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THE RESONANT AMPLIFIER OF THE ACTIVE ELECTRICAL POWER WITH ADDITIONAL VOLTAGE SOURCE. SUGGESTIONS, ANALYSIS, NUMERICAL ESTIMATES

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ABSTRACT *The problem of increasing energy saving in industry leads to the need to develop new technical devices. The paper presents and analyzes the circuit of the resonance amplifier of active electric power, evaluates the characteristics of electromagnetic processes for the fundamental substantiation of the operation of real devices based on this circuit. Mathematical analysis of electromagnetic processes taking place was carried out using strict methods of the theory of electric circuits. The advantages of this scheme in comparison with similar previous proposals are shown. The device includes four active-reactive circuits that are inductively connected. The first of them is an input circuit with a harmonic signal source that needs to be amplified. The second circuit generates enhanced reactive power in the "voltage resonance" mode. The third circuit with an additional voltage source provides reactive power output from the second circuit in the "resonance of currents" mode without adverse effects on amplification processes. The fourth circuit, inductively connected to the third circuit, contains an output load - a resistor that simulates the allocation of active power. On the basis of the analysis and numerical evaluation of the characteristics of the processes taking place in the proposed scheme of the resonance amplifier of active electric power, its basic efficiency is shown. The calculations of the experimental model made it possible to formulate recommendations for the selection of circuit elements of a working resonant amplifier with a high efficiency for low-impedance output loads. The considered real parameters of the device make it possible to minimize the dissipation of the energy of converted electrical signals and to increase the amplification factor of the electric power of harmonic currents and voltage by choosing the element base. The obtained results can be considered as practical recommendations for the creation of real devices for amplifying active electric power for use in various industries.*
Keywords: *resonant amplifier of the active power; active-reactive electrical circuits; voltage resonance; current resonance.*

РЕЗОНАНСНИЙ ПІДСИЛЮВАЧ АКТИВНОЇ ЕЛЕКТРИЧНОЇ ПОТУЖНОСТІ З ДОДАТКОВИМ ДЖЕРЕЛОМ НАПРУГИ. ПРОПОЗИЦІЇ, АНАЛІЗ, ЧИСЛОВІ ОЦІНКИ

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АНОТАЦІЯ *Проблема підвищення енергозбереження у промисловості призводить до необхідності розробки нових технічних пристроїв. В роботі представлена та проаналізована схема резонансного підсилювача активної електричної потужності, проведені оцінки характеристик електромагнітних процесів для фундаментального обгрунтування роботи реальних приладів на основі даної схеми. Математичний аналіз електромагнітних процесів, що відбуваються, проводився строгими методами теорії електричних контурів. Показано переваги даної схеми в порівнянні з аналогічними попередніми пропозиціями. У складі приладу розглянуті чотири активно-реактивних контури, які індуктивно пов'язані між собою. Перший з них – це вхідний контур з джерелом гармонічного сигналу, який необхідно посилити. Другий контур генерує посилену реактивну потужність в режимі «резонанс напруги». Третій контур з додатковим джерелом напруги здійснює вихід реактивної потужності з другого контуру в режимі «резонанс струмів» без зворотного впливу на процеси підсилення. Четвертий контур, індуктивно з'єднаний з третім контуром, містить вихідне навантаження – резистор, який моделює виділення активної потужності. На основі аналізу та чисельної оцінки характеристик процесів, що протікають у запропонованій схемі резонансного підсилювача активної електричної потужності, показана її принципова працездатність. Проведені розрахунки експериментальної моделі дозволили сформулювати рекомендації щодо вибору елементів схеми робочого резонансного підсилювача з високим коефіцієнтом корисної дії для низькоомних вихідних навантажень. Розглянуті реальні параметри приладу дозволяють шляхом вибору елементної бази виключити до мінімуму розсіювання енергії перетворених електричних сигналів і підвищити коефіцієнт підсилення електричної потужності гармонічних струмів та напруги. Отримані результати можна розглядати як практичні рекомендації для створення реальних пристроїв для підсилення активної електричної потужності при застосуванні у різних галузях промисловості.*
Ключові слова: *резонансний підсилювач активної напруги; активно-реактивні електричні кола; резонанс напруги; резонанс струмів.*

Introduction

The growing energy needs of mankind is evident in our time all over the world. The increasing role of electricity both in industry and in everyday life is emphasized, for example, in works [1-3]. One of the general directions for solving the energy challenges of today is the development and

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improvement of alternative energy sources [4-7]. However, at present, we still have quite a lot of unresolved issues that do not allow us to consider such a direction as finally sufficient. Another direction can be considered the development of technical devices that would make it possible to improve the energy performance of existing energy sources, for example, on the basis of resonance phenomena.

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 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 possess 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 of the electromagnetic energy [8-10]. 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 [11].

The efficiency of the electric resonance-rectifier circuit for the renewable energy conversion is analyzed in the work [12]. The scientific edition [13] 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 [14,15] 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 [16] 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 [17] 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. Of practical interest is the development of a circuit of a resonant amplifier of electrical energy, where (unlike the previous analogue) active electrical energy is generated, which can be physically used to perform various works, for example, for the systems proposed by the authors of the works [18,19] for non-contact work on repairing vehicles.

The aim of the work

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.

1. Problem formulation, main calculation dependencies

1.1. 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.

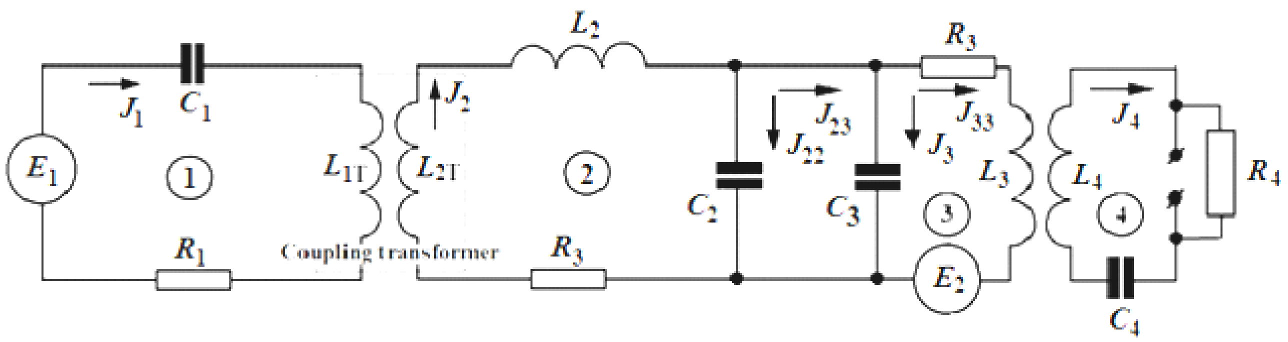

Fig. 1 - Electrical equivalent scheme of the resonant amplifier of the active electrical power

The first of them – 1 with source of the harmonic voltage – E_1 – 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 ower 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.

1.2. Problem formulation

Let's consider the proposed scheme and its parameters in more detail.

- The input serial circuit 1 contains the capacitance C_1, the inductance L_{1T} (primary the winding of the coupling transformer between the circuits 1–2), the active resistance R_1 and the source of the harmonic voltage $E_1(t) = E_1 \cdot \sin(\omega t)$ (E_1 is the amplitude, ω is the angular frequency, t – 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 $E_2(t) = E_2 \cdot \sin(\omega t)$ (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 $\omega_1 = 1/\sqrt{L_1C_1}; \omega_2 = 1/\sqrt{L_2C_2}$; $\omega_3 = 1/\sqrt{L_3C_3} = \omega_4 = 1\sqrt{L_4C_4}$ – the amplifier resonant frequency: $\omega_1 = \omega_2 = \omega_3 = \omega_4 = \omega$.

The main task of the research is to evaluate the integrated efficiency of the amplifier as a whole by finding the appropriate gain coefficients depending on the parameters of this circuit.

1.3. 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 [20].

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 [20]:

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

where $k_{34} \in [0,1]$ is the coefficient of the electromagnetic coupling level between the circuit 3 and the circuit 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_4, 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_{C_3} is the voltage on the capacitance C_3.

The currents being excited can be found from the linear algebraic equations system (1) [18].

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

where $Q_3 = \dfrac{\omega L_3}{R_3}, Q_4 = \dfrac{\omega L_4}{R_4}$ are the Q-factors of the circuits 3 and 4 correspondingly.

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:

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

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 [20]:

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

where J_1 and J_2 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; $L_{2S} = \left(L_{2T} + L_2\right)$ is the summary inductance of the circuit 2.

Under resonance conditions

$$\omega \cdot L_{2S} - 1/\omega C_2 = 0; \quad \omega L_{1T} - 1/\omega C_1 = 0$$

the equations system (6) accepts the view:

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

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

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

where

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

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

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

where

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

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

The necessary condition of the extremum existence for the function $Z = Z\left(\omega M_{12}\right)$ is being written in the view [12]:

$$\frac{dZ\left(\omega M_{12}\right)}{d\left(\omega M_{12}\right)} = \frac{\left(\omega M_{12}\right)^2 - R_1 R_2}{\left(\omega M_{12}\right)^2} = 0. \quad (10)$$

As it follows from the expression (10), the equivalent resistance module reaches the minimum under $\left(\omega M_{12}\right)_{\min} = \sqrt{R_1 \cdot R_2}$. 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:

$$\omega k_{12}\sqrt{L_{1T}L_{2T}} = \sqrt{R_1 R_2} \ . \tag{11}$$

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

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

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).

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

$$\begin{cases} J_1 = \dfrac{E}{2R_1}; \\ \mathrm{U}_{C_2} = -E_1 \dfrac{1}{2\omega C_2 \cdot \sqrt{R_1 \cdot R_2}} = \\ = \left\| \dfrac{1}{\omega C_2} = \omega L_{2S} \right\| = -E_1 \dfrac{\omega L_{2S}}{2\sqrt{R_1 \cdot R_2}}. \end{cases} \tag{13}$$

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.

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

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

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

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):

a) from circuit 1 to circuit 2

$$K_{1-2} = \frac{P_{2m}}{P_{1m}} = \frac{Q_2}{2};$$

b) from circuit 2 to circuit 4

$$K_{2-4} = \frac{P_{4m}}{P_{2m}} = \left(\frac{L_{2S}}{L_3} \right) k_{34}^2 Q_4; \tag{16}$$

c) from circuit 1 to circuit 4,

$$K_{1-4} = \frac{P_{4m}}{P_{1m}} = \frac{Q_2}{2}\left(\frac{L_{2S}}{L_3} \right) k_{34}^2 Q_4.$$

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:

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

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:

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

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.

1.4. 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: $\omega = 2\pi \cdot 25000$ Hz, $L_{1T} = L_{2T} = L_3 =$ 14,8 μH, $L_2 = 169$ μH, $R_2 = 0{,}35$ Om, $R_1 = R_3 = 0{,}1$ Om, $k_{34} = 0{,}1$.

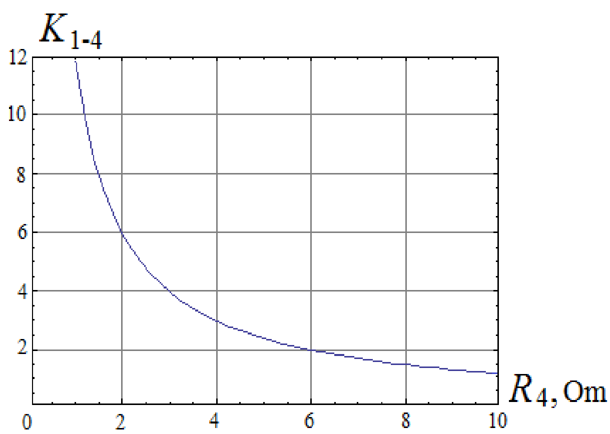

Fig. 2 – The amplifying efficiency of the active power as function from the load resistance without taking into account the power contribution of the additional source

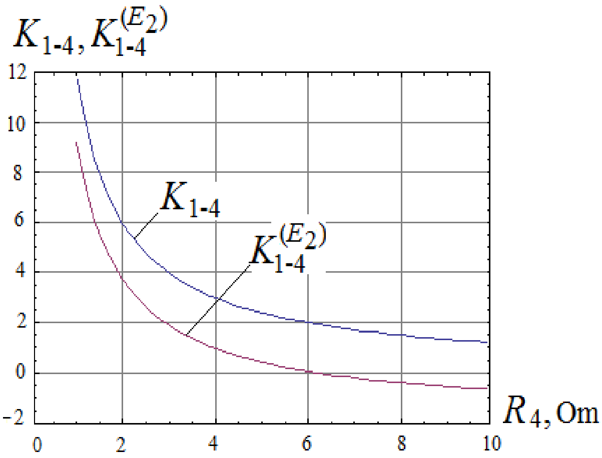

Fig. 3 – Illustration of the additional source power influence on the active power amplifying in dependence on the load resistance

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

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

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

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.

Conclusions

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.

An expression for the coefficient of integral transformation of the device is obtained, which is related to the power of the additional source and makes it possible to estimate the efficiency of the amplifier as a whole.

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.

Список літератури

1. Energy Technology Perspectives 2017. Catalysing Energy Technology Transformations. International Energy Agency, France: IEA Publications, 2017. doi: 10.1787/energy_tech-2017-en.
2. Petrović S. N., Diachuk O., Podolets R., Semeniuk A., Bühler F., Grandal R., Boucenna M., Balyk O. Exploring the long-term development of the ukrainian energy system. *Energies*. 2021. Vol. 22. no. 14. P. 7731. doi: 10.3390/en14227731.
3. Mengi-Dincer H., Ediger V. S., Yesevi C. G. Evaluating the International Renewable Energy Agency through the lens of social constructivism. *Renewable and Sustainable Energy Reviews*. 2021. Vol. 152. P. 111705. doi: 10.1016/j.rser.2021.111705.
4. Mercure J.-F., Salas P., Vercoulen P., Semieniuk G., Lam A., Pollitt H., Holden P. B., Vakilifard N., Chewpreecha U., Edwards N. R., Vinuales J. E. Reframing incentives for climate policy action. *Nature Energy*. 2021. Vol. 12. no. 6. P. 1133-114. doi: 10.1038/s41560-021-00934-2.
5. Kies A., Schyska B., Bilousova M., Sayed O., Jurasz J., Stoecker H. Critical review of renewable generation datasets and their implications for European power system models. *Renewable and Sustainable Energy Reviews*. 2021. Vol. 152. P. 111614. doi: 10.1016/j.rser.2021.111614.
6. Gong E., Ali S., Hiragond C., Kim H., Powar N., Kim D., Kim H., In S.-I. Solar fuels: research and development strategies to accelerate photocatalytic CO_2 conversion into hydrocarbon fuels. *Energy & Environmental Science*. 2021. Vol. 3. no. 15. P. 880-937. doi: 10.1039/D1EE027114J.
7. Barrows S., Homer J., Orrell A. Valuing wind as a distributed energy resource: A literature review. *Renewable and Sustainable Energy Reviews*. 2021. Vol. 152. P. 1116782021. doi: 10.1016/j.rser.2021.111678.
8. Whittaker Ed. T. *A History of the theories of ether and electricity Vol. 1: The classical theories* (2. ed.), London. Nelson Publ., 1951.
9. Etkin V. A. *The Theoretical Basis's of the Non-Fuel Power Engineering*. Altaspera Publ. & Literary Agency Inc., 2013.
10. Tesla N. *My Inventions and Other Writing*. Dover Drift Edition. Dover Publication Inc., 2016.
11. Shedleski Ty. *Inventions of Nikola Tesla: A Complete Set of Patents*. Book Shed. 2014.
12. Boström C., Ekergård B., Leijon M. Electric resonance-rectifier circuit for renewable energy conversion. *Applied Physics Letters*. 2012. Vol. 100(4). doi: 10.1063/1.3680097.
13. Tokio Ohta. *Energy Technology: Systems, Sources and Frontier Conversion*. Elsevier Science Ltd., 2012. 245 p.
14. Batygin Yu. V., Serikov G. S., Shinderuk S. A. Main calculation relationships in double-circuit of the resonant amplifier of electrical power. *Bulletin of NTU "KhPI"*. 2018. Vol. 32(1308). P. 59-64.
15. Batygin Yu. V., Shinderuk S. A., Serikov G. S. The quantitative indices of the induction effects and the resonance phenomena in the Tesla transformer. *Danish Scientific Journal*. 2018. Vol. 11-1. P. 72-79.
16. Likhovid Yu. M. The resonant power amplifier. Patent UA №103215. 2015.
17. Batygin Yu. V., Shinderuk S. A., Serikov G. S., Yeryomina E. F. Resonant electric power amplifier. Experimental research. *Promising technologies and devices*. 2018. Vol 13. P. 18-25.
18. Batygin Yu. V., Shinderuk S. O., Chaplygin E. O., Fendrikov D. V. Double-circuit resonant electric power amplifier for magnetic-pulse processing of metals. *Technical Electrodynamics*. 2022. Vol. 3. P. 29-36. doi: 10.15407/techned2022.03.029.
19. Batygin Yu. V., Shinderuk S. O., Yeryomina O. F., Chaplygin E. A. Electromagnetic processes in a flat rectangular system with an inductor between thin bifilar coils. *Technical Electrodynamics*. 2021. Vol. 1. P. 3-9. doi: 10.15407/techned2021.01.003.
20. Thomson J. J. *Elements of the Mathematical Theory of Electricity and Magnetism*. Wentworth, 2016.
21. Kantorovich L. *Mathematics for Natural Scientists. Fundamentals and Basics*. Springer Nature Switzerland AG, 2016. 526 p. doi: 10.1007/978-1-4939-2785-2.

References (transliterated)

1. Energy Technology Perspectives 2017. Catalysing Energy Technology Transformations. International Energy Agency, France: IEA Publications, 2017. doi: 10.1787/energy_tech-2017-en.
2. Petrović S. N., Diachuk O., Podolets R., Semeniuk A., Bühler F., Grandal R., Boucenna M., Balyk O. Exploring the long-term development of the ukrainian energy system. *Energies*, 2021, vol. 22, no. 14, pp. 7731, doi: 10.3390/en14227731.
3. Mengi-Dincer H., Ediger V. S., Yesevi C. G. Evaluating the International Renewable Energy Agency through the lens of social constructivism. *Renewable and Sustainable Energy Reviews*, 2021, vol. 152, pp. 111705, doi: 10.1016/j.rser.2021.111705.
4. Mercure J.-F., Salas P., Vercoulen P., Semieniuk G., Lam A., Pollitt H., Holden P. B., Vakilifard N., Chewpreecha U., Edwards N. R., Vinuales J. E. Reframing incentives for climate policy action. *Nature Energy*, 2021, vol. 12, no. 6, pp. 1133-114, doi: 10.1038/s41560-021-00934-2.
5. Kies A., Schyska B., Bilousova M., Sayed O., Jurasz J., Stoecker H. Critical review of renewable generation datasets and their implications for European power system models. *Renewable and Sustainable Energy Reviews*, 2021, vol. 152, pp. 111614, doi: 10.1016/j.rser.2021.111614.
6. Gong E., Ali S., Hiragond C., Kim H., Powar N., Kim D., Kim H., In S.-I. Solar fuels: research and development strategies to accelerate photocatalytic CO_2 conversion into hydrocarbon fuels. *Energy & Environmental Science*, 2021, vol. 3, no. 15, pp. 880-937, doi: 10.1039/D1EE027114J.
7. Barrows S., Homer J., Orrell A. Valuing wind as a distributed energy resource: A literature review. *Renewable and Sustainable Energy Reviews*, 2021, vol. 152, pp. 1116782021, doi: 10.1016/j.rser.2021.111678.
8. Whittaker Ed.T. *A History of the theories of ether and electricity vol. 1: The classical theories* (2. ed.), London. Nelson Publ., 1951.
9. Etkin V. A. *The Theoretical Basis's of the Non-Fuel Power Engineering*. Altaspera Publ. & Literary Agency Inc., 2013.
10. Tesla N. *My Inventions and Other Writing*. Dover Drift Edition. Dover Publication Inc., 2016.
11. Shedleski Ty. *Inventions of Nikola Tesla: A Complete Set of Patents*. Book Shed. 2014.
12. Boström C., Ekergård B., Leijon M. Electric resonance-rectifier circuit for renewable energy conversion. *Applied Physics Letters*, 2012, vol. 100(4), doi: 10.1063/1.3680097.
13. Tokio Ohta. *Energy Technology: Systems, Sources and*

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Frontier Conversion. Elsevier Science Ltd., 2012. 245 p.
14. Batygin Yu. V., Serikov G. S., Shinderuk S. A. Main calculation relationships in double-circuit of the resonant amplifier of electrical power. *Bulletin of NTU "KhPI"*, 2018, vol. 32(1308), pp. 59-64.
15. Batygin Yu. V., Shinderuk S. A., Serikov G. S. The quantitative indices of the induction effects and the resonance phenomena in the Tesla transformer. *Danish Scientific Journal*, 2018, vol. 11-1, pp. 72-79.
16. Likhovid Yu. M. The resonant power amplifier. Patent UA №103215. 2015.
17. Batygin Yu. V., Shinderuk S. A., Serikov G. S., Yeryomina E. F. Rezonansnyj posyljuvach elektrychnoi' potuzhnosti. Eksperymental'ni doslidzhennja. *Perspektyvni tehnologii' ta prylady*. 2018, vol. 13, pp. 18-25.
18. Batygin Yu. V., Shinderuk S. O., Chaplygin E. O., Fendrikov D. V. Double-circuit resonant electric power amplifier for magnetic-pulse processing of metals. *Tekhnichna Elektrodynamika*, 2022, vol. 3, pp. 29-36, doi: 10.15407/techned2022.03.029.
19. Batygin Yu. V., Shinderuk S. O., Yeryomina O. F., Chaplygin E. A. Electromagnetic processes in a flat rectangular system with an inductor between thin bifilar coils. *Tekhnichna Elektrodynamika*, 2021. vol. 1, pp. 3-9, doi: 10.15407/techned2021.01.003.
20. Thomson J. J. *Elements of the Mathematical Theory of Electricity and Magnetism*. Wentworth, 2016.
21. Kantorovich L. *Mathematics for Natural Scientists. Fundamentals and Basics*. Springer Nature Switzerland AG, 2016. 526 p., doi: 10.1007/978-1-4939-2785-2.

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