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Pulse Resonance Active-Power Amplifier. Offer and Justification of Workability

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Formulation of the Problem: This work was initiated by the current energetics needs, due to the depletion of natural resources and the rapidly growing needs of the world economy.

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Pulse Resonance Active-Power Amplifier. Offer and Justification of Workability

Yu. V. Batygin [α], S. O. Shinderuk [σ] & E. O. Chaplygin [ρ]

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Methodology: When deriving the main analytical relationships to justify the fundamental possibility of resonant amplification of active electric power, it turned out to be sufficient to confine ourselves to the proposal and study of an amplifier circuit with a single excitation of a current pulse in the load. The mathematical apparatus of research is a set of provisions and methods for calculating transient processes in electrical circuits with active-reactive elements.

Novelty: For the first time, with a theoretical and experimental justification of the workability, a circuit of a pulsed amplifier of the active electrical power of a harmonic signal was proposed, consisting of two series contours with common capacitive storage. The first of them is a reactive power amplifier, and the second is a converter of reactive power into active power released when the excited current flows in any electrical load.

Main Results: With the justification of capacity, a circuit of a pulsed resonant active electric power amplifier is proposed, consisting of two series circuits with common capacitive energy storage. Analytical dependencies are obtained for the main characteristics of the ongoing electromagnetic processes and it is shown that the phenomenon of voltage resonance allows one to achieve an increase (by more than an order of magnitude!) in the active power of a harmonic voltage source. Based on the analysis, numerical estimates, and experimental testing, the workability of the proposed circuit of a pulsed resonant amplifier of active electric power is substantiated.

Practical Significance: A method for resonant amplification of the active electric power of harmonic signals is proposed. On a practical example, indicating the specific values of the circuit elements, its workability is illustrated. The results obtained can be used as the basis of a real technical device for obtaining resonant electrical energy from the surrounding space.

Keywords: harmonic signals, series circuits, voltage resonance, pulse mode, active electric power amplification.

I. INTRODUCTION

The expert estimates of the growing need in power resources are convincing in the multiple works of the International Energy Agency that has been fairly recognized for reliability of various forecasts on the global economic development. The prospective analysis results discussed at the relevant global forums specifically point out the development of the electric-power industry as a prerequisite for successful solving the tasks of the modern scientific-technical progress. According to the thought leaders, by 2060, the share of electricity in all end-consumption sectors will have to increase by more than twice [1]. In the background of the depleted natural resources, the so-called alternative power sources become rather important and significant. The known developments include wind generators, solar cells, gravity-driven systems, etc. However, their multiple advantages do not surpass the limited practical use of such sources that is, primarily, due to low productivity and considerable dependence on climatic conditions.

Along with the given offers on using the Earth and Sun energy, the studies of resonance phenomena are becoming more relevant, this may provide for considerable increase in the power output of technical systems of specific purpose.

Resonance, as a key to the "energy burst" in oscillatory systems of any physical nature, was first noted in the works by Nikola Tesla. Based on this idea, he created an "Apparatus for producing electric currents of high frequency and potential" (1896) with extra high voltage conversion ratio ($k>1000$) [2]. The ideas of N. Tesla were then developed in a number of scientific articles and monographs [3-7].

Thus, in work [3], electric oscillations are excited by the sea-waves energy conversion. The authors of the cited work substantiated the usability of the offer and showed that this was in the resonant mode of the circuit designs with the resistance-reactance components where considerable increase in the power output took place.

The work [4] offered the resonance switching of several power sources and loads to be used in the integrated power supply systems. According to the authors, the main advantage of such decision is, first of

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all, significant savings of power resources due to loss reduction in the resonant modes.

The resonance power converters of the solar cells in the space vehicles are described by the authors of the work [5]. The specific character of the performed study is the impact of vacuum on the output characteristics of the electrical equipment with resistance-reactance components in the resonant mode.

The works [6, 7] can be combined by identical from the physical point of view approaches to creation of resonance reactive-power amplifiers. This, the Ukrainian patent [6] protects the circuit design solution, where the series parallel *RLC*-circuits are switched into the circuit of the high-frequency sine voltage source. According to the author, the multiple reactive power increase of the output signal should be in the regime of the current resonance. The other approach to the same task is offered in the work [7]. It offers the idealized circuit design with two inductive coupled series resonant circuits. The idealization with zero active resistance of the output circuit shows possible considerable increase in the reactive power of the harmonic output signal. The general disadvantages of the last offers are essential difficulties in their usability.

The work [8] is devoted to the creation of the resonance reactive-power amplifier that offers a scheme with real series contours and adjustable inductive coupling between them. The authors conducted the theoretical analysis of the existing processes and, in contrast to the previously cited works [6, 7], the successful practical approbation of the amplifier model version was implemented. The opportunity of the reactive power amplification by more than ~ 33÷35 times was demonstrated by experiment.

As to the usability of the mentioned developments, for example, the magnetic pulse attraction of thin-wall metals being the basis for the modern repair technology of the body components of vehicles can be referred to [9]. Introduction of the resonance amplifier as an element of the electrical circuits for the capacitor storage charge and the discharge to the attraction tool winding will provide for meeting the basic requirements for the modern processing technologies [10, 11].

The next step to solve the problems of the modern electric-power industry is the creation of the harmonic-signal active-power amplifiers. Such devices can operate in the single excitation mode of the current pulse in a load or in the mode when the current in the load is represented as the continuous subsequence of the recurring signals.

The purpose of the work is to propose and justify the workability of a pulsed resonant amplifier of active electric power, consisting of two subsequent contours with a common capacitive energy storage, analysis of ongoing electromagnetic processes and numerical estimates of their main characteristics.

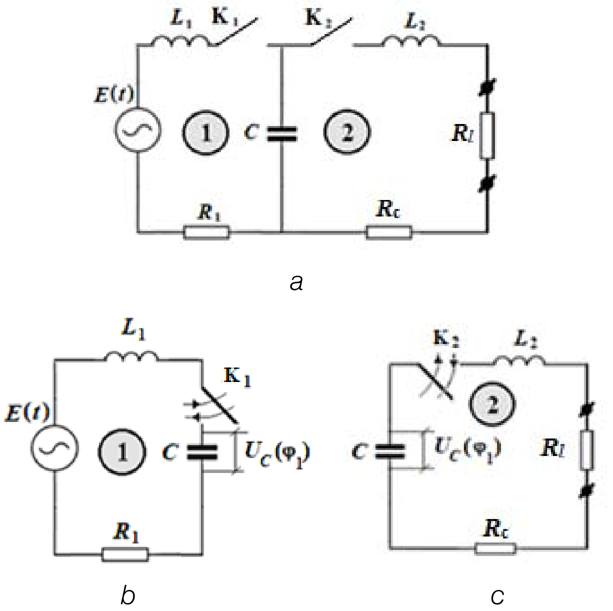
II. SUBJECT OF INVESTIGATIONS. PROBLEM STATEMENT

This paper is offering and studying the electrical scheme of the amplifier with single excitation of the current pulse in the load what is quite sufficient for substantiation of a practical possibility of the resonant of the active electrical power amplification.

a) *Electrical Circuit, Principle of Operation*

Fig. 1a shows the electrical circuit of the pulse resonance active-power amplifier. It consists of two series circuits with common capacitor storage *C*.

Circuit 1 is a subsequent R_1L_1C-contour (L_1 – inductance, R_1 – active resistance of conductors, including inductor winding). In the voltage resonance mode, the capacity *C* is charged till the specified voltage level U_{C0}. The stored electric energy will be equal to $W_0 = \left(C \cdot U_{C0}^2\right)/2$ (Fig. 1b).



a

b

c

Fig. 1: Electrical circuit of the pulsed resonance amplifier of the active electrical power (a); the series contour of the harmonic-signal reactive-power amplification (b); the series contour with the active load of the amplifier – R_l (c)

Circuit 2 is the active-reactive R_2L_2C-contour (L_2–inductance, R_2– total active resistance of all contour elements, R_2=R_c+R_l, R_c,R_c – active resistance of the conductors, including inductor winding, R_l– active load of the amplifier). In the voltage resonance mode, the charged capacity *C* is generating the active power in the load – R_l(Fig. 1c).

The pulsed operation mode of the proposed resonance power amplifier is implemented by single changeover of switches $K_{1,2}$ in the circuits. With the closed loop circuit K_1 and open circuit K_2, the capacitive storage C is charged to the specified voltage level (Fig. 1b). Should mark in contrast to the known chargers [6, 9, 10], the proposed series contour, in the voltage resonance mode, provides for charging the capacity to the voltage that considerably exceeds the source voltage (by the number of times being equal to the tuned-circuit Q-factor). Further on, the switch K_1 opens, and the switch K_2 closes. The capacity C is discharged to the active load R_l(Fig. 1c).

From the physical point of view, series contour 1 is the reactive power amplifier [6, 8], and contour 2 is the reactive-to-active power converter.

b) Problem Formulation

- Own resonant frequencies of the first and second circuits are – $\omega_1 = 1/\sqrt{L_1 \cdot C}$ and $\omega_2 = 1/\sqrt{L_2 \cdot C}$, respectively.
- The circuit 1 is excited by harmonic voltage $E(t)=E_m \sin(\omega_1 \cdot t)$, with the frequency being equal to own frequency of the first series circuit ω_1 and amplitude E_m (t – time).
- The charge circuit 1 Q-factor should be quite large ($Q_1=(\omega_1 \cdot L_1)/R_1>>1$), to ensure minimum power loss and maximum possible voltage capacity C.
- The discharge circuit 2 Q-factor ($Q_2=(\omega_2 \cdot L_2)/R_2$ –var) in accordance with the charge circuit 1 Q-factor should ensure maximum possible active power amplification in the load R_l.
- We suppose that the load resistance is much more than the resistance of the other discharge circuit elements, thus, $R_l>>R_c$ and $R_2 \approx R_l$.
- Corresponding to the operation principle of the proposed scheme of the amplifier of the active power, the theoretical description of its operation provides for considering the transition processes in each of its individual contour.

III. DESIGN RATIOS, QUALITATIVE ANALYSIS

a) Charge circuit 1 of the capacitive storage C (Fig. 1b)

In the Laplace image space, the equation of the state relative to the voltage on the capacitive storage at the zero initial conditions is as follows [7, 12]:

$$p^2 U_C(p) + 2\delta_1 \cdot p U_C(p) + \omega_1^2 \cdot U_C(p) = \omega_1^2 \cdot E(p), \quad (1)$$

where p – is a variable in the Laplace space, $U_C(p)=L\{U_C(t)\}$, $U_C(t)$ – is the voltage on capacity, $\delta_1=R_1/2L_1$ – is the attenuation factor, $E(p)=L\{E(t)\}$, $E(t)$ – is the harmonic voltage of the source.

According to the problem statement made, the energy dissipation in the charge circuit is minimum that means sufficient small value of the relative attenuation factor $\delta_{10}=\delta_1/\omega_1=1/2Q_1<<1$ and provides for neglecting the second-order additive components relative to value $\sim \delta_{10}$.

In this case, the voltage original across capacity C, as it follows from equation (1), with the involved time dependence for exciting voltage of the source $E(t)$, will be described by expression [12]:

$$U_C(t) = E_m \omega_1 \int_0^t e^{-\delta_1 \cdot (t-x)} \sin(\omega_1 (t-x)) \sin(\omega_1 \cdot x)\, dx \quad (2)$$

After calculating the integral in (2), neglecting the $\sim \delta_{10}^2 -$ order additive components and introducing a new variable $\phi = \omega_1 t$ – the excited signal phase, we obtain that

$$U_C(\varphi) \approx -E_m \cdot Q_1 \cdot \left(1 - e^{-\frac{1}{2 \cdot Q_1} \cdot \varphi}\right) \cdot \cos(\varphi) \quad (3)$$

The current in circuit 1 is determined by differencing the ratio (3) [7, 12]. Considering the voltage resonance condition $Q_1=(\omega_1 \cdot L_1)/R_1=1/(\omega_1 \cdot C) \cdot R_1$ when neglecting the $\sim$ $1/2Q_1$ values, we obtain that

$$J_1(\varphi) = (\omega_1 \cdot C) \cdot \frac{dU_C(\varphi)}{d\varphi} \approx \frac{E_m}{R_1} \cdot \left(1 - e^{-\frac{1}{2 \cdot Q_1} \cdot \varphi}\right) \cdot \sin(\varphi) \quad (4)$$

The reactive power of the signal in the capacity C is determined as the product of expressions (3) and (4) [12].

$$P_1(\varphi) \approx -\frac{E_m^2}{R_1} \cdot \frac{Q_1}{2} \cdot \left(1 - e^{-\frac{1}{2 \cdot Q_1} \cdot \varphi}\right)^2 \cdot \sin(2\varphi) \quad (5)$$

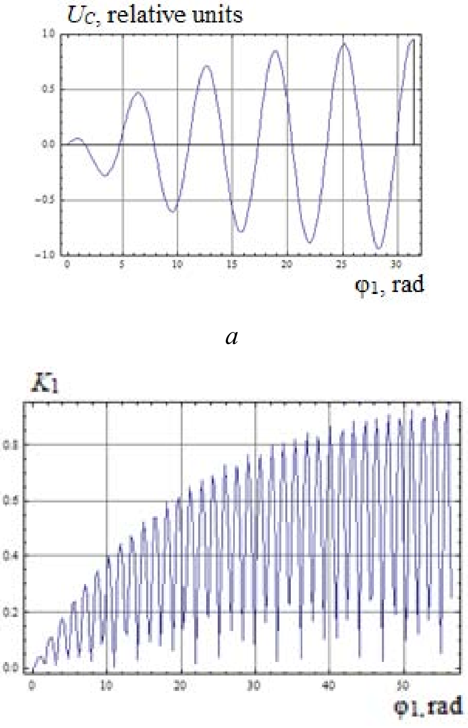
As it follows from (5), in the established mode at $\varphi>>1/2Q_1$ the amplitude ratio of the power output of the charge circuit to the power input of the voltage source is proportional to Q_1 that evidences the reliability of the ratios obtained for voltage, current and power.

The reactive power amplification ratio, as the relation module of the capacity power (5) to the voltage source power, will be described by the following dependence:

$$\left|\frac{K_1(\varphi_1)}{0{,}5 \cdot Q_1}\right| = \left|\frac{P_1(\varphi_1)}{P_{0m}}\right| = \left|\left(1 - e^{-\frac{1}{2 \cdot Q_1} \cdot \varphi_1}\right)^2 \cdot \sin(2 \cdot \varphi_1)\right|. \quad (6)$$

Note: Power amplitude of the voltage source with the voltage resonance in the series contour of charge is $P_{0m} = E_m^2 / R_1$.

The qualitative illustration of the obtained dependences of the charge voltage and the reactive power amplification ratio from the power source voltage phase till the moment of the charge finish for the charge circuit with the Q-factor of $Q_1=5.0$ is given in Fig. 2.



a

b

Fig. 2: Capacity charge voltage (a) and reactive power amplification ratio (b) (ϕ_1 – phase at the time of the charge finish)

As it follows from the dependences in Fig. 2, the first maximum of the charge voltage is ahead of the amplification ratio maximum. Thus, we have $U_C\approx1.0$ at $\phi_1\approx32$ rad., while $K_1\approx0.8$ with the same phase value when the charge finish (time moment the circuit opening!). That is, in this resonant circuit, the energy accumulation also continues after the first maximum of the charge voltage. The reactive power amplification ratio can reach maximum only at the circuit opening time that correspond to the positive or negative maximums of the charge voltage.

b) *Discharge unit 2 of the capacitive storage C (Fig. 1b)*

At the charge circuit opening time and the discharge circuit closing time, the voltage of the capacitive storage, as it follows from (3), will be determined by the dependence:

$$U_{C0}=U_C(\varphi_1)=-E_m\cdot Q_1\left(1-e^{-\frac{1}{2\cdot Q_1}\cdot\varphi_1}\right)\cdot\cos(\varphi_1), \quad (7)$$

It is of practical interest to consider the modes when the circuit can have no inductance ($L_2=0$), that is, the capacity is discharged directly to the active load or when the active load is connected via the solenoid with the fixed inductance value ($L_2\neq0$).

i. *Capacitor discharge to active load ($L_2=0$)*

We suppose that the aperiodic capacitor discharge starts immediately upon charge finish. The current in the active load considering (7) will be described by the following dependence [7, 12]:

$$J_2(\varphi)=J_2(\varphi)=\frac{E_m\cdot Q_1}{R_2}\left(1-e^{-\frac{1}{2\cdot Q_1}\cdot\varphi_1}\right)\cos(\varphi_1)e^{-\frac{1}{(\omega_1\cdot C)\cdot R_2}\cdot(\varphi-\varphi_1)} \quad (8)$$

$$\varphi\geq\varphi_1.$$

The instant signal power (8) in the load resistance R_2 is determined by the ratio [7, 12]:

$$P_2(\varphi)=J_2^2(\varphi)\cdot R_2=\frac{(E_m\cdot Q_1)^2}{R_2}\times$$
$$\times\left(1-e^{-\frac{1}{2\cdot Q_1}\cdot\varphi_1}\right)^2\cdot\cos^2(\varphi_1)\cdot e^{-\frac{2}{(\omega_1\cdot C)\cdot R_2}\cdot(\varphi-\varphi_1)} \quad (9)$$

The maximum amplification ratio is determined as maximum ratio of the power output in the load to the source power at $\phi_1\rightarrow(\pi\cdot n,\ n=0,1,2,\ldots)>>2Q_1$ and $\phi=\phi_1$:

$$K_{2\max}=\frac{P_2(\varphi=\varphi_1)\big|_{\varphi_1\to(\pi\cdot n,\ n=0,1,2\ldots\ldots)>>2Q_1}}{P_{0m}}=\frac{R_1}{R_2}\cdot Q_1^2 \quad (10)$$

It follows from (10) that with certain selection of the element base of the proposed circuit, it is possible to strengthen the instant harmonic signal power, as:

$$K_{2\max} = \frac{R_1}{R_2} \cdot Q_1^2 = \frac{\left(\frac{L_1}{C}\right)^2}{R_1 \cdot R_2} > 1 \qquad (11)$$

Note: $\sqrt{(L_1/C)} = Z_1 -$ is the wave resistance of the charge circuit.

For quantitative illustration of the obtained ratios, some preliminary estimates can be made. For example, for the charge circuit 1 Q-factor of Q_1=5, as it follows from the graph in Fig. 2a, the charge length can be minimally estimated by the value φ≤32≈5 of the power source voltage periods.

The calculations for phase distribution of the discharge current (8) with the same conditions and variations in the relative value of the active load R_1/R_2=var are given in Fig. 3.

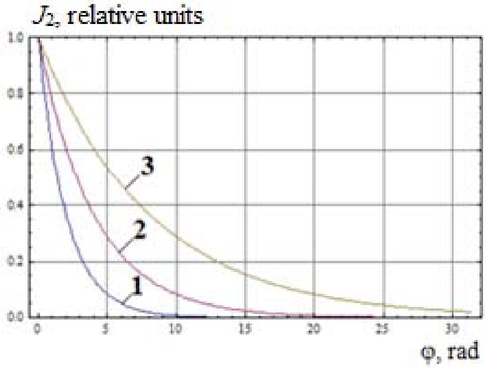


Fig. 3: Phase dependence of the discharge current rated to the maximum, 1 – R_1/R_2 = 0,1; 2 – R_1/R_2 = 0,05; 3 – R_1/R_2 = 0,025

As it follows from the calculations, the duration of the discharge current gets closer to the relevant duration of the charge of the capacitive storage with quite large load resistance values. But the increased load resistance at the constant voltage of the capacity charge means the decreased output signal power.

Therefore the discharge circuit design with the capacity connected immediately to the active load is of poor efficiency for the resonant amplification of the active power due to rather small duration of the discharge current in the load.

ii. *Capacity discharge through inductance to the active resistance, $L_2 \neq 0$*

In contrast to the previous considerations, since the amplifier circuits can work at different frequencies, the characteristics of the existing processes are better to be expressed not in the phase but in the time functional ratios.

We suppose that the variable capacity discharge in the voltage resonance mode starts immediately upon charge. The current in the active load considering at $\sqrt{L_2/C} >> 0.5 \cdot R_2$ considering (7) will be described by the following exponentially-damping harmonic time dependence [7, 12]:

$$J_2(t) \approx \frac{E_m}{R_2} \cdot \frac{Q_1}{Q_2} \cdot \left(1 - e^{-\frac{1}{2Q_1} \cdot \omega_1 \cdot t_1}\right) \times$$
$$\times \cos(\omega_1 \cdot t_1) \cdot e^{-\frac{1}{2Q_2} \cdot \omega_2 \cdot (t - t_1)} \sin(\omega_2 \cdot (t - t_1)),\ t \geq t_1, \qquad (12)$$

where t is the current time, t_1 – is the end time of the capacity charge and the start time of the capacity discharge, $\omega_2 \approx 1/\sqrt{L_2 \cdot C}$ and Q_2=$(\omega_2 \cdot L_2)/R_2$=$1/(\omega_2 \cdot C) \cdot R_2$ – is own frequency and tuned-circuit Q-factor in the representations that correspond to the voltage resonance in the discharge circuit.

The momentary signal power (12) in the load resistance R_2 is determined by the ratio [7, 12]:

$$P_2(t) = J_2^2(t) R_2 = \frac{E_m^2}{R_2} \left(\frac{Q_1}{Q_2}\right)^2 \left(1 - e^{-\frac{1}{2Q_1} \cdot (\omega_1 \cdot t_1)}\right)^2 \times$$
$$\times \cos^2(\omega_1 t_1) e^{-\frac{1}{Q_2} \cdot \omega_2 \cdot (t - t_1)} \sin^2(\omega_2 (t - t_1)),\ t \geq t_1 \qquad (13)$$

The maximum amplification ratio is determined as maximum ratio of the power output in the load to the source power amplitude at $(\omega_1 \cdot t_1) \rightarrow (\pi \cdot n, n = 0,1,2\ldots) >> 2Q_1$.

$$K_{2\max} = \frac{P_2(\omega_1 t_1 \rightarrow \pi \cdot n >> 2Q_1)}{P_{0m}} =$$
$$= \frac{R_1}{R_2} \cdot \left(\frac{Q_1}{Q_2}\right)^2 e^{-\frac{1}{Q_2} \cdot \frac{\pi}{2}} = \frac{R_2}{R_1} \cdot \left(\frac{\omega_2}{\omega_1}\right)^2 e^{-\frac{1}{Q_2} \cdot \frac{\pi}{2}} \qquad (14)$$

It follows from (14) that with certain selection of the element base of the proposed circuit, it is possible to strengthen the instant harmonic signal active power. In contrast to the analog previously considered, the amplification ratio contains dependence on the squared ratio of the charge and discharge circuit Q-factors that provides for additional opportunities for efficient implementation of the proposed circuit.

For quality illustration of the time dependence of the active power in the load, we write (13) with normalization to power accumulated in the capacity at the discharge initial time:

$$P_0(t) = \frac{P_2(t)}{\frac{E_m^2}{R_2} \left(\frac{Q_1}{Q_2}\right)^2 \left(1 - e^{-\frac{1}{2Q_1}(\omega_1 t_1)}\right)^2 \cos^2(\omega_1 t_1)} =$$
$$= e^{-\frac{1}{Q_2} \omega_2 (t - t_1)} \sin^2(\omega_2 (t - t_1)),\ t \geq t_1 \qquad (15)$$

The calculation results are given in Fig. 4, where $Q_2=10$, $\phi=\omega_2\cdot(t-t_1)$, $\phi_2=\omega_2\cdot(t_2-t_1)=10\cdot(2\cdot\pi)$ – the phase length of the specified interval of the discharge process, t_2 – end time of discharge.

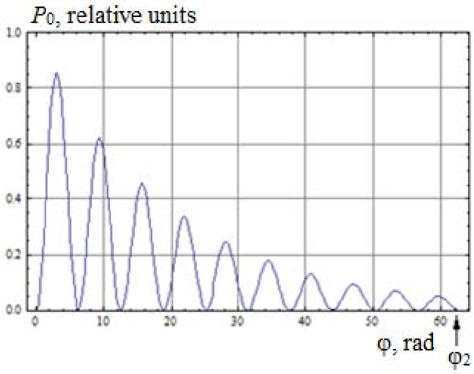


Fig. 4: Phase dependence of the power in the active loaded amplifier

The following indicators of the proposed amplifier at the specified length interval of the discharge process can be obtained from the dependence in Fig. 4.

- The maximum amplification ratio of the mean active power can reach:

a) if $\{Q_1/Q_2=10,\ R_1/R_2=1,\ 2Q_2>>\pi\}$, we obtain $\overline{K}_{2\max}\approx 15.2$;

б) if $\{Q_1/Q_2=50,\ R_1/R_2=0{,}1,\ 2Q_2>>\pi\}$, we obtain $\overline{K}_{2\max}\approx 38.0$.

- When selecting the amplifier circuit parameters, the mandatory exceedance of the charge circuit Q-factor in contrast to the similar discharge circuit value $(Q_1/Q_2) >> 1$ should be used as reference.
- The allowed ratio of the active resistances of the charge circuit and the load value (R_1/R_2) is corrected by the assumed ratio of the circuits Q-factors (Q_1/Q_2) of amplifier, in general.

IV. NUMERICAL ESTIMATES

We perform calculations that illustrate the potential efficiency of the proposed amplifier using the example of the model with discharge to load through inductance with single-time synchronous activation/deactivation of switches of the charge and discharge circuits. The parameters of the accepted model are taken from analogs given in work [8].

a) Circuit Operation

i. The schematic circuit of experimental model No.1 is given in Fig. 1a.

ii. In the initial position, the switch K_1 is closed, the switch K_2 is open.

iii. Efficiency of charge circuit 1:

  a. With the switch K_1 closed and the K_2 open, the voltage source E is connected, the capacity charge C takes place.
  b. When charged, the switch K_1 open, the capacity C remains charged to the maximum possible resonant voltage $U_{C0}=E\cdot Q_1$, where E is the source voltage.

iv. *Efficiency of discharge circuit 2:*

  a. Simultaneously with the switch K_1 opening in charge circuit 1, the switch K_2 closes in charge circuit 2.
  b. The active power of the amplified input harmonic signal is determined in the load resistance $R_l\approx R_2$.

b) Circuit Components

i. *Harmonic signal reactive power resonant amplification unit*

  a. Harmonic voltage generator $E(t)=E_m\cdot\sin(\omega_0\cdot t)$, $E_m\approx 1\ldots 10$ V amplitude, $\omega_0=2\cdot\pi\cdot f_0$, $f_0=25000$ Hz – operating frequency.
  b. Inductance $L_1=172.8\ \mu$H.
  c. Capacity $C=0.234\ \mu$F.
  d. Active resistance $R_1=0.46\ \Omega$.
  e. Q-factor $Q_1=(\omega_1\cdot L_1)/R_1\approx 59$.

Note: Own design frequency of circuit 1: $f_1 = 1/2\pi\cdot\sqrt{L_1\cdot C_1}\approx f_0 = 25000$ Hz.

ii. *Active load connection unit*

  a. Inductance $L_2=172.8\ \mu$H.
  b. Capacity $C=0.234\ \mu$F.
  c. Active resistance of conductors $R_c=0.46\ \Omega$.
  d. Active load resistance $R_l=5\ \Omega$ or $R_l=10\ \Omega$.
  e. According to the accepted assumption, the total active resistance of the circuit is $R_2\approx R_l$.
  f. Q-factor $Q_2=(\omega_2\cdot L_2)/R_2\approx 5$.

Note: Own design frequency of circuit 2: $f_2 = 1/2\pi\cdot\sqrt{L_2\cdot C_2}\approx f_0 = 25000$ Hz coincides with resonant frequency of the charge circuit f_1.

c) Calculations

i. *Charge voltage on the capacitive storage*

The design curve in Fig. 5 makes it possible to know the charge voltage for capacity that can be obtained depending on the charge time. This, the maximum voltage established by the charge circuit Q-factor requires charging for ~ 0.004 sec that makes ~ 100 source voltage periods for the assumed frequency of ~ 25 kHz. However, 50% of maximum voltage is achieved for much shorter time ~ 0.05 sec (almost by one order of magnitude lower than the charge time before maximum).

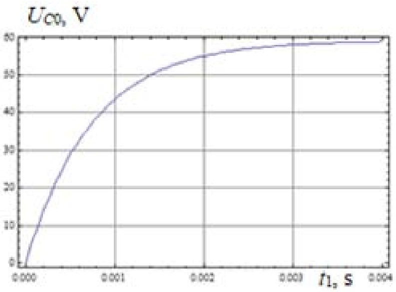


Fig. 5: Envelope of the maximum charge voltage normalized to the source voltage amplitude depending on the charge time

ii. *Amplification ratio (14)*

a. At $R_2=5\ \Omega$

$$\overline{K}_{2\max} = \left(\frac{J^2_{2\max}\cdot R_2}{\frac{E^2}{R_1}}\right) = \frac{R_2}{R_1}\cdot e^{-\frac{\pi}{2\cdot Q_2}}\Bigg|_{Q_2\approx 5,0} \approx 8.6.$$

b. At $R_2 = 10\ \Omega$

$$\overline{K}_{2\max} = \left(\frac{J^2_{2\max}\cdot R_2}{\frac{E^2}{R_1}}\right) = \frac{R_2}{R_1}\cdot e^{-\frac{\pi}{2\cdot Q_2}}\Bigg|_{Q_2\approx 2,5} \approx 12.4.$$

iii. *Discharge current as function of a variable $\varphi=\omega_2\cdot(t-t_1)$*

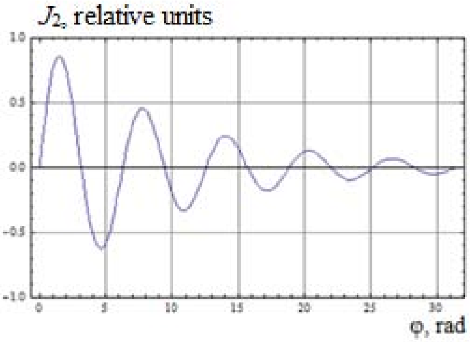


Fig. 6: Functional dependence of the current in the load normalized to the maximum

To summarize the results obtained, the dependences in Fig. 2, 5, 3 and 6 should be referred to.

Thus, the curves in Fig. 2 and Fig. 5 illustrate the capacity charge *C* to the specified voltage level U_{C0} for any discharge circuit 1 design. The graphs in Fig. 3 and Fig. 6 describe the capacity discharge *C* to the active load in the absence and presence of inductance in discharge circuit 2.

For practical use, the comparison of dependences for various design solutions for output circuit in Fig. 3 and Fig. 6 is of particular interest. As it follows from calculations, when the inductance is connected in the discharge circuit, the duration of the current pulse in the load increases significantly. The noted fact allows us to recommend this circuit solution for operation not only in the pulse mode but also in the periodic mode of the proposed active power amplifier.

V. EXPERIMENTAL APPROBATION

The operability of the proposed circuit of a pulsed amplifier of the active electric power of a harmonic signal and the reliability of the results of a theoretical study of the occurring electromagnetic processes were verified experimentally.

a) *The element base of the amplifier (the circuit diagram is shown in Fig. 1)*

i. *Circuit charge No.1:*

a. The sinusoidal voltage source with amplitude – $E_m = 1$ V and working frequency – f_1= 25000 Hz;
b. The inductance – $L_1 = 172.2\ \mu$H;
c. The capacity – $C = 0.234\ \mu$F;
d. The active resistance of the circuit elements – $R_1 = 0.55$.

ii. *Circuit discharge No.2:*

a. The inductance – $L_2 = L_1 = 172.2\ \mu$H;
b. The capacity – C = 0.234 μF;
c. The active resistance of the circuit elements – R_C = 0.55Ω.
d. The load active resistance – R_l = 5.6 Ω.

b) *Experimental Results*

i. *Work of the experimental model*

The element base of the experimental model of the active electric power amplifier ensures its operation in the voltage resonance mode with an operating frequency of *~25 kHz*. The choice of the proposed scheme is explained by its relative simplicity. The peculiarity consists in the cyclical repetition of the "charge – discharge" processes, which is ensured by the synchronized operation of electronic switches – K_{12}. At a given minimum voltage on the capacitance –*C*, the key K_1 closes and K_2 opens. The capacity is being charged. At a given maximum voltage on the capacitance, the key K_1 opens and K_2 closes. Through the inductance – L_1 the capacitance – *C* is discharged to the active load – R_l.

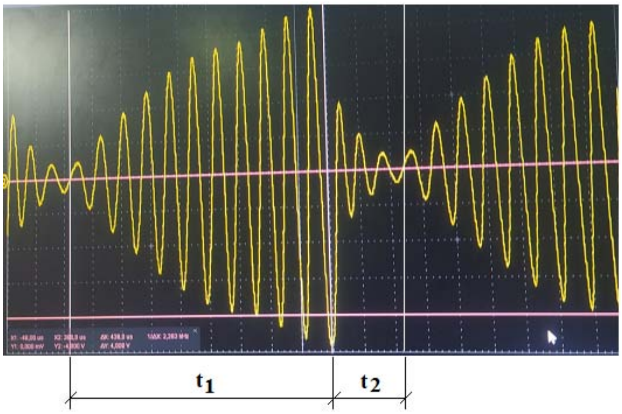


Fig. 7: A typical oscillogram of the voltage across the capacitance, t_1 – is a charge time (in terms of theoretical consideration – $t_1 = \Delta t$), t_2 – is a discharge time

ii. *Measurements and Calculations*

a. The voltage amplitude of the source – is $E_m = 1$ *V*, the working frequency – is $f_1 \approx 24930$ Hz;
b. The voltage on the reactive elements of the charge circuit: the amplitude on the inductance – is $U_{L_1} = 48.2$ V, the amplitude on the capacitance – is $U_C = 48.6$ *V* ($U_{L_1} \approx U_C$, but they have opposite directions what is verified the voltage resonance regime!);
c. The current amplitude in the charge circuit – is $J_1 \approx 1.8$ A;
d. The enter power amplitude – is $P_1 \approx 1.8$ W;
e. Q-factor of the charge circuit as the ratio of the average voltage on the reactive elements and the amplitude of the source voltage, – $Q_1 = 48.4$ (the calculation value ~ is 49.18);
f. The amplification of reactive power on the capacitance – is $K_C = \frac{U_C^2 \cdot (2\pi f_0) \cdot C}{E_m \cdot J_1} = 48.096$;
g. The current amplitude in the discharge circuit – is $J_1 \approx 1.7$ A;
h. The power amplitude in the load – is $P_l \approx 15.8$ W;
i. Q-factor of the discharge circuit – $Q_2 \approx 4.8$;
j. The coefficient of the amplification of active power in the load – is $K \approx 8.7$.

Summary

- The measurement results are quite close to the previously obtained numerical estimates of similar quantities.
- The experiments performed have demonstrated the workability of the proposed circuit of a pulsed resonant amplifier of active electric power.

VI. CONCLUSIONS

1. A scheme of the pulsed resonant amplifier of the active electric power is proposed, consisting of two series circuits with a common capacitive energy storage.
2. Analytical dependences for the main characteristics of the occurring electromagnetic processes are obtained and it is shown that the phenomenon of voltage resonance allows to achieve an increase (by more than an order of magnitude!) of the active power of a harmonic voltage source.
3. On the basis of the analysis, numerical estimates and experimental testing, the viability of the proposed circuit of a pulsed resonant amplifier of the active electric power is substantiated.

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