business. Limitless flexibility of the practice and its potential for self-organization of staff allowed to achieve efficiency where other approaches did not work.

No wonder that with the active development of information technology sphere Kanban boards were used to organize activities. The principle of organizing activities is incredibly simple for each process or task created cards. They contain a due date, a description and the name of the performer. Such cards are attached to the column among which may be: Beclog - tasks to be completed, tasks currently under development, tasks completed but not yet handed over to testers, tasks ready to be handed over to the testing department passing project management (PM) tasks, completed tasks.

The above-mentioned order is not mandatory, and depending on the specifics of the project improvised columns may be added. Such columns may include specify (to clarify parameters) and execute (to take up work).

Conclusion

The theoretical aspects outlined in this paper are the next stage in the formation of a methodology and algorithmization of the transition to new standards of higher education institutions, in particular scientific libraries, as components of such organizations. One of the stages and methods has already been published in (Zinchenko, 2021). The information in this paper is a systematization of existing open data and allows to form models of the work of service structural units. The second part of the work will analyze the practical stock of this research, which is being tested in real conditions.

References

1. *Manifest hnuchkoyi rozrobki* (2022) *Wikipedia*. Wikimedia Foundation. Available at: https://uk.wikipedia.org/wiki/Маніфест_гнучкої_розробки (Accessed: August 29, 2022).
2. Stobierski, T. (2021) *Agile vs. Scrum: What's the difference?*, *Northeastern University Graduate Programs*. Available at: https://www.northeastern.edu/graduate/blog/agile-vs-scrum/ (Accessed: March 15, 2022).
3. *Metodologiya CI/CD: kak razvivatsya* (2021) *ITG BY*. Available at: https://itglobal.com/ru-by/company/blog/methodology-ci-cd/ (Accessed: February 19, 2022).
4. *What is the difference between Scrum and agile methodology* (2021) *Merehead*. Available at: https://merehead.com/blog/scrum-vs-agile-difference/ (Accessed: March 18, 2022).
5. Mijacobs (21AD) *What is Scrum? - azure DevOps*, *Azure DevOps | Microsoft Learn*. Available at: https://docs.microsoft.com/en-us/devops/plan/what-is-scrum (Accessed: March 21, 2021).
6. ZINCHENKO, I. *et al.* (2021) "Methodology for the implementation of web standards to the activities of academic libraries," *Revista Română de Informatică și Automatică*, 31(4), pp. 45–54. DOI: https://doi.org/10.33436/v31i4y202104.

Отримана в редакції 05.08.2023. Прийнята до друку 05.09.2023. Received 05 Augast 2023. Approved 15 September 2023. Available in Internet 12 September 2023.

UDC 621.382

METHOD OF INCREASING EFFICIENCY, MEAN OF CONTROL AND TOOL OF ANALYSIS OF THE USE ENERGY OF POWER SOURCE PULSE LASER RANGE FINDER

[1]Pavlo Bratiuk, [2]Leonid Ozirkovskyy
[1,2]Lviv Polytechnic National University, Lviv, Ukraine
ORCID: [2]https://orcid.org/0000-0003-0012-2908
E-mail: [1]pavlo.bratiuk.tr.2019@lpnu.ua, [2]leonid.d.ozirkovskyi@lpnu.ua

DOI: 10.15673/atbp.v15i3.2620

Abstract. *The latest results of a series researches of the revealed paradox of energy balance disturb and its manifestations in electrical circuits are presented in order to increase the efficiency of the conversion of energy voltage direct current into pulsed energy of other forms, on the example of improving the use energy of the power source of pulsed solid-state laser range finder. It is show, that the efficiency of simultaneous conversion in a load with active linear or nonlinear resistance of the energy, which accumulated in the inductive and capacitive storage, can reach the efficiency of its accumulation. For this the first time offered the aperiodic mode of the transient process in the oscillating circuit* *use to combined the dual properties of inductive and capacitive energy storages and method of automatically switching their parallel connection during accumulation by them energy in series connection during conversion accumulated energy, particular, into optical pulses in the range finder. In total, proposed method of converting energy voltage direct current into pulsed energy of other forms, mean of objective control and tool of modeling and analyzing the use of energy primary power sources make up a set of measures for increasing energy efficiency separate nodes mobile devices of telecommunications, automation and robotics, what is especially actual in the existing conditions limited energy resources.*

Анотація. *Наведено останні результати серії досліджень виявленого парадоксу порушення енергетичного балансу та його проявів в електричних колах з метою підвищення ефективності перетворення енергії напруги постійного струму в імпульсну енергію інших форм на прикладі вдосконалення використання енергії джерела живлення імпульсного твердотільного лазерного далекоміра. Показано, що ефективність одночасного перетворення в навантаженні з активним лінійним або нелінійним опором енергії, яка акумулюється в індуктивному та ємнісному накопичувачах, може досягати ефективності її накопичення. Для цього вперше запропоновано використання аперіодичного режиму перехідного процесу в коливальному контурі для поєднання подвійних властивостей індуктивних і ємнісних накопичувачів енергії та методу автоматичного перемикання їх паралельного з'єднання при накопиченні ними енергії в послідовне з'єднання при перетворенні накопиченої енергії, зокрема, в оптичні імпульси в далекомірі. Загалом запропонований спосіб перетворення енергії напруги постійного струму в імпульсну енергію інших видів, засіб об'єктивного контролю та інструмент моделювання та аналізу використання енергії первинних джерел живлення складають комплекс заходів щодо підвищення енергоефективності окремих вузлів мобільних пристроїв телекомунікації, автоматизації та робототехніки, що особливо актуально в існуючих умовах обмеженості енергетичних ресурсів.*

Keywords: capacitive storage, inductive storage, disturbed energy balance, transient process, aperiodic mode, loads with linear or non-linear active resistance.

Ключові слова: ємнісний накопичувач, індуктивний накопичувач, порушений енергетичний баланс, перехідний процес, аперіодичний режим, навантаження з лінійним або нелінійним активним опором.

I. Introduction

Use of moveables means of telecommunications, automation and robotics in solving practically important tasks is quickly growing. This requires their further improvement, and convenient criterion in order is the efficiency of energy uses of primary power source, which often is batterie of galvanic cells or accumulators.

For example, reducing the energy consumption of a pulsed solid-state laser rangefinder (PLR) extends the duration of its continuous operation. Or for the same duration of continuous operation it allows to expand the measured distance by increasing the energy of optical pulses, the emission of is spent a large part of the consumed energy. And therefore, energy-saving measures are taken, example, the automatic shutdown, or the limitation of certain functions during the breaks in work. However, it is clear that it is more expedient to increase the effectiveness of PLR when they are performing their main functions.

In fig. 1 shows energy flows of various forms, the carriers of which are electric current and optical pulses, as well as nodes in which the form of energy of the primary source, or its parametersis converted. For example, the value of voltage direct current for PLR components, that require voltages, what higher or lower from battery voltage, such as laser diodes, microprocessor, display, etc.

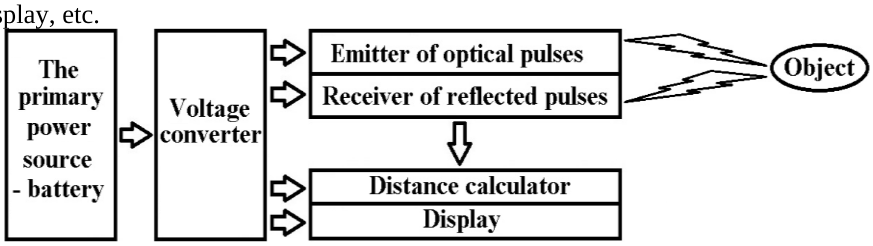

Fig. 1 - Structural scheme of PLR with energy flows of various forms and parameters

In total, for powering any mobile devices of telecommunication, automation and robotics it is necessary to converts not only the amount of direct voltage or current (dc-dc), but also the type of current, for example, alternating on direct (ac-dc) – as during charging batteries from alternating current networks etc.

For all types of such conversions (most often dc-dc, ac-dc, and also dc-ac, ac-ac) powerful pulse devices are used, in which the energy, accumulated over relatively long time, is consumed during converting in relatively short time. And in current conditions limited energy resources increasing efficiency this convertions in mobile means of telecommunications, automation and robotics is especially actual.

II. Literature analysis

2.1. Basics of the bildings of impulse converters energy voltage direct current

The foundation bildings of the dc-dc converters are pulse devices, in which inductive and capacitive energy storages perform separate functions, arising from their dual properties, namely: inductives - voltage amplification, and capacitives - current amplification [1, p. 73].

With the help of inductive storages are obtained voltage pulses of given amplitude and duration, the power of which can exceed the power of the primary source in the ratio of the duration of energy accumulation to the duration of the pulses [1, p. 74 - 76]. And with the help of capacitive storage devices the energy of these pulses is saved in the form energy of direct current voltage, which can be lower or higher than the voltage of the primary source.

According to the circuit of the generator of powerful pulses with an inductive storages [1, p. 73], the all basic types of dc-dc converters, and their subsequent modifications are being built, for which the largest manufacturers of semiconductor devices have is developed and constantly replenished a wide range of element base, oriented to the various needs their application, as example, [2 – 4].

As first, these are basic converters without galvanic isolation of the load circle, namely: boost (step-up) converter [2, p. 10; 5, p. 85-90; 6, p. 261-264], buck (step-down) converter [2, p. 10; 5, p. 95-102; 6, p. 257-260], inverting buck-boost converter [2, p. 10; 5, p. 107-114; 6, p. 265-269], and a buck-boost converter without inversion (cúk converter) [6, p. 269-275]. In these converters inductive and capacitive energy storages simultaneously are used to perform the specified separate functions.

The same applies to modifications of converters with galvanic isolation of the load circle: flyback converter [2, p. 10; 5, p. 118-126], forward converter [2, p. 11; 5, p. 135-140], two-stroke (push-pull converter) [2, p. 11; 5, p. 146-149], half-bridge converter [2, p. 12; 5, p. 154-158], and full-bridge converter [2, p. 12; 5, p. 162-165]. In such converters inductive storage units with several windings are used, however, the functions of inductive and capacitive storage units remain separate.

Known ways of increasing the efficiency of basic dc-dc converters, example, by optimizing load modes of capacitive energy storage [7], and everything progres their circuitry [8], also do not go beyond of scope separation functions inductive and capacitive energy storages. This applies to cases when the result is achieved by parallel or series connection of several identical basic converters, for example [9], and when new principles are involved, that not used in the basic converters.

As a result of such involv into flyback converter are received a self-oscillating power supplies [5, p. 209-252]. In such converters the inductive storage is used to form a feedback circuit, which ensures its oscillating mode. However, this mode does not cover of the capacitive storages voltage direct current, and the functions of inductive and capacitive storages remain separate.

The same applies to such combined modifications of converters, as:

– LLC resonant half bridge converters [6, p. 385-440; 10], where an additional LC circle is entered into the basic half-bridge converter [5, p. 154-158];

– SEPIC (Single Ended Primary Inductance Converter) [5, p. 171-208], which contain basic converters in a boost-buck-boost sequence, and two inductive storage that can be wound on the same magnetic core and connected by a coupling capacitor;

– Zeta [11], which contain basic converters in the buck-boost-buck sequence, opposit to SEPIC.

In [12], it is proposed to connect the source of input energy in converters of all modifications through the LC lattice network, which the author called a Z-source, and claims that its unique properties provide advantages not available to other methods. This statement is not convincing, because the LC lattice network is used in analog and digital filters, for example, [13, p. 186-189]. It is obvious that an additional filter will improve the distortion reduction of the output voltage of any converter.

For example, the comparison in [14] of Z-source, Zeta and SEPIC converters by the amount of harmonic distortion, power factor and the ability to adjust the output voltage shows that these criteria are satisfied by Zeta, and not by Z-source converter.

In this manner, common to the bildings and ways of improvement of the all considered dc-dc converters, based on the principles [1], is that they contain:

1) only one method of converting voltage direct current sources into voltage pulses with using an inductive storages;

2) only one method of saving energy pulses voltage in the form of energy voltage direct current with using a capacitive storages;

3) numerous methods of their improvement, by including in the circles the source of the input voltage, the inductive storage, or the load, of additional inductances and capacitors, which are not directly involved during the accumulation and conversion of energy, but are necessary for the involvement of new principles in the bilding of known converters, or the strengthening of their filtering properties;

4) efficiency energy conversion, which theoretically can reach 100% and serves as a criterion evaluating various methods of improvements, but its increase is not the goal of these methods which, at the same time, do not go beyond the scope of separates functions inductive and capacitive storages energy.

In the table 1 shows the energy efficiency indicators of the dc-dc converters of voltage and current, the circuits of which are consideres in [5] and are available, as ready-made examples for modeling in the Multisim 11.0 environment, in the files of the directory "...\National Instruments\Circuit Design Suite 11.0\samples\SMPS Circuits\ Transient Analysis". All circuits are used unchanged, but for measurements they have two wattmeters are included and an active resistance of 0.1 Ohm, which is used to simulate power losses, which is not provided by the idealized model source voltage direct current from the Multisim environment. The included components do not change the functioning of the converters, and bring it closer to real conditions.

Table 1 - Efficiency of dc-dc converters described in [5]

Modification and circuits of the converter	P_1 - power, that consumed from the source		P_2 - power, that converted into the load		Energy conversion ratio
	P1 (Вт)	Cos (φ)	P2 (Вт)	Cos (φ)	$\frac{P_2}{P_1}$
Boost voltage-mode [5, p. 89] (file Boost_VM.ms11)	14,43	0,765	12,02	1,0	0,833
Buck current-mode [5, p. 103] (file Buck_CM.ms11)	124,90	0,871	90,40	1,0	0,724
Flyback voltage-mode [5, p. 127] (file Flyback_VM.ms11)	30,21	0,337	23,32	1,0	0,772
Forward current-mode [5, p. 145] (file Forward_CM.ms11)	124,86	0,385	112,00	1,0	0,897
Push-pull current-mode [5, p. 152] (file Push_CM.ms11)	145,86	0,622	112,10	1,0	0,768
Half-bridge voltage-mode [5, p. 158] (file Half_VM.ms11)	129,31	0,940	112,00	1,0	0,866

From table 1 it can be seen, that of the ratio P_2/P_1 of the power, converted in a load with an active linear resistance, to the power, consumed from a voltage source, for all researched converters approaches unity to varying degrees. Also, in the circle of the source of direct current voltage the power factor **Cos(φ) < 1**, which indicates of energy circulation, the possibilities use of which in known sources is not considered.

2.2. Analysis of the dynamics of energy accumulate and conversion

Convenient models of inductive and capacitive storages, which provide an opportunity to take into account active energy losses in them, are RL and RC links.

Known sources, for example [15, p. 215-217, 366-368; 16, p. 212-263; 17, p. 261-320], do not consider the peculiarities of the dynamics of transient processes in RC and RL links. According to the results of [18], in [19], on the basis methods and results of the specified sources, is compared the dynamics of energy accumulate and conversion during of transient processes the connection of RC and RL links to a direct current voltage source, and their short circuit after disconnect from a source.

Transient processes in RC and RL links describe the same nonlinear functions, and the formulas for voltages and currents during transient processes can be obtained one from the other by replacing the parameters u_L with i_C, i_L with u_C, and **L** with **C**, which is a consequence of the dual properties of inductance **L** and capacitance **C**.

Namely, during the accumulation of energy:

$$\boldsymbol{u_C(t) = U\left(1 - e^{\frac{-t}{RC}}\right)}, \text{ and } \boldsymbol{i_L(t) = \frac{U}{R}\left(1 - e^{\frac{-tR}{L}}\right)}. \quad (1)$$

And, similarly, during energy conversion:

$$\boldsymbol{u_C(t) = U \cdot e^{\frac{-t}{RC}}}, \text{ and } \boldsymbol{i_L(t) = \frac{U}{R} e^{\frac{-tR}{L}}}. \quad (2)$$

At the proper value of **L**, **C** and **R**, transient processes in RL and RC links describe the same non-linear graphs of rise and fall of current **i_L(t)** and voltage **u_C(t)**, which are completely superimposed, as shown in fig. 2.

In fig. 2, on the left are superimposed graphs of the current and voltage rise, which correspond to the accumulation of source energy in the inductance **L** and capacitance **C**, and on the right - graphs of the current and voltage drop corresponding to the conversion of energy in the resistance **R**. Dashed straight lines connect in fig. 2 points on the graphs of the rise and drop of current and voltage, in which the processes of energy accumulation by inductance **L** and capacitance **C**, and the conversion of the energy accumulated by them in the resistance **R** are completed. They represent imaginary linear dependences of current and voltage, which would take place under the condition that transient processes in RL and RC links are described by linear functions.

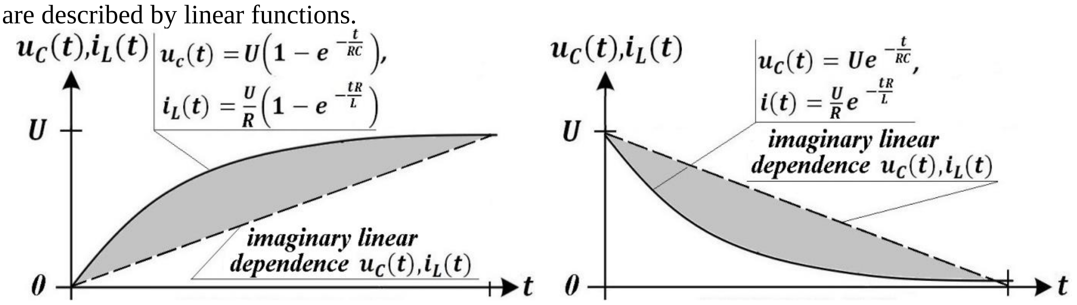

Fig. 2 - Superimposed nonlinear graphs of the rise and drop of current iL(t) and voltage uC(t), and corresponding imaginary linear dependencies

Graphs in fig. 2 show the difference of the dynamics of energy accumulation and conversion during transient processes into RL and RC links. With the help of tinting in fig. 2 shows the direction, magnitude, and dynamics of exceeding the rate of rise and drop of nonlinear graphs of current and voltage relative to the rate of rise and drop of imaginary linear dependencies, that correspond to them.

From formulas (1) and (2) and fig. 2 it can be seen, that increase the resistance **R** brings the non-linear graphs of current and voltage rise and drop closer to imaginary linear dependences, the efficiency of energy accumulation in inductance **L** and capacitance **C** decreases, and the efficiency conversion accumulated energy in resistance **R** increases. A comparison of the dynamic of the rise and drop of current and voltage shows, that the efficiency of energy accumulation is higher than the efficiency of conversion of this accumulated energy.

The same follows from the equivalent transformation of the classical notation of the formulas for the energy $\mathbf{W_C}$ and $\mathbf{W_L}$, accumulated in the RC and RL links:

$$\boldsymbol{W_C = \frac{1}{2}U^2 \cdot C \;\rightarrow\; 2 \cdot W_C = U^2 \cdot C}, \tag{3}$$

$$\boldsymbol{W_L = \frac{1}{2}I^2 \cdot L \;\rightarrow\; 2 \cdot W_L = I^2 \cdot L}. \tag{4}$$

The multiplier **"½"** in (3) and (4) relates the efficiency of $\mathbf{W_C}$ and $\mathbf{W_L}$ energy accumulates to the virial theorem [20, p. 83-86], according to which twice the average total kinetic energy is equal to a multiple of the average total potential energy. Instead, in the formula for calculating the conversion of energies (3) and (4) into Joule heat $\mathbf{W_J}$ in the resistance **R** lacks the factor **"½"**, therefore, it does not comply with the virial theorem, and efficiency conversion of the accumulated energy $\mathbf{W_C}$ and $\mathbf{W_L}$ during the closes of the RC and RL links is in half as much:

$$\boldsymbol{W_J = U \cdot I \cdot t = I^2 \cdot R \cdot t = \frac{U^2}{R}t}. \tag{5}$$

Also, the dual properties of capacitance and inductance in closes RC and RL links are manifested in the fact, that for a certain duration of the transient process the capacitance **C** is equivalent to a voltage source, whose dynamic resistance is less, than the resistance **R**, and the inductance **L** is equivalent to a current source, whose dynamic resistance is greates, than the resistance **R**. Therefore, for some time of the transient process, the change in the dynamic resistances of the inductance and capacitance in the series RLC circuit corresponds to the optimal conversion of the accumulated energy in the resistance **R**, and its dynamic should approach to the dynamic of accumulation energy.

In fig. 3 dashed line shows the expected superimposed graph of current $\mathbf{i_L(t)}$ and voltage $\mathbf{u_C(t)}$ during optimal energy conversion, which is inversely symmetrical to the real graphs of current and voltage during energy accumulation in fig. 2 on the left, and for comparison, the graph of the current and voltage drop, and the imaginary linear dependence from fig. 2 right.

The expected result coincides with the conclusion [7], that of the three loads modes of the supercapacitor bank, namely, with unchanged resistance, current or power the best energy use is provided by the last of them. In [7] a graph of the voltage drop of such bank in the unchanged power mode is presented, which qualitatively corresponds to the expected graph in fig. 3.

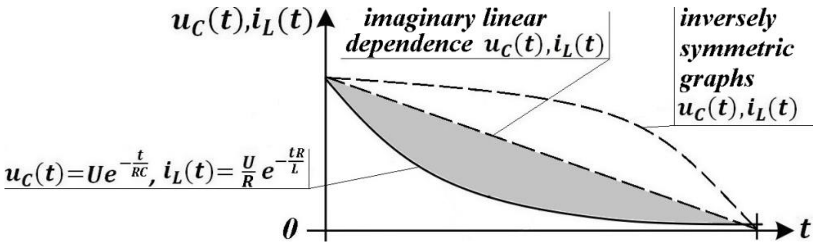

Fig. 3 - Expected superimposed graph of current iL(t) and voltage uC(t)

2.3. Analysis of energy conversion efficiency

Classical analysis of RLC circles, for example, [16, 264-305; 17, 321-370], does not include a comparison the efficiency of energy conversion in different modes of the transition process, namely: oscillating (underdamped), critically (critically damped), aperiodic (overdamped). On the basis methods of the specified sources, and the example of the "Damped Harmonic Oscillation" calculation of the "Engineering Applications" section of Mathcad 15.0 such a comparison is made in [19].

Unit values of inductance **L**, capacitance **C**, and non-zero initial conditions for accumulation of charge **Q** by capacitance **C** are used for the calculations, and values **R1**, **R2**, **R3** are used for resistance **R**, under which the oscillating, critical, and aperiodic modes of the transient process occur, respectively. The accumulated energy $\mathbf{W_C}$ and the non-zero initial conditions of its transformation are determined by the charge **Q**, therefore the differential equation of the current in a series RLC circuit is written in terms of the ratio of the charge **Q** and time **t**:

$$\boldsymbol{W_J = I^2 \cdot R \cdot t = \left(\frac{Q}{t}\right)^2 R \cdot t = \frac{Q^2}{t}R}, \tag{6}$$

$$\boldsymbol{L\frac{d^2Q(t)}{dt^2} + R\frac{dQ(t)}{dt} + \frac{Q(t)}{C} = 0 \;\rightarrow\; \frac{d^2Q(t)}{dt^2} + 2 \cdot \delta\frac{dQ(t)}{dt} + \omega_0^2\frac{Q(t)}{C} = 0}, \tag{7}$$

коли, $\boldsymbol{Q(0) = Q_0}$, $\boldsymbol{\tau = 0}$, $\boldsymbol{\frac{dQ(t)}{dt} = 0}$.

According to the results of calculations (6) and (7) in fig. 4 graphs of change of charge **Q** are shown on top, and energy conversion of W_C in oscillating, critical and aperiodic modes is shown on the bottom. It can be seen from the tinted area that more energy is converted in resistance **R3** in the aperiodic mode than in resistances **R1** and **R2** in the oscillating and critical modes, respectively.

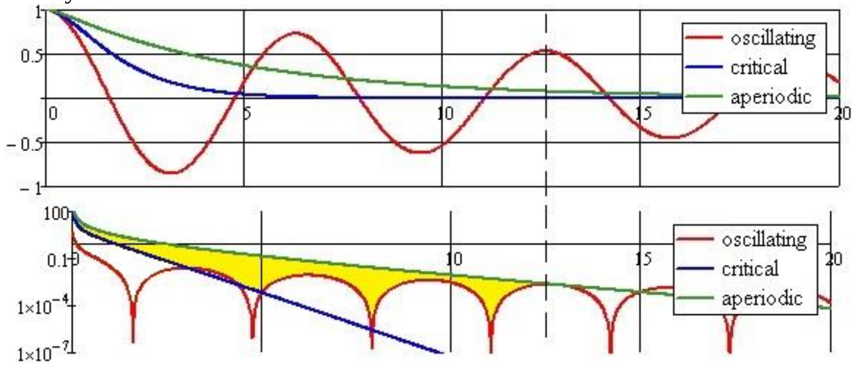

Fig. 4 - Graphs of charge change and energy converted in oscillating, critical and aperiodic modes of the transition process

2.4. Summary of the analysis

The efficiency of energy use during the periodic power on of the laser diode to a direct current voltage, which obtain from dc-dc converters of known modifications, can to varying degrees is approaching 100%, depending on modification of converter.

Existes unused potential of the combination of the dual properties of capacitive and inductive energy storages, also energy circulation in the circles of direct current sources phenomena, which can be realized in help aperiodic mode of the transition process in a series RLC circuit in order converting the direct current voltages into pulses to power laser diode PLR, wich should improve use primary source energy.

III. Object and methods of research

The object of the research is to reduce energy consumption from the primary source by increasing the level of efficiency of conversion of direct current voltage energy into pulses energy in a load with active resistance in a series RLC circuit in the aperiodic mode of the transient process on level of efficiency accumulation energy of direct current voltage in a parallel LC circuit, taking into account losses during processes accumulation and conversion energy.

The research have carried out using the methods of classical analysis of transient processes during commutation of electric circuits by solving ordinary differential equations in Cauchy form by the Runge-Kutta method with a constant step using Mathcad 15.0, simulation modeling in the Multisim 11.0 environment, and of full-scale experiments on a working model.

IV. Results

4.1. Modeling results and their basis

The discovery and study of the paradox of disturbed energy balance [18; 19] allowed to propose a method [21], as alternative to separating functions of inductive and capacitive energy storages. Their properties are combined during automatically switch the parallel connection of inductive and capacitive storage during energy accumulation to their serial connection during conversion accumulated energy. At the same time, the dynamic balance of voltages on inductive and capacitive storage in a parallel LC circuit in fig. 5 on the left is disturbed by the electromotive force (EMF) of self-induction inductive storage in the series RLC circuit in fig. 5 on the right.

As consequence, increasing the efficiency of the conversion of the accumulated energy in the load **R**, what is a manifestation of the paradox of disturbed energy balance, and **corresponds** to the virial theorem [20, p. 83-86].

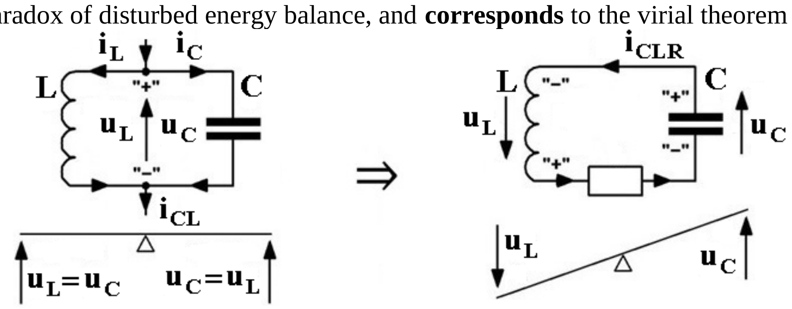

Fig. 5 - Dynamics balance of voltages on inductive and capacitive energy storage in a parallel LC circuit (left), and its disturb in a series RLC circuit (right)

In fig. 6 present an illustration is given the manifestation of the paradox for the example of a system of bodies T_1 and T_2 with equal masses $m_1 = m_2$, where EK_1 and EK_2 are kinetic, and EP_1 and EP_2 are potential energies of these bodies.

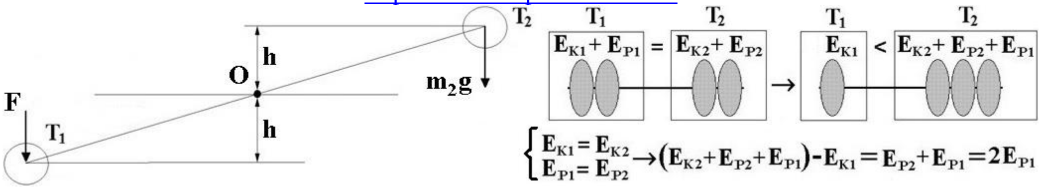

Fig. 6 - Mechanism, model and result of the manifestation disturbed energy balance

In fig. 6 from the left, the force **F** lowers the body $\mathbf{T_1}$ by a distance **h** below the level of the center of mass **O**, and its total energy decreases by the some potential energy $\mathbf{EP_1}$. The total energy of the body $\mathbf{T_2}$, which the force **F** simultaneously raises to a distance **h** above the level of the center of mass **O**, increases (accumulates) by the same energy, namely $\mathbf{EP_1}$, and is equal to the work done **A**:

$$A = F \cdot h = h \cdot g \cdot m_1 = h \cdot g \cdot m_2, \tag{5}$$

where **g** is the acceleration of free fall.

The potential energy of the body $\mathbf{T_2}$ after the disturb energy balance can be to calculate by converting it into kinetic energy. When under the influence of its weight $\mathbf{m_2 \cdot g}$ the body $\mathbf{T_2}$ falls from a height of $\mathbf{2 \cdot h}$ above the level of the $\mathbf{T_1}$, then at the moment when the $\mathbf{T_2}$ arrive the level of the $\mathbf{T_1}$, it will acquire kinetic energy:

$$\frac{m \cdot v^2}{2} = 2 \cdot h \cdot g \cdot m_2, \tag{6}$$

where **v** is the speed of the body $\mathbf{T_2}$, $\mathbf{m = m_1 = m_2}$.

We have a paradox: the energy in the right part (6), which the body $\mathbf{T_2}$ acquired during the rise, is twice the energy (5) spent on performing work **A** to raise the body $\mathbf{T_2}$ to a height **h** above the level of the center of mass **O**.

At one time, the law of conservation energy is fulfilled, and this paradox is its consequence: the total energy of the system of bodies $\mathbf{T_1}$ and $\mathbf{T_2}$, which is equal to the sum of their total energies $\mathbf{(EP_1+EK_1)}$ and $\mathbf{(EP_2+EK_2)}$, is unchanged before and after disturbed energy balance and is equal to $\mathbf{(EP_1+EK_1+EP_2+EK_2)}$. Also, disturb balance of the system of bodies $\mathbf{T_1}$ and $\mathbf{T_2}$ corresponds to the virial theorem in that the difference between the total energy of the body $\mathbf{T_2}$, which has acquire energy $\mathbf{EP_1}$, and the total energy of the body $\mathbf{T_1}$, which has lost energy $\mathbf{EP_1}$, always is $\mathbf{2 \cdot EP_1}$.

Also, along with disturb voltage balanc, as shown in fig. 5 on the right, during the transient process into the series RLC circuit, take place the opposite changes dynamic resistances of the inductive and capacitive energy storage, as stated in clause 2.2 occurs. Therefore, for some time their dynamics resistances acquire values, which are optimal for the effective conversion of energy into resistance **R**.

On conjugate models in the form of systems of ordinary differential equations transient processes in the aperiodic mode were calculated during:

– energy accumulation in zero initial conditions in the model in fig. 7 above for the parallel LC circuit in the scheme in fig. 8 on the left;

– conversion of accumulated energy in non-zero initial conditions in the model in fig. 7 from below for a series RLC circuit in the scheme in fig. 8 on the right.

$$a0 := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \quad a(t, X) := \begin{bmatrix} \frac{-(R0 + RC)}{L1} \cdot X_0 + \frac{RC}{L1} \cdot X_1 + \frac{-1}{L1} \cdot X_2 + \frac{1}{L1} \cdot E \\ \frac{RC}{L} \cdot X_0 + \frac{-(RL + RC)}{L} \cdot X_1 + \frac{1}{L} \cdot X_2 \\ \frac{1}{C} \cdot X_0 + \frac{-1}{C} \cdot X_1 \end{bmatrix} \quad A := rkfixed(a0, 0, ts, na, a)$$

$$ta := A^{\langle 0 \rangle} \quad i := A^{\langle 1 \rangle} \quad iLa := A^{\langle 2 \rangle} \quad uCa := A^{\langle 3 \rangle} \quad iLa_{na} = 2.201 \quad uCa_{na} = 7.711$$

$$c0 := \begin{bmatrix} iLa_{na} \\ (-uCa)_{na} \end{bmatrix} \quad c(t, X) := \begin{bmatrix} \frac{-(R + RL + RC)}{L} \cdot X_0 + \frac{-1}{L} \cdot X_1 \\ \frac{1}{C} \cdot X_0 \end{bmatrix} \quad C := rkfixed(c0, ts, tm, nc, c)$$

Fig. 7 - Conjugate models of accumulation and conversion energy

In the schemes in fig. 8 is marked: **E** – direct current voltage source; $\mathbf{R_0}$ and $\mathbf{L_0}$ are loss resistance and parasitic inductance in the source circuit **E**; **L**, **C** and $\mathbf{R_L}$, $\mathbf{R_C}$ – inductance, capacity and loss resistances of energy storages; **R** – load.

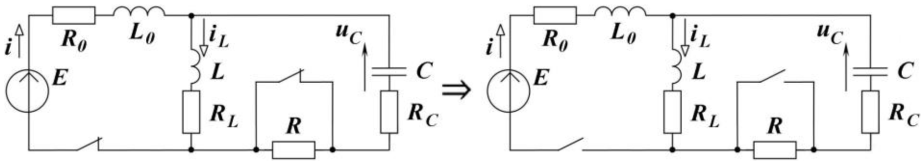

Fig. 8 - Connection of inductive and capacitive energy storage, as well as loads during energy accumulation and conversion

Simulations in the Mathcad environment confirmed, that the efficiency of energy conversion in a series RLC circuit in the aperiodic mode of the transient process can exceed 100%.

In the table 2 presents the results of power measurement during simulation in the Multisim environment of energy conversion by the method [21] in six variants of circuits, when a load with a linear or nonlinear active resistance is connected on circle of inductive or capacitive storage. All variants circuits provide energy conversion whit the ratio $\mathbf{P_2/P_1}$ of more than unity, taking into account losses. Also, similarly were performed full-scale experiments.

Table 2 - Efficiency of energy conversion by the method [21]

Variants circuits by type of load and him connect	P_1 - power, that consumed from the source		P_2 - power, that converted into the load		Energy conversion ratio
	P_1 (Вт)	Cos (φ)	P_2 (Вт)	Cos (φ)	$\frac{P_2}{P_1}$
1 - linear, in series with L	10,494	0,416	11,530	1,0	1,099
2 - nonlinear, in series with L	3,379	0,226	3,641	0,934	1,077
3 - linear, in series with C	4,649	0,203	4,934	1,0	1,061
4 - nonlinear, in series with C	2,543	0,162	2,561	0,897	1,007
5 - linear, with galvanic isolation	6,283	0,351	7,480	1,0	1,19
6 - nonlinear, with galvanic isolation	12,145	0,393	13,347	0,509	1,099

In fig. 8 shows variants circuits **"3"** and **"4"**, where the load is connected to points **"A"** and **"B"**. Resistors **R1**, **R2**, **R3** modeled energy losses in the source **V1** and storages **L** and **C**, respectively. As a load with a linear resistance, a resistor **R** with with a resistance of **3 Ohms** and power of **6 W** was used, and with a non-linear – an **LED1** with a power of **5 W**. Wattmeters **XWM1**, **XWM2** and an oscilloscope **XSC1** are provided to measure the power, consumed from the source **V1** and converted to the load **R**, or **LED1**, and to visualize the voltage pulses on the load.

Source **V2** forms pulses control of the electronic key **Q1**. When **Q1** is open, under the action of a direct current voltage source **V1** parallel currents flow through the storages **L** and **C**, which simultaneously accumulation energy. The conduction direction of the diode **D1** allows the current to flow **through** the storage **C**, but shunts the parallel connected load **R**, eliminating its influence. Accumulated energy depends on the values of inductance **L** and capacitance **C**, the duration pulse of control the key **Q1**, and the source voltage **V1**.

When **Q1** is closes, the current stops flowing through the storages, and there is an EMF of the self-induction of the inductance **L**, the polarity of which is opposite to the voltage of the source **V1** and the direction of conduction of the diode **D1**, which closes. And the parallel connection of storages **L** and **C** is automatically switched to their serial connection with load **R**. Because of action of the EMF of self-induction current flows through the series-connectes load **R** and the storage **C**. The polarity of the potential difference the storage **C** is opposite to the polarity of the EMF of self-induction, as a result, the current pulse in the load **R** is greater than in the case of a single storage **L**, without using the storage **C** as a current amplifier.

In fig. 9 and 10 on left are presented oscillograms, obtained in the Multisim environment, and on right - on the working model. Oscillograms in fig. 9 received for linear load, and in fig. 10 - for nonlinear load. On the oscillograms on the right are drawn imaginary linear dependencies, as in fig. 2 and 3, which show, that the oscillograms qualitatively correspond to the graph in fig. 3, confirming that the working model functions according to the predictions of the theoretical justification and simulation results.

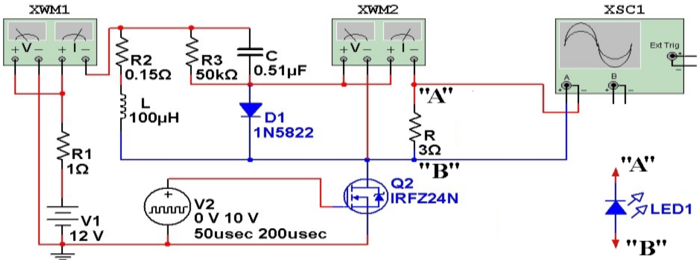

Fig. 8 - Load connection for "3" and "4" variants circuit

Promising are the variants of the circuits with galvanic isolation, in which the inductive storage with two windings additionally ensures matching of the resistances load and inductive and capacitive storages. In the variants of circuit **"1"** and **"2"** this can be achieved without galvanic isolation, using an inductive storage with output from part of the winding, but this has not yet been investigated.

According to the table 2, for all variants of the circuits in a direct current voltage source circle power factor **Cos(φ) < 1**, and energy circulation occurs. In a load circle with a linear resistance **Cos(φ) = 1**, and the energy flows in only one direction, instead, **Cos(φ) < 1** when load has a nonlinear resistance, and the energy circulate. Due to the increased efficiency of energy conversion, also its circulation in the circle the direct current voltage source, it is possible to recuperate that part of the energy, that is not completely converted in a load because the dynamic resistances of inductive and capacitive energy storage are not optimal for the entire duration of the transient process in the aperiodic mode in the series RLC circuit.

Therefore, the application of the method [21] should improve use the energy of the battery, in comparison with the periodic power on of the light diode to a direct current voltage, obtained from dc-dc converters of known modifications, as show by the comparison energy conversion ratio in the tables 1 and 2.

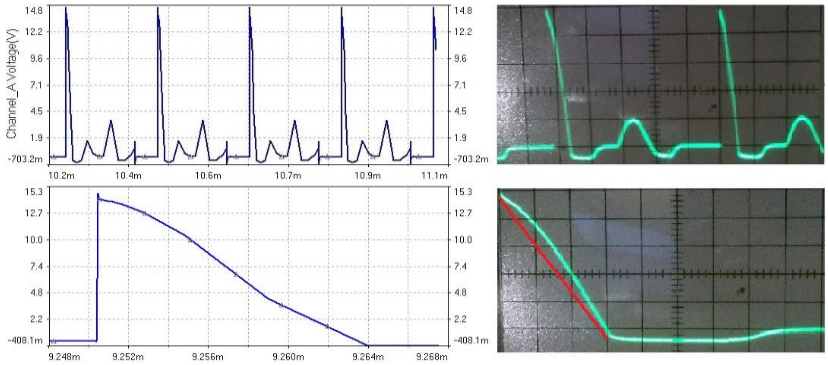

Fig. 9 - The form of voltage pulses on a linear load

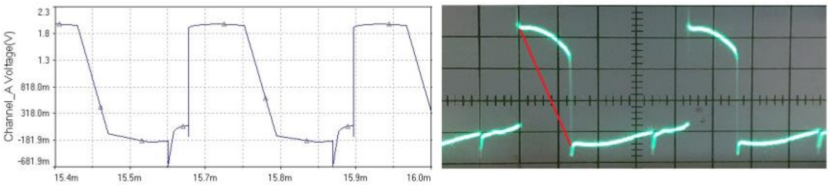

Fig. 10 - The form of voltage pulses on a nonlinear load

4.2. A procedure and a mean for controlling the efficiency of energy use

For furthers research is required objective control of the efficiency converting energy voltage direct current by the simultaneous use of two wattmeters to compare the power consumed from the source, and converted to the load, as in the circuit in fig. 8. But, unlike to wattmeters of sinusoidal voltages and currents of industrial frequency (50 - 60 Hz), wattmeters for measurements in the range from dc current to ultrasonic frequencies, on which work pulse dc-dc converters of all modifications, have a high cost and are not common.

In order to perform full-scale experiments was designed and made a simple and inexpensive two-channel device for monitoring energy use according to the circuit in fig. 11, built on the basis of the Arduino Nano open-source platform and INA 219 current sensors from Texas Instruments. Photo of monitoring the efficiency of energy use for **"4"** variant of the circuit in fig. 8 is shown in fig. 12.

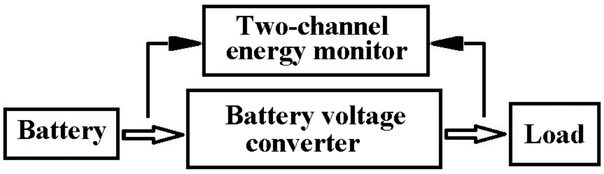

Fig. 11 - Circuit for monitoring the efficiency of energy use

Implementation of the devices for objective control of energy uses behind the circuit in fig. 11 will be can useful, as for purpose of researching potential opportunities, and during production and repair in order the providing of the efficiency of the use of energy of primary power sources PLR, also other mobile devices of telecommunication, automation and robotics in general, and will help to the fulfillment of international energy saving standards, especially in conditions of limited energy resources, power outages, etc.

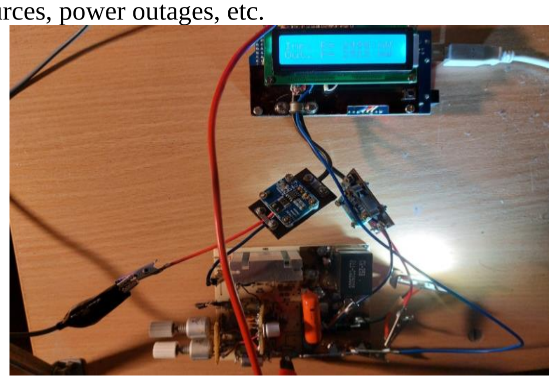

Fig. 12- Monitoring the efficiency of energy use for "4" variant of the circuit in fig. 8

4.3. A tool for modeling and analyzing the efficiency of energy use

To analyze the energy use of power sources of mobile devices, the technology of analytical modeling of fault-tolerant systems has been tested [22].

This technology allows you to apply the duration of continuous operation, as a criterion for evaluating and complex optimization of indicators, related to energy efficiency, for example, determination of the permissible intensity of consumption energy, the required battery capacity, configurations delivery kit - power of the charger, the needs for a spare battery, etc.

In the table 3 presented the basic structural-automatic model for studies of the duration of continuous operation of mobile devices over periods of time, multiples of 24 hours, under conditions of power outages and with available energy resources.

Table 3 - Basic structural-automatic model of energy use

Basic events	Conditions and circumstances basic events	Intensity of the base event	Intensity of the alternative event	State vector modification rules
Battery discharge	V1=1	Λ	1	V1:=0
Battery charging from power bank	V2=1 AND V3<N	M	1	V1:=1;V3:=V3+1
	V2=1 AND V3=N			V1:=1; V2:=0
	V2=0			V1:=0

The model takes into account the list of main parameters, that have an impact the duration of continuous operation, in particular:

N – the number of battery charges provided by an available energy resource, such as a power bank;
λ – intensity of the base event "Battery discharge";
μ – intensity of the basic event "Battery charging from power bank".

The components of the state vector of the structural-automatic model describe the following conditions and circumstances during operation:

V1 – battery status: 1 – charged, 0 – discharged;
V2 – power bank status: 1 – charged, 0 – discharged;
V3 – the number of used battery charges from the power bank.

In fig. 13 presents example obtained with the help of the ASNA-1 software module [23] the dependences of the probability of the duration of the continuous operation on intensity of battery discharge.

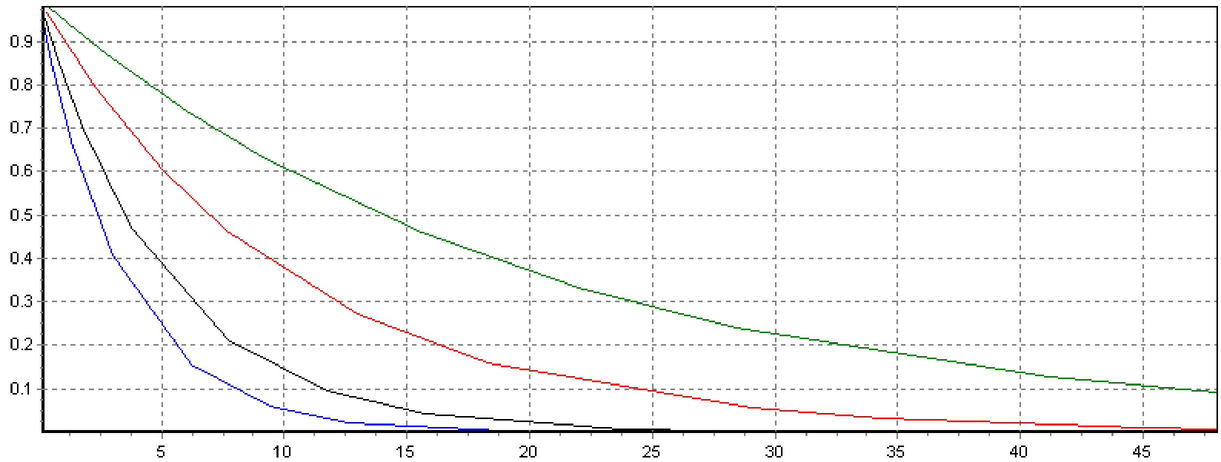

Fig. 13 - Dependence of the probability of continuous operation for 48 hours for four values of the intensity of battery discharge

The basic model provides for the expansion of the list of basic parameters and the number of components of the state vector for detailized modeling of ensuring continuous operation in difficult conditions of energy resource limitation.

V. Conclusions

Together, the proposed method of converting direct current voltage into pulses for the purpose of powering laser diode of a pulsed laser rangefinder, the procedure and mean of objective control and the tool for modeling and analysis of the use of energy from primary power source, that makes up a set of measures for meeting the growing requirements of energy efficiency end autonomy in the difficult conditions of limiting energy resources and power supply interruptions. Continuation of research on use of manifestations the paradox of a disturb energy balance will be useful in order to improve the efficiency of other nodes of mobile devices of automation, robotics and telecommunications, not only electronic, but, for example, mechanical.

References

1. Bluhm, Hansjoachim. (2006). *Pulsed Power Systems: Principles and Applications*. Springer-Verlag Berlin and Heidelberg GmbH & Co. KG.
2. ON Semiconductor. (2014, April 4). Energy Efficient Innovations. Switch-Mode Power Supply. *Reference Manual.* SMPSRM/D.
3. STMicroelectronics. (2007, March). TM SEPIC converter in PFC Pre-Regulator. *Application Note*. AN2435.
4. STMicroelectronics. (2007, June). 27 W Output power ultra wide range input flyback converter. *Application Note*. AN2439.
5. Basso, Christophe P. (2001). *Switch-Mode Power Supply. SPICE Cookbook*. (1st edition). McGraw-Hill.
6. Rashid, M. H. (2014). *Power Electronics Devices, Circuits and Applications*. (4th ed.). Pearson.
7. Betten, John. (2008, October 15). Pump and dump - delivering more power than you thought possible! *Electrical Design News.* http://www.edn.com/pump-and-dump-delivering-more-power-than-you-thought-possible/
8. Fang, Lin Luo, Hong, Ye. (2017). *Advanced DC/DC Converters*. (Second Edition). Power electronics and applications series. Taylor & Francis, CRC Press.
9. Peng, X., W. Jia, Lee, F. C. (2003, January). Multiphase coupled-buck converter – A novel high efficient 12 V voltage regulator module. *IEEE Transactions on Power Electronics.* Vol. 18, No. 1, 74-82. DOI: 10.1109/TPEL.2002.807082
10. ON Semiconductor. (2016). Basic Principles of LLC Resonant Half Bridge Converter and DC/Dynamic Circuit Simulation Examples. *LLC Application Note*. AND9408/D. https://www.onsemi.com/pub/Collateral/AND9408-D.PDF
11. Falin, J. (2010). Designing DC/DC converters based on ZETA topology. *Analog Applications Journal*. Texas Instruments Incorporated. https://www.ti.com/lit/an/slyt372/ slyt372.pdf?ts=1660462865780&ref_url=https%253A%252F%252Fwww.google.com%252F
12. Peng, F. Z. (2003, Mar.-Apr.) Z-source inverter. *IEEE Transactions on industry applications*. Vol. 39, No. 2, 504-510.
13. Lam, Harry Y. F. (1979). *Analog and digital filters; design and realization*. Prentice-Hall.
14. Joseph, J. J., Josh, F., Lamare, R. and Mathew, B. V. (2019, November). Analysis of Power Electronic Converters for Electric Vehicle Applications. *Journal of Physics: Conference Series*. Vol. 1362.
15. Purcell, Edward M., Morin, David J. (2013). *Electricity and magnetism. Third edition*. Cambridge university press.
16. Nilsson, James W., Riedel, Susan A. (2011). *Electric circuits. Ninth edition*. Prentice Hall.
17. Hayt, William H. Jr., Kemmerly, Jack E., Durbin, Steven M. (2012). *Engineering circuit analysis*. (Eighth edition). McGraw-Hill.
18. Bratiuk, P. V. (2020). Modelyuvannya protsesiv nakopychuvannya enerhiyi v elektromekhanichnykh systemakh na pidstavi polozhen teoremy virialu [Modeling of energy storage processes in electromechanical systems on the basis of the provisions of the viral theorem]. *Elektromekhanichni i enerhozberihaiuchi systemy [Electromechanical and energy saving systems], 3/2020 (51)*, 8-18. DOI: 10.30929/2072-2052.2020.3.51.8-18. [in Ukrainian].
19. Bratiuk, P. V. (2021). Doslidzhennya aperiodychnoho rezhymu pid chas perekhidnoho protsesu v kolyvnomu koli z metoyu peretvorennya enerhiyi elektrychnoho strumu na teplo dzhoulya [Study of the aperiodic regime during the transient process in an oscillating circuit in order to convert the energy of an electric current into the heat of a joule]. *Elektromekhanichni i enerhozberihaiuchi systemy [Electromechanical and energy saving systems], 1/2021 (53)*, 15-26. DOI: 10.30929/2072-2052.2021.1.53.15-26. [in Ukrainian].
20. Goldstein, H., Poole, C., Safko, J. (2001). *Classical Mechanics*. (Third edition). Addison-Wesley.
21. Bratiuk, P. V. (2021). *Sposib peretvoriuvannia enerhii strumu v enerhiiu impulsiv [The method of converting current energy into pulses energy]. UA Patent No. 144614.* https://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=271791&chapter=description [in Ukrainian].
22. Bobalo, Yu. Ya., Volochii, B. Yu., Lozynskyi, O. Yu., Mandzii, B. A., Ozirkovskyi, L. D., Fedasiuk, D. V., Scherbovskykh, S. V., Yakovyna, V. S. (2013). *Matematychni modeli ta metody analizu nadiinosti radioelektronnykh, elektrotekhnichnykh ta prohramnykh system: monohrafiia. [Mathematical models and methods of reliability analysis of radioelectronic, electrical engineering and software systems: monograph].* Lviv: Vydavnytstvo Lvivskoi politekhniky [Lviv: Lviv Polytechnic Publishing House]. [in Ukrainian].
23. Volochiy, B., Mandziy, B., Ozirkovskyi, L. (2012) Extending the features of software for reliability analysis of fault-tolerant systems. Computational Problems of Electrical Engineering, 2012, vol. 2, no. 2, pp. 113-121.

Отримана в редакції 18.07.2023. Прийнята до друку 15.08.2023. Received 25 July 2023. Approved 15 August 2023. Available in Internet 12 September 2023.