connected to a resonant amplifier from [9].

4 CONCLUSION

Paper proposes scheme of a self-sustaining resonant converter of the reactive into active power. It contains two inductively coupled parallel circuits connected to reactive elements of the output circuit of the reactive power resonant source suggested.

The obtained analytical dependencies justify the practical operability of the proposed resonant converter circuit with an auxiliary parallel circuit instead of a harmonic voltage additional source.

It is shown that chosen parameters of the proposed self-sustaining converter enable both energy conversion and increase in the input electric power thus realized conversion coefficient is $K_{conv}\approx 1.14>1.0$.

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