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Introduction of an additional source of harmonic signal into the circuit of the electric power resonant amplifier

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Annotation. Problem. *The problems of the electric power industry, caused by the depletion of the natural resources of the planet and the need to replace them, initiate the development of new physical and technical solutions with the practical use of the known natural phenomena.* ***Goal.*** *The purpose of this work is to propose to introduce an additional source of a harmonic signal (voltage or current) into the circuit of a resonant amplifier of electric power, to obtain calculated analytical dependencies for numerical estimates of the characteristics of ongoing electromagnetic processes, which make it possible to give a fundamental justification for the real performance of the proposed circuit as a whole, taking into account the interaction of all its functional components.* ***Methodology****. This work, ultimately, involves the use of resonant phenomena in circuits with active-reactive elements and their theoretical analysis using the mathematical apparatus of the theory of electrical circuits.* ***Result****s. It is proposed to implement the resonant amplifier circuit in the form of four active-reactive closed circuits inductively coupled to each other. Moreover, in a practical embodiment, inductive couplings can be carried out using HF ferrites. The first circuit is the input circuit with the harmonic power source to be amplified. The second circuit generates amplified reactive power in the "voltage resonance" mode. The third circuit with an additional harmonic voltage source outputs reactive power from the second circuit in the "current resonance" mode. The fourth circuit, inductively coupled to the third circuit, contains the output load of the entire resonant amplifier. This is a resistor that simulates the release of active power.* ***Originality.*** *Physically, the introduction of an additional source in the third circuit is equivalent to the creation of a "negative active resistance", which makes it possible to create conditions for excitation of current resonance with the minimum possible distortion and, ultimately, to reduce the reverse effect on the amplifying processes in the second circuit (reactive power amplifier). The analysis and numerical evaluation of the characteristics of the proposed scheme of the active electric power resonant amplifier showed its fundamental viability.* ***Practical value****. As an example, calculations of currents and voltages in the circuit of an experimental model were made, which enabled to formulate recommendations for the selection of elements of a real active electric power amplifier with high efficiency for low-resistance output loads.*

Key words: *resonance amplifier, inductive connections, additional harmonic signal source, resonance of currents and voltages, active-reactive circuit.*

Introduction

As it follows from the information generalization represented in the different scientific publications the resonance can be a key to the energetic spike in the oscillatory systems of the different physical nature. For example, the historical facts of the bridge constructions mechanical destroying are well known to the world science but they are non-obvious in the sense of the their physical causality. There are many analogical questions to the resonant phenomena appearance in the heat processes, the electrical circuits and much other. Their analysis leads to the fundamental question formulation about a source the energy of which allows fulfilling a work what is impossible in traditional understanding of the physical processes cause-effect tie. There are different hypothesizes the essence of which consists in some universal substance existence which posses by the great energetic potential (for example, it can be the “dark matter", the "physical vacuum", the ether etc.). In dependence on the realization conditions this potential can become apparent in a sharp burst kind of the thermal energy, of the nuclear energy and finally of the electromagnetic energy [1–3]. Not stopping on the works dedicated to the fundamental questions of our Universe structure the undoubted interest of the world public to the known technical elaborations which are directed to solution of the modern power engineering problems should particularly extracted [4].

Analysis of publications

The efficiency of the electric resonance-rectifier circuit for the renewable energy conversion is analyzed in the work [5]. The scientific edition [6] is dedicated to a concise technical overview of energy technology: the sources of energy, energy systems and frontier conversion. Here are the advanced converters, catalysts, fuel cells, membranes, metal-hydrides, refrigerators and M.H.D. solar cells, finally. The articles [7, 8] illuminate the theoretical investigations of the electromagnetic processes in Tesla transformer which was the first technically realized suggestion of the voltage resonant amplifier. The got results and the numerical estimates agree well with the qualitative conclusions of the Great Inventor. Appearance of the Patent [9] is conditioned by the practical interest to the power resonant amplify. The subject of the invention is related to the impact excitation systems in the electrical power engineering but It can find application in the uninterrupted power supply units, in the electromagnetic vibration transmitting apparatuses etc. Finally, the work [10] is dedicated to the experimental justification of the electrical power resonant amplifier workability. To the authors opinion the main result of the conducted investigations is the experimental fact when the output reactive electrical power exceeds more than ~33 times of the source input power.

The practical interest represents a scheme elaboration of the electrical energy resonant amplifier where (unlike the previous analogue!) the active electrical power is generated which can be used physically for the different works fulfilling.

The aim of the present investigation is the scheme suggestion of the active electrical power resonant amplifier, analysis and numerical estimates of the flowing electromagnetic processes characteristics for the principally justification of the suggested scheme real workability.

Purpose and Tasks

Electrical scheme, action principle.

The electrical equivalent scheme of the suggested resonant amplifier of the active electrical power consisting of the four resonant circuits is represented on Fig. 1.

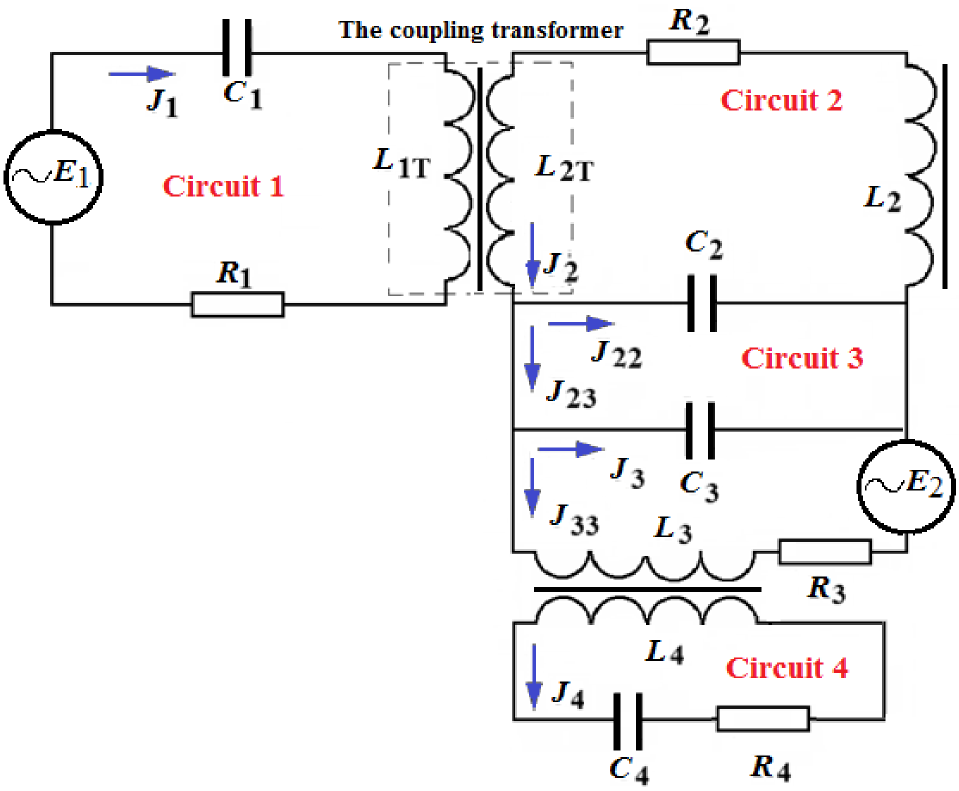

Fig. 1. Electrical equivalent scheme of the resonant amplifier of the active electrical power

The first of them – 1 with source of the harmonic voltage – E_1 is the amplifier input circuit. Its current and voltage transmit to the second serial circuit – 2 with help of the coupling transformer «L_{1T} – L_{2T}». Here the amplified reactive power from the output element (the capacitance – C_2) transmits to input (the capacitance – C_3) of the parallel resonant circuit – 3. The latter one is inductively coupled with the serial circuit – 4 the output element of which is modeled by resistor – R_4. This is the load where the amplified active electrical power is liberated.

The particularity of the suggested scheme consists in what the parallel circuit – 3 contains the additional source of the harmonic voltage – E_2. Its appointment consists in the conditions creation for the "current resonance" regime in which a back influence on the serial circuit – 2 is excluded.

A relation of the active power in the output element of the circuit – 4 (load, resistor – R_4) to the power of the energy source in the input circuit – 1 is the quantitative index of the electromagnetic energy conversion in suggested scheme of the resonant amplifier of the active electrical power.

Problem formulation.

- The input serial circuit – 1 contains the capacitance – C_1, the inductance – L_{1T} (the primary winding of the coupling transformer between the circuits 1–2), the active resistance – R_1 and the source of the harmonic voltage $E_1(t) = E_1 \cdot \sin(\omega \cdot t)$ (E_1 – is the amplitude, ω – is the angular frequency, t – is the time).
- The amplifying serial circuit – 2 contains the inductance – L_{2T} (this is the secondary winding of the coupling transformer between the circuits 1–2), the capacitance – C_2 (the output element), the inductance – L_2 and active resistance – R_2 (this can be the resistance of the winding inductances and coupling wires).
- The parallel circuit – 3 contains the capacitance – C_3, the active resistance – R_3 (the resistance of the windings inductances and the coupling wires), the inductance – L_3 and the additional source of the harmonic voltage – $E_2(t) = E_2 \cdot \sin(\omega \cdot t)$ (E_2 – is the amplitude).
- The output serial circuit – 4 contains the inductance – L_4, the capacitance – C_4 and the resistor – R_4 which models the amplifier active load.
- The frequencies of all resonant circuits are equal to each other resonant frequency.

$$\omega_1 = \frac{1}{\sqrt{L_1C_1}} = \omega_2 = \frac{1}{\sqrt{L_2C_2}} = \omega_3 = \frac{1}{\sqrt{L_3C_3}} = $$
$$= \frac{1}{\sqrt{L_3C_3}} = \omega_4 = \frac{1}{\sqrt{L_4C_4}} = \omega - \text{is the amplifier}$$

Main calculation dependencies.

The calculation dependencies for the workability theoretical justification of the suggested scheme are based on the physically "transparent" phenomenological statements and the strict mathematical approach with the electrical circuit theory methods usage [11].

We shall start from the "output" circuits of the amplifier resonant.

According to the equivalent scheme on Fig. 1 the state equations in the serial and parallel circuits – 3 and 4 accept the view [11]:

$$\begin{cases} R_4 \cdot J_4 + i\omega\left(k_{34} \cdot \sqrt{L_3L_4}\right) \cdot J_{33} = 0; \\ \left(i\omega L_3 + R_3\right) J_{33} + i\omega\left(k_{34}\sqrt{L_3L_4}\right) J_4 - \\ -E_2 = U_{C_3}; \\ J_3 = i\omega C_3 \cdot U_{C3}, \end{cases} \quad (1)$$

where $k_{34} \in [0, 1]$ – is the coefficient of the electromagnetic coupling level between the circuits – 3 and 4; J_4 – is the current in the circuit – 4 with the inductance – L_4, with the capacitance – C_4 and the active resistance of the load – R_4; J_{33}, J_3 – are the currents in branches of the circuit– 3; J_{33} – is the current in the branch with the inductance – L_3,with active resistance – R_3 and additional source of the harmonic voltage – E_2; J_3 – is the current in the branch with the capacitance – C_3; U_{C3} – is the voltage on the capacitance – C_3.

The currents being excited can be found from the linear algebraic equations system (1) [9].

$$\begin{cases} J_4 = -\dfrac{i\omega\left(k_{34} \cdot \sqrt{L_3L_4}\right)}{R_4} \cdot J_{33}; \\ J_{33} = \dfrac{U_{C_3} + E_2}{\left(i\omega L_3 + R_3 \cdot \left(1 + k_{34}^2 \cdot Q_3 \cdot Q_4\right)\right)}; \\ J_3 = i\omega C_3 \cdot U_{C_3}, \end{cases} \quad (2)$$

The current – J_{23} in the output from the capacitance – C_2 can be determined as sum the currents in the branches of the parallel circuit taking into account the resonance:

$$J_{23} = J_3 + J_{33} = \frac{\left(E_2 + iU_{C_3}\left(\frac{1}{Q_3} + k_{34}^2 Q_4\right)\right)}{R_3\left(iQ_3 + \left(1 + k_{34}^2 \cdot Q_3 \cdot Q_4\right)\right)}. \quad (3)$$

From (3) we receive that for $J_{23} = 0$ the next condition has to be fulfilled:

$$E_2 = -i \cdot U_{C_3} \cdot \left(\frac{1}{Q_3} + k_{34}^2 \cdot Q_4\right). \quad (4)$$

It should be marked that in practices, the necessary voltage of the additional source can be determined when the voltage amplitude variation till to obtain the zero current in the input to the circuit – 3 from the capacitance – C_2 in the circuit – 2.

With help of (2) and (4) we find the voltage and current in the load active resistance – R_4:

$$\begin{cases} U_4 = U_{C_3} \cdot \left(k_{34} \cdot \sqrt{\frac{L_4}{L_3}}\right) \cdot e^{-i \cdot \frac{\pi}{2}}; \\ J_4 = \frac{U_{C_3}}{R_4} \cdot \left(k_{34} \cdot \sqrt{\frac{L_4}{L_3}}\right) \cdot e^{-i \cdot \frac{\pi}{2}}. \end{cases} \quad (5)$$

Let us return to analysis of the condition (4). If this condition is fulfilled the "current resonance" regime is excited in the parallel circuit – 3. The current in the output from the capacitance – C_2 to the circuit – 3 is equal to zero (J_{23} = 0). The electromagnetic processes in the resonant circuits – 2 and 1 are flowing independently on the processes in the circuits – 3 and 4.

The last final conclusion allows analyzing excitation of the circuit – 2 and 1 by the source of the harmonic voltage – E_1 without any coupling with the circuits – 3 and 4.

The state equations system has the view [11]:

$$\begin{cases} E_1 = \left(i\left(\omega L_{1T} - \frac{1}{\omega C_1}\right) + R_1\right) J_1 + i\omega M_{12} J_2; \\ -i\omega \cdot M_{12} J_1 = \left(i\left[\omega L_{2S} - \frac{1}{\omega C_2}\right] + R_2\right) J_2; \end{cases} \quad (6)$$

where J_{12} – are the currents in the circuits – 1 and 2, correspondingly; $M_{12} = k_{12} \cdot \sqrt{L_{1T} L_{2T}}$ – is the mutual inductance, $k_{12} \in [0, 1]$ – is the coefficient of the electromagnetic coupling level between the circuits 1–2; $L_{2S} = (L_{2T} + L_2)$ – is the summary inductance of the circuit – 2.

Under resonance conditions

$$\left\{\left(\omega \cdot L_{2S} - \frac{1}{\omega C_2}\right) = 0, \left(\omega L_{1T} - \frac{1}{\omega C_1}\right) = 0\right\}$$

the equations system (6) accepts the view

$$\begin{cases} E_1 = J_1 \cdot R_1 + i\omega M_{12} \cdot J_2; \\ -i\omega M_{12} \cdot J_1 = R_2 \cdot J_2. \end{cases} \quad (7)$$

The expressions for the currents being excited can be got from (7).

Should mark that parameter – Z in (8) can be interpreted as a module of the equivalent inductive resistance. It ties the source power voltage – E_1 with the resonant current – J_2 in the second circuit. And as it follows from the corresponding expression in (8) this tie has the strictly inductive character.

Let us rewrite the corresponding expression for J_2 separately for strict clearness in the further analysis of the flowing electromagnetic processes.

$$\begin{cases} J_1 = E \cdot \frac{R_2}{\left((\omega M_{12})^2 + R_1 \cdot R_2\right)}; \\ J_2 = -i \cdot \frac{E_1}{Z}, \end{cases} \quad (8)$$

where $Z = \frac{(\omega M_{12})^2 + R_1 \cdot R_2}{\omega M_{12}}$.

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$$J_2 = -i \cdot \frac{E_1}{Z}, \quad (9)$$

where $Z = \frac{(\omega M_{12})^2 + R_1 \cdot R_2}{\omega M_{12}}$.

Obviously, the functional dependence $Z = Z(\omega M_{12})$ has to have a minimum what determines a maximum of the current – J_2 as of function of the argument – (ωM_{12}).

The necessary condition of the extremum existence for the function – Z = Z(ωM_{12}) is being written in the view [12]:

$$\frac{dZ(\omega M_{12})}{d(\omega M_{12})}=\frac{(\omega M_{12})^2-R_1R_2}{(\omega M_{12})^2}=0. \quad (10)$$

As it follows from the expression (10), the equivalent resistance module reaches the minimum under $(\omega M_{12})_{\min}=\sqrt{R_1\cdot R_2}$. And the corresponding resistance minimum will equal to – $Z_{\min}=2\sqrt{R_1\cdot R_2}$.

In the terms of the parameters of the circuits – 2 and 1 the realization condition of the minimal value of the equivalent resistance – Z has the view:

$$\omega\cdot k_{12}\cdot\sqrt{L_{1T}\cdot L_{2T}}=\sqrt{R_1\cdot R_2}. \quad (11)$$

The estimate of the electromagnetic coupling coefficient which provides the secondary current maximum – $J_{2\max}$ follows from the expression (11).

$$k_{12-\max}=\sqrt{\frac{R_1\cdot R_2}{(\omega\cdot L_{1T})\cdot(\omega\cdot L_{2T})}}. \quad (12)$$

Physically, the found minimum of the equivalent resistance ting the secondary current with the voltage – E_1 of the power source and determining the maximum power amplifying can be explained by the minimally possible return of the energy from the secondary circuit – 2 to the primary circuit – 1. At that all this process is being provided by the electromagnetic coupling level between the circuits correspondingly to the formula (12).

$$\begin{cases} J_1=\dfrac{E}{2R_1}; \\ U_{C_2}=-E_1\cdot\dfrac{1}{2\omega C_2\cdot\sqrt{R_1\cdot R_2}}= \\ =\left\|\dfrac{1}{\omega C_2}=\omega L_{2S}\right\|=-E_1\cdot\dfrac{\omega L_{2S}}{2\sqrt{R_1\cdot R_2}}. \end{cases} \quad (13)$$

To calculate the integral coefficient of the active electrical power conversion in the suggested scheme of the resonant amplifier the formulas should be written for the current in the circuit – 1 and the voltage in the “output element” – L_2 of the circuit – 2.

Taking into account that $U_{C_3}=U_{C_2}$, after substitution of the expression for U_{C_2} to (5) we find the voltage and current in the load active resistance – R_4.

$$\begin{cases} U_4=-E_1\cdot\dfrac{\omega L_{2S}}{2\sqrt{R_1\cdot R_2}}\cdot\left(k_{34}\cdot\sqrt{\dfrac{L_4}{L_3}}\right); \\ J_4=-E_1\cdot\dfrac{\omega L_{2S}}{2R_4\sqrt{R_1\cdot R_2}}\left(k_{34}\cdot\sqrt{\dfrac{L_4}{L_3}}\right). \end{cases} \quad (14)$$

According to (13) and (14) the power amplitudes in the circuit – 1, in the circuit – 2 and in the circuit – 4 (the amplifier output of the active electrical power) will be determined by the following dependencies.

$$\begin{cases} P_{1m}=\dfrac{E_1^2}{2R_1}; \\ P_{2m}=\dfrac{E_1^2}{R_1}\cdot\dfrac{Q_2}{4}; \\ P_{4m}=E_1^2\cdot\dfrac{R_2}{4R_4\cdot R_1}\cdot Q_2^2\cdot\left(k_{34}^2\cdot\dfrac{L_4}{L_3}\right), \end{cases} \quad (15)$$

where $Q_2=\dfrac{\omega L_{2S}}{R_2}$ – is the Q-factor of the circuit – 2.

The conversion coefficients of the electrical power in the suggested scheme of the resonant amplifier can be found as the relations of the corresponding values from the expressions (15):

$$\begin{cases} \text{a) from circuit } - 1 \text{ to circuit } - 2, \\ K_{1-2}=\dfrac{P_{2m}}{P_{1m}}=\dfrac{Q_2}{2}; \\ \text{b) from circuit } -2 \text{ to circuit } - 4, \\ K_{2-4}=\dfrac{P_{4m}}{P_{2m}}=\left(\dfrac{L_{2S}}{L_3}\right)\cdot k_{34}^2\cdot Q_4; \\ \text{c) from circuit } -1 \text{to circuit } -4, \\ K_{1-4}=\dfrac{P_{4m}}{P_{1m}}=\dfrac{Q_2}{2}\cdot\left(\dfrac{L_{2S}}{L_3}\right)\cdot k_{34}^2\cdot Q_4. \end{cases} \quad (16)$$

The introduced power – P_{E_2} (of the additional source) normalized on the power – P_{2m} which is introduced from the circuit – 2 (under the resonant conditions) is being determined by the expression:

$$\left|\frac{P_{E_2}}{P_{2m}}\right| = \left(\frac{1}{Q_3} + k_{34}^2 \cdot Q_4\right), \qquad (17)$$

where $P_{2m} = \dfrac{U_{L_3}^2}{\omega L_3}$ – is the power introduced from the circuit – 2 in the terms of the parameters of the circuit – 3.

For practice, the formula allowing the efficiency integral estimation of the amplifier in the whole is interesting. It can be got as relation:

$$K_{1-4}^{(E_2)} = \left|\frac{P_{4m} - P_{E_2}}{\mathrm{P}_{2m}}\right| = \frac{Q_2}{2}\left(k_{34}^2 Q_4 \left(\frac{L_{2S}}{L_3} - 1\right) - \frac{1}{Q_3}\right), \quad (18)$$

where P_{4m} – is the output power in the load active resistance in the terms of the amplifier parameters.

As it follows from the formula (18) the active power in the load which is determined with taking into account power of the additional source can be considered as some efficiency conditional characteristic which permits evaluating the minimally possible value of the output power in the scheme of the considered amplifier.

Analysis, numerical estimates

From physical consideration it is obvious that for the amplifier efficiency maximum a contribution of the power additional source in exciting the "current resonance" in the parallel circuit has to be minimal. As it follows from dependencies (4), (17) and (18), for this it is necessary quite high Q-factor – $Q_3 >> 1$ and quite weak electromagnetic coupling with the serial circuit in aggregate with quite small Q-factor, so that – $k_{34}^2 \cdot Q_4 << 1$. Simultaneously, the dependence for the power conversion coefficient – (16), (17) and (18) demands increasing parameter – $k_{34}^2 \cdot Q_4$.

The efficiency illustrations of the experimental model of the active power resonant amplifier are represented on Fig. 2, Fig. 3. The following initial data were accepted for calculation: $\omega = 2 \cdot \pi \cdot 25000$ Гц, $L_{1T} = L_{2T} = L_3 = 14{,}8$ мкГн, $L_2 = 169$ мкГн, $R_2 = 0{,}35$ Ом, $R_1 = R_3 = 0{,}1$ Ом, $k_{34} = 0{,}1$.

Practically straight-proportional tie of the conversion integral coefficient and the power of the additional source follows from the calculations results on Fig. 2.

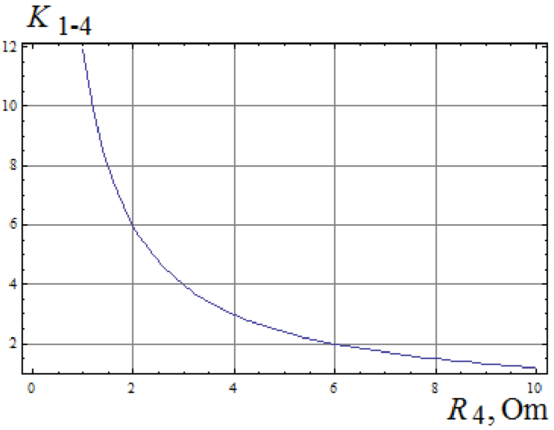

Fig. 2. The amplifying efficiency of the active power as function from the load resistance without taking into account the power contribution of the additional source

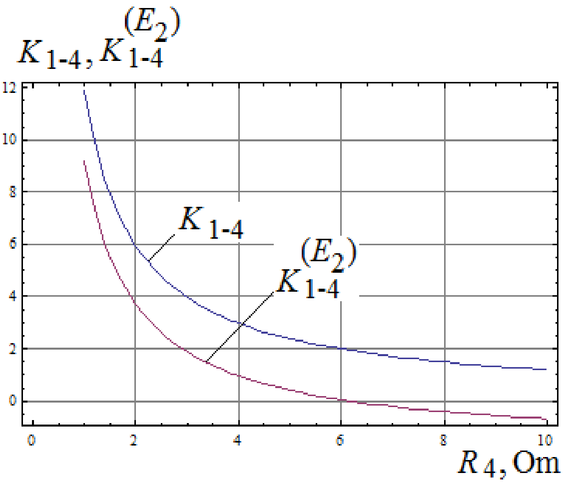

Fig. 3. Illustration of the additional source power influence on the active power amplifying in dependence on the load resistance

Really, a substitution of (17) into the expression for $K_{1\text{–}4}$ from (16) leads to the relationship:

$$K_{1-4} = \frac{Q_2}{2} \cdot \left(\frac{L_{2S}}{L_3}\right) \cdot \left(\left|\frac{P_{E_2}}{P_{2m}}\right| - \frac{1}{Q_3}\right). \qquad (19)$$

Physically, this tie supposes the growth possibility of the conversion coefficient but with the simultaneous growth of the power of the additional source.

Finally, last comment. The curves on Fig. 3 illustrate the output power falling down in the dependence on the load resistance with and without taking into account the power of the additional source.

Conclusion

The resonant amplifier scheme of the active electrical power which is represented by the series of the inductively coupled resonant circuits is suggested.

The distinguishing particularity of the present suggestion is introduction of the additional source of the harmonic voltage what permits excluding the back influence of the output currents and voltages on the processes of their resonant amplifying.

The conclusions about the real workability of the active power suggested amplifier are formulated on the basing the numerical estimates and the characteristics analysis of the flowing processes.

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Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Введення додаткового джерела гармонічного сигналу в схему резонансного підсилювача електричної потужності

Анотація. Проблема. *Проблеми електроенергетики, зумовлені виснаженням природних ресурсів планети, і їх заміщення ініціюють розробки нових фізико-технічних рішень із практичним використанням відомих природних явищ.* ***Мета.*** *Метою даної роботи є пропозиція ввести додаткове джерело гармонічного сигналу (напруги або струму) в схему резонансного підсилювача електричної потужності, отримання розрахункових аналітичних залежностей для чисельних оцінок характеристик протікаючих електромагнітних процесів, які дозволяють дати принципове обґрунтування реальної працездатності запропонованої схемі в цілому з урахуванням взаємодії всіх її функціональних складових.* ***Методологія****. Прийняті в роботі підходи до вирішення поставленої мети базуються на використання резонансних явищ у контурах з активно-реактивними елементами та їх теоретичний аналіз із залученням математичного апарату теорії електричних ланцюгів.* ***Результати.*** *Схему резонансного підсилювача пропонується реалізувати у вигляді чотирьох активно-реактивних замкнутих контурів, що індуктивно пов'язані між собою. Причому в практичному варіанті виконання індуктивні зв'язки можуть здійснюватися за допомогою високочастотних феритів. Перший контур є вхідним контуром із джерелом гармонічної потужності, яку необхідно підсилити. Другий контур генерує посилену реактивну потужність режимі «резонансу напруг». Третій контур з додатковим джерелом гармонічної напруги здійснює виведення реактивної потужності другого контуру в режимі «резонансу струмів». Четвертий контур, індуктивно пов'язаний з третім контуром, містить вихідне навантаження всього резонансного підсилювача. Це резистор, моделює вивільнення активної потужності.* ***Оригінальність.*** *Фізично, введення додаткового джерела в третьому контурі еквівалентно створенню «негативного активного опору», що дозволяє створити умови для збудження резонансу струмів з мінімально можливим спотворенням і, в кінцевому підсумку, знизити зворотний вплив на підсилювальні процеси в другому контурі (підсилювач реактивної потужності). Проведений аналіз та чисельні оцінки характеристик запропонованої схеми резонансного підсилювача активної електричної потужності показали її принципову дієздатність.* ***Практичне значення****. Як приклад виконані розрахунки струмів і напруг у схемі експериментальної моделі, що дозволило сформулювати рекомендації щодо вибору елементів реального діючого підсилювача активної електричної потужності, що має високі показники ефективності для низькоомних вихідних навантажень.*

Ключові слова: *резонансний підсилювач, індуктивні зв'язки, додаткове джерело гармонічного сигналу, резонанс струмів та напруг, активно-реактивний контур.*

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