MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

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Guidelines to laboratory works on discipline THEORETICAL FUNDAMENTALS OF ELECTRICAL ENGINEERING

For full-time students' education in academic discipline 141"Electric Power, Electrical Engineering and Electromechanics"

Part 3
DC AND AC NONLINEAR CIRCUITS, MAGNETIC CIRCUITS, TRANSIENTS IN CIRCUITS WITH NONLINEAR ELEMENTS

Dnipro
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Рекомендовано до видання навчально-методичним відділом (протокол № від за поданням науково-методичної комісії зі спеціальності 141 – Електроенергетика, електротехніка та електромеханіка (протокол № 21/22-01 від 30.08.2021 р.)

Методичні вказівки англійською мовою до лабораторних робіт з дисципліни «Теоретичні основи електротехніки», частина 3 (розділи: «Нелінійні електричні кола постійного та змінного струмів. Магнітні кола» та «Перехідні процеси у нелінійних колах») для студентів спеціальності 141 – Електроенергетика, електротехніка та електромеханіка / В.С. Хілов; Нац. техн. ун-т. «Дніпровська політехніка» – Д.: НТУ "ДП", 2021. – 30 с.

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Методичні вказівки англійською мовою призначено для виконання лабораторних робіт з дисципліни «Теоретичні основи електротехніки», частина 3 (розділи: «Нелінійні електричні кола постійного та змінного струмів. Магнітні кола» та «Перехідні процеси у нелінійних колах»). В інструкціях до виконання лабораторних робіт наведено основний матеріал, який викладається на протязі одної чверті семестру та відповідає затвердженій програмі. Кожна лабораторна робота складається з назви, мети, програми та етапів виконання, методичних вказівок, контрольних запитань.

Друкується в редакції автора.

Introduction

One of the most important types of classes in the course "Theoretical fundamentals of electrical engineering" is the performance of laboratory work. To increase the efficiency of the laboratory practicum, these methodical instructions have been developed.

Methodical instructions are intended for laboratory work in the discipline "Theoretical fundamentals of electrical engineering" (part 3, modules 5 "DC and AC Nonlinear Circuits, Magnetic Circuits, Transients in Circuits with Nonlinear Elements") for full-time students’ education in academic discipline: 141"Electric Power, Electrical Engineering and Electromechanics".

These laboratory works contain all the basic material, which is taught during two quarters of the semester and corresponds to the approved program.

Each laboratory work consists of the name, objective, program and stages of work execution, guidelines, control questions.

Duration of laboratory work is two academic hours; independent preparation for work - one hour; report - one hour.

The objective of laboratory classes is to consolidate the theoretical knowledge gained in lectures, and the acquisition of skills in experimental research of electrical circuits.

The process of laboratory work is designed for four stages: independent preparation for laboratory classes; experimental research on the stand; registration of research results; obtain the credit for laboratory work.

Independent preparation for the laboratory lesson is carried out in accordance with the topic and objective of the work. This is an in-depth study of the relevant sections of the TFEE course, the selection of individual parameters of the schemes, recording the necessary analytical relationships, drawings of schematic diagrams and tables for experimental results, answers to questions posed in the task.

The report is compiled by each student independently and is the main document in the performance and defense of laboratory work, which is drawn up in a separate notebook (18 sheets). Graphs and vector diagrams are built at scale. The report on each laboratory work should contain the main items: 1. Number and title of the work; 2. Objective of work; 3. Program of work c; 4. Analysis of results; 5. Conclusions on the performed calculations and their experimental verification. In addition to the main points, the report should contain additional points that are listed in each paper.

Experimental research is conducted at the training and research stand by teams of 2-3 students. The team receives permission to draw up an electrical circuit only after an interview with the tutor.

The student during the laboratory work must:

• follow the rules of electrical safety, which are given in the guidelines for laboratory work;

• perform laboratory work according to the appropriate method;

• make a report on the performance of laboratory work;

• protect the results of previous laboratory work;

• to receive an assessment for a laboratory module through a certain form of modular control (protection of reports on laboratory work).

BASIC SAFETY RULES
WHEN PERFORMED A LABORATORY PRACTICUM

1. Only students who are acquainted with the rules of safety in the electrical laboratories of the university are allowed to take the laboratory practicum.
2. Before passing the next cycle of the laboratory practicum in the electrical laboratories of the university, students must study the safety instructions and receive additional instruction before starting work in each subsequent laboratory. Students, after getting acquainted with the rules of safety and instructed, must sign the logbook for compliance with safety rules and liability for violation.
3. During work in electric laboratories it is forbidden to switch on laboratory stands under voltage, to make any switching on or switching in the main distribution cabinet, to change safety locks, and after automatic switching off by the protective equipment to do switching on again without the permission of the tutor conducting laboratory practicum.
4. Drawing up of electric schemes and all changes in electric schemes should be carried out at the switched-off voltage. It is impossible to switch in the scheme in work before check of its serviceability.
5. It is forbidden to leave current conductors with or without voltage in the passages between workplaces. It is forbidden to make any switches in the power supply circuits of the research stands.
6. It is possible to use conductors for drawing up schemes only on condition of sufficient area of their section by the provided value of currents. Conductors must be intact insulation and lugs. Particular care should be taken when studying circuits with series connections of inductors and capacitors, as resonant overvoltage’s are possible in such circuits.
7. Keep in mind that a disconnected capacitor can retain a dangerous residual charge, so it must be discharged before connecting to the circuit. Do not touch uninsulated current-carrying parts of electrical circuits that are or may be with voltage.
8. If during the laboratory work on the stand there is a characteristic smell of burnt plastic, strong buzzing of electrical equipment, smoke, or a sudden movement of the arrows off-scale of measuring instruments, you must immediately turn off the voltage and notify of the tutor.
9. In the event of an emergency (may be a person under voltage, a short circuit on the lab stand, breakage of current-carrying wires, fire etc.) first of all with the switch turns off the lab stand from the power supply, and if necessary, the button "Off 95 "the power supply of the classroom is disconnected. Button "Off. 95 "is in the distribution cabinet.
10. The fire is extinguished by a carbon dioxide fire extinguisher located at the workplace of the duty laboratory assistant. There is also a first aid kit with medicines for first aid.

Laboratory Work 4-TFEE – 3/1

THE EXPERIMENTAL ANALYSIS PROCESSES IN THE DC CIRCUIT CONNECTION WITH NONLINEAR ELEMENT

Objective

Experimental determination of the volt-ampere characteristics in the forked DC nonlinear circuit

Work program

1. Assembling of the research circuit.
2. The experimental definition of the volt-ampere circuit characteristics.
3. The plotting of volt-ampere characteristics.
4. Calculation the input dynamic $R_{dyn}(U)$ and static $R_{st}(U)$ circuit resistances.
5. Plotting of dependence $R_{st}(U),\ R_{dyn}(U)$.
6. Calculation nonlinear circuit currents and voltages by the method of equivalent generator.
7. Analysis results. Summary.

Work Stages

Stage 1. Assembling of the research circuit.

To aggregate the circuit on a panch board of the educational-research stand according to Fig.1.1.

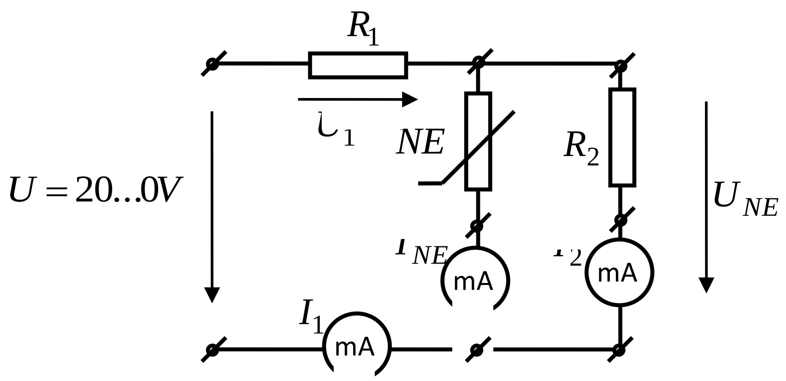

Figure 1.1. - Scheme of the studied circle

There are used next elements in the electric scheme:

- adjustable DC voltage source chosen from the bloc of DC voltage;
- resistor R_1 is chosen by nominal value about 250 Ω, and R_2 about 750 Ω;
- as nonlinear element is used semiconductor double-anode diode *KC*-type, that works in voltage stabilization mode.

1.2. After the check of electric circuit to switch on supply source.

Stage 2. The experimental definition of the volt-ampere circuit characteristics.

2.1. To set the maximum meaning of the output voltage of the source of adjustable DC voltage source from the DC voltage bloc.

2.2. To decrease the value the of the output voltage of the source of adjustable DC voltage to *15 V* and to measure voltage on nonlinear element by the multimeter. If voltage on nonlinear element is changed more then on *1 V* to find and eliminate malfunction in the circuit.

2.3. To set *U=20 V* the value of the source of DC voltage and to measure the voltage U_1 and U_{NE}, and also currents I_1, I_2, I_{NE}. Data of measurement one should enter into Table 1.1.

Table1.1.

Experimental determination of voltages and currents in a nonlinear circuit

U, V	20	18	16	14	12	10	8	6	4	2	0
U_1, *V*											
U_{NE}, *V*											
I_1, *мА*											
I_2, *мА*											
I_{NE}, *мА*											

2.4. To decrease the value of the output voltage of the source of adjustable DC voltage on 2 *V* and to measure voltages U_1, U_{NE} and currents I_1, I_2, I_{NE} . Measurement result tabulate into Table 1.1.

2.5. To repeat item 2.4 to vanish the output voltage of the source of adjustable DC voltage.

Stage 3. The plotting of volt-ampere characteristics.

3.1. To choose scales for the plotting of volt-ampere characteristics.

3.2. In the same system of coordinates to build volt-ampere characteristics $U_{NE}(I_2)$, $U_{NE}(I_{NE})$, $U_1(I_1)$, $U_{NE}(I_1)$, $U(I_1)$.

Stage 4. Calculation of input dynamic $R_{dyn}(U)$ and static $R_{st}(U)$ circuit resistances.

4.1. According to data of Table 1.2 to calculate resisters R_{st}, R_{dyn}.

Table 1.2.

The static and dynamic resistances numerical values calculation

U, V	20	18	16	14	12	10	8	6	4	2
I_1, мА										
R_{st}, Ω										
R_{dyn},										

Ω										

4.2. Value of the current I_1 for corresponding input voltage U is taken from Tabl1.1.

Stage 5. Plotting of dependence $R_{st}(U)$, $R_{dyn}(U)$.

5.1. To choose scales for the plotting of volt-ampere characteristics.
5.2. In the same system of coordinates to build graphs $R_{st}(U)$, $R_{dyn}(U)$ according to data of Table 1.2.

Stage 6. Calculation of nonlinear circuit currents and voltages by the method of equivalent generator.

6.1. Calculate the internal resistance of equivalent generator concerning to branch with nonlinear element.
6.2. To calculate EMF of open circuit of equivalent generator concerning to branch with nonlinear element at input voltage *20 V*.
6.3. Using the known nonlinear dependence $U_{NE}(I_{NE})$ and data of items 6.1, 6.2 to find by graphic method the current and voltage on nonlinear element.
6.4. Compare measuring result with calculation data.

The Report must contain

1. The number and name of the laboratory work.
2. The work program.
3. Tables 1.1, 1.2.
4. Scheme of probe circuit.
5. Calculation of equivalent generator parameters.
6. Figures 1.2, 1.3.
7. Deduce on carrying out calculations and experimental check.
8. The conclusions of the laboratory work.

Methodical direction

Stage 2. Measuring currents and voltages in circuit gets for all branches at the same time at set input voltage.

Stage 4. Input resistance is defined in every working point for data of Table 1.2

$$R_{st} = \frac{U}{I_1},\ \Omega.$$

Values of current I_1 is necessary to be changed from milliamperes to amperes.
Input dynamic resistance is defined on working part according to data in Table 2

$$R_{dyn} = \frac{\Delta U}{\Delta I_1},\ \Omega.$$

Stage 6. At the calculation do not take account of the internal resistance of the source of adjustable DC voltage.

The internal resistance of equivalent generator concerning nonlinear element

$$R_{int} = \frac{R_1 \cdot R_2}{R_1 + R_2}, \ \Omega.$$

Current of the open circuit equivalent generator

$$I_{oc} = \frac{U}{R_1 + R_2}, \text{ A.}$$

where $U=16$ *V*.

EMF of open circuit equivalent generator

$$E_{oc} = I_{oc} \cdot R_2, \ V.$$

In the same reference grid we draw volt-ampere characteristics $U_{NE}(I_{NE})$, $U_{int}(I_{int})$. Data for construction $U_{NE}(I_{NE})$ are taken from Table1, but the volt-ampere characteristic of linear element R_{int} $U_{int}(I_{int})$ is built on two points. Graphically to define current and voltage on nonlinear element at calculated E_{os}.

We do linearization at working point of the characteristic of nonlinear element. For this it is changed by resistance R_{st} (Fig.1.2) or R_{dyn} (Fig.1.3) and supplementary EMF (E). For linearized scheme define currents I_1, I_2.

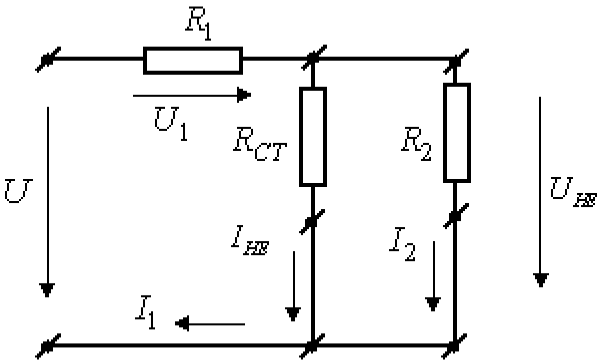

Figure 1.3. - Linearization at a working point

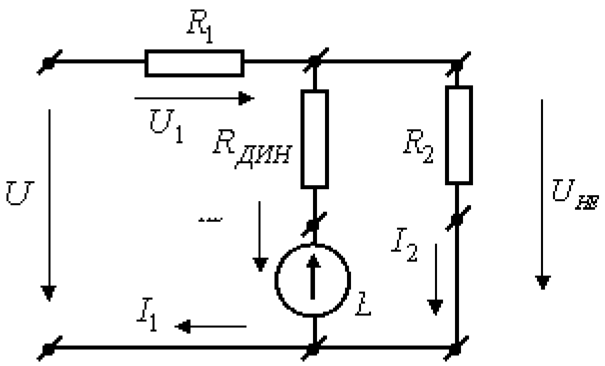

Figure 1.4. - Linearization on the work section

Questions for check knowledge

1. Why nonlinear circles do not calculate by the superposition method?
2. In what case can be calculated nonlinear circle by the method of equivalent generator?
3. What is understood under the static resistance of nonlinear element?
4. What is a dynamic resistance of nonlinear element?
5. Why is the static resistance of nonlinear element always positive?
6. At what conditions the dynamic resistance of nonlinear element is positive, and at what - negative?
7. How graphically is calculated the circle with nonlinear elements included series?
8. What restrictions are imposed on calculation of the circle, if nonlinear elements are connected as parallel?
9. What are peculiarities of the calculation of circles with nonlinear elements combined in connection?

10. How to compose a power balance for the nonlinear circuit?

Laboratory Work TFEE – 3/2

EXPERIMENTAL STUDY OF PROCESSES IN AN ELECTRIC CIRCUIT WITH A COIL CONTAINING IRON CORE

Objective

Experimental determination of equivalent circuit parameters of the replacement scheme of the coil with iron core

Work program

1. Assembling of the research circuit.
2. The current curve of the coil with iron core oscillographic testing.
3. Measuring the current, voltage, active power.
4. Calculation of input dynamic $R_{dyn}(U)$ and static $R_{st}(U)$ circuit resistances.
5. Plotting of dependence $R_{st}(U)$, $R_{dyn}(U)$.
6. Calculation of nonlinear circuit currents and voltages by the method of equivalent generator.
7. Analysis results. Summary.

Work Stages

Stage 1. Assembling of the research circuit.

1.1. To assemble electric scheme that is shown on Figure 2.1.

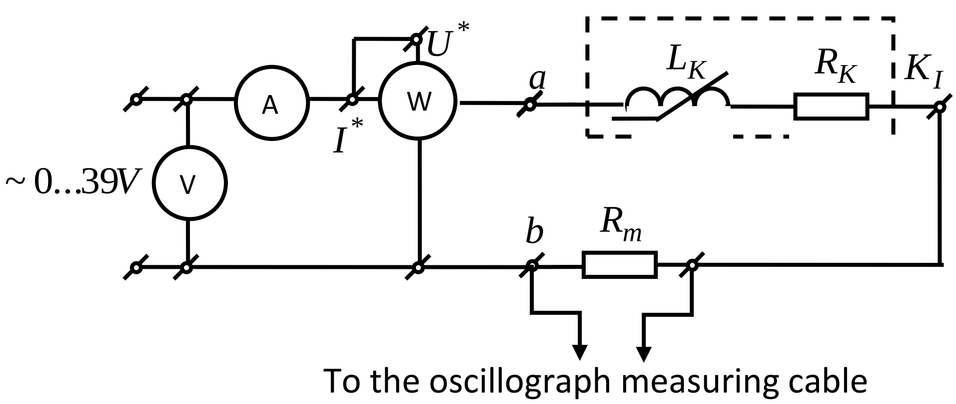

Figure 2.1. - Scheme of the studied circle

In the scheme there are used elements:

– feed source – the single-phase voltage of three-phase voltage bloc (50 Hz, 0 ...39, 9 V);

– coil with iron core situated in bottom of patch board (for the realization of experiment we choose coil of coil #1);

- measuring resistance is chosen in the range $R_m = 1...2\Omega$.

1.2. After the verification of electric scheme to include feed.

2. The current curve of the coil with iron core oscillographic testing.

2.1. Switch on tumbler electronic oscillograph “mains” (“сеть”) and give to warm up oscillograph till the appearance of horizontal line on the screen.

2.2. To connect oscillograph measuring cable on the output voltage of measuring resistance R_m.

2.3. By voltage divider “amplifier U” (“усилитель U”) is installed a convenient scale as to axis of ordinates, and by the switch of “deflection” (“развертка”) is installed a convenient scale as to axis of abscissas.

2.4. Rotate handle “level” (“уровень”) clockwise till firmly, and after then by handle “stabilization” (“Стаб”) to attain the signal disappearance from oscillograph screen. Then rotate handle “level” (“уровень”) counterclockwise to attain the distinct and synchronized images of investigated signal.

2.5. To install the output voltage of the feet source 10 V.

2.6. To connect oscillograph measuring cable on measuring resistance R_m. To choose scales.

2.7. To append a tracing paper to the oscillograph screen and to copy image or to photograph current curve from oscillograph screen at the voltage of source 10 V. To write down scales as to y-axises and x-coordinate. (Current curve line is sinusoidal).

2.8. To enlarge an input voltage till significance U=39, 9 V.

2.9. If it is necessary to change the scale of current curve.

2.10. To copy a current curve line from oscillograph screen or to photograph the one at the voltage of source 39.9 V. (Current curve line is nonsinusoidal).

3. Measuring the current, voltages, active power.

3.1. To install the output voltage of the feed source 39.9 V.

3.2. One should be determined with the division value of electrical measuring instruments – milliammeter and wattmeter.

3.3. Voltage is measured by multimeter; to take off indications with scales of milliammeter and wattmeter. To put down data in table 1.

Table 2.1.

Measured and calculated research results

measure				calculate													
U	I	P	R_M	L_S	U_Φ	ψ_Φ	P_M	P_C	g_{CT}	I_n	I_μ	ψ_μ	L_μ	Q_μ	Q_S	Φ	
V	*A*	*Wt*	Ω	*H*	*V*	*deg*	*Wt*	*Wt*	*Sm*	*A*	*A*	*deg*	*H*	*var*	*var*	*Wb*	

3.4. To disconnect the feed source, to detach coil with iron core from scheme and to measure the ohmic resistance of coil R_M by multimeter. To put down the result of measurement in Table 2.1.
3.5. To switch off lab table from external feed source.
4. The calculation of parameters of the simplified replacement scheme.
4.1. As to the basic data of table 1 to perform the calculation of parameters of the simplified replacement scheme.
4.2. The results of calculations are entered in Table 2.1.
5. Plotting of simplified phasor diagram.
5.1. As to the table 1 to plot the simplified phasor diagram.
6. The calculation of the customized replacement scheme.
6.1. Supposing leakage flux is on average 10% with respect to main magnetic flux, to calculate the digital significance of leakage inductance.
6.2. As to the basic data of table 1 to perform the calculation of the specified parameters of the coil with steel core replacement scheme.
7. Plotting of specified phasor diagram.
7.1. As to the calculated values of table 1 to plot the specified phasor voltages diagram combined with phasor current diagram.

The Report must contain

1. The number and name of the laboratory work.
2. Objective.
3. The work program.
4. Fig. 2.1, Table 2.1.
5. Calculation of the simplified and specified replacement schemes parameters.
6. Phasor diagrams according to the simplified and specified replacement schemes.
7. The analysis of results and conclusions of the laboratory work.

Methodical direction

To the Stage 2. Because the magnetic flux is proportional to applied voltage at increasing voltage the coil magnetic conductor is saturated, it brings to the decrease of circuit inductance and the decrease of inductive reactance. That is why in increasing voltage the magnetic conductor is saturated (Fig.2.2, a) and current in coil begins to change not as to sinusoid (Fig.2.2, b), what is seen on current oscillograms (Fig.2.2, c, d).

To the Stage 4. For the calculation of electric AC circuits with nonlinear inductive element (coil with steel core), the ones are replaced by the series or parallel replacement scheme (Figs. 2.3, 2.4).

On the schemes resistance R_M is ohmic resistance of the wires of winding coil (the resistance of the coil copper). In the simplified replacement schemes the magnetic leakage flux is neglected. That is why the leakage inductance and inductive reactance of the dissipation contour are equal to zero.

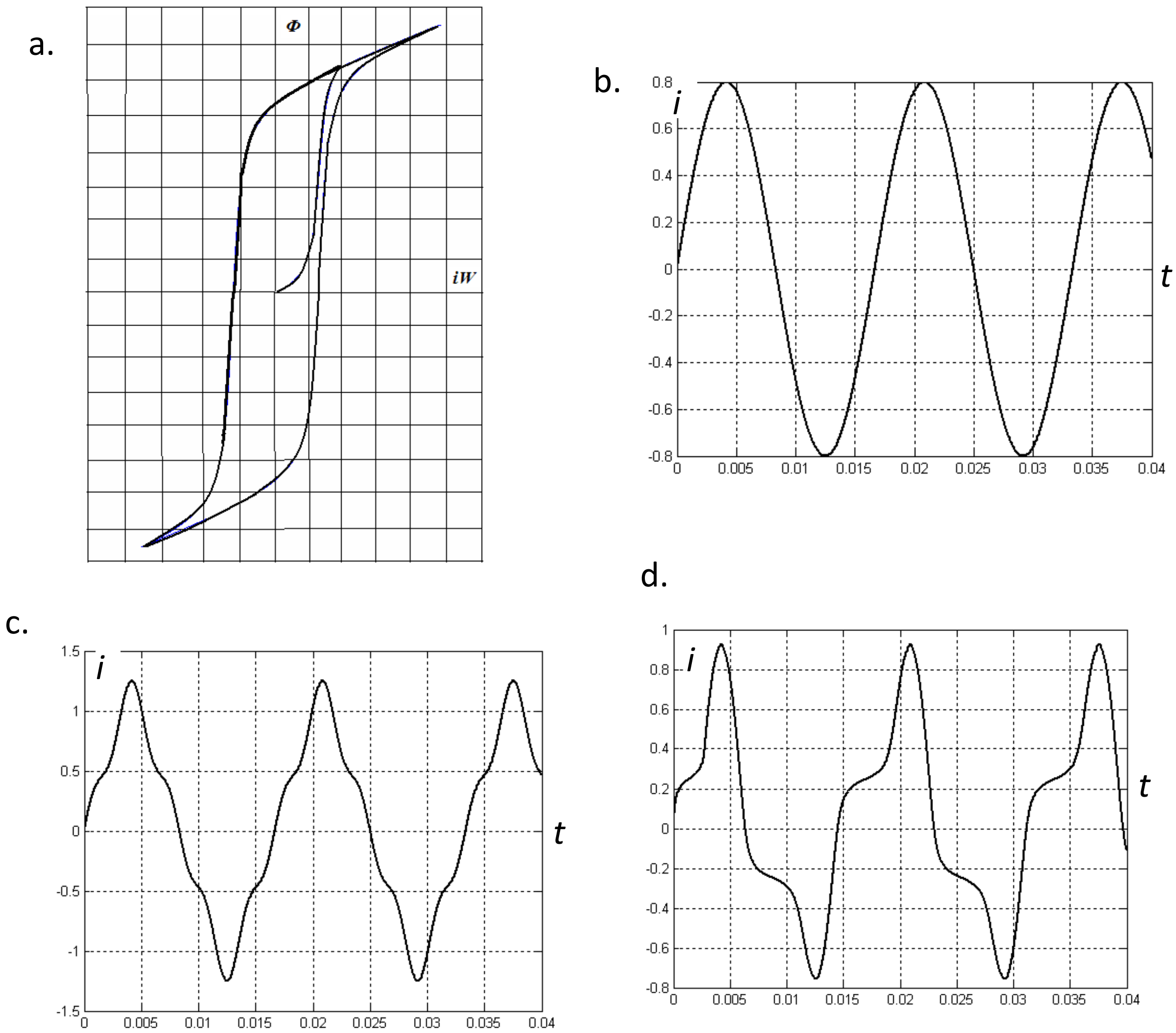

Figure 2.2. - Hysteresis curve of the core magnetization (a), current curves of the coil with steel core with unsaturated core (b), initial (c) and deep (d) saturation of the core of the magnetic circuit

Ohmic resistance R_{CT} and appropriate conduction G_{CT} take into account the presence of active losses in magnetic conductor core (ohmic resistance of core steel takes into account the presence of active losses on magnetic conductor core remagnetization). Reactive resistance x_{μ} and conductance b_{μ} take into account the presence of main magnetic flux which is closed on magnetic conductor core.

For the calculation of the parameters of the replacement scheme there is made assumption that in the circuit there flows equivalent sinusoidal current a value of which is determined by ammeter.

We neglect leakage inductance (approximate calculation)

$$x_S = 0 .$$

Reactive power which is distinguished in inductance stipulated by the main flux is determined by relation

$$Q = \sqrt{S^2 - P^2} \text{ , var,}$$

where $S=UI$, VA – apparent consumed power;
U, I, P – the measured voltage significances, V, equivalent current, A, active power, Wt.

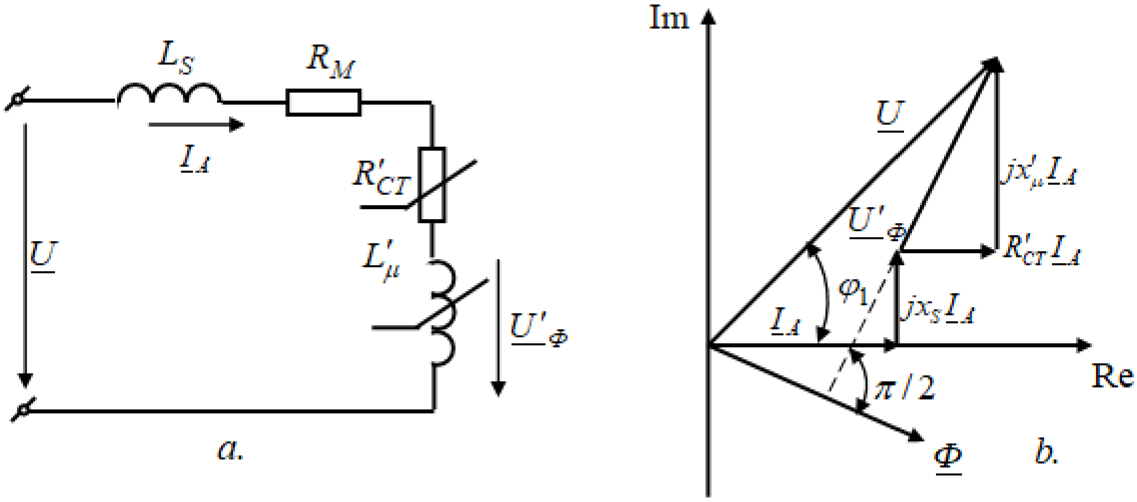

Figure 2.3. - Series equivalent circuit (a) and its vector diagram (b) of the coil with steel core

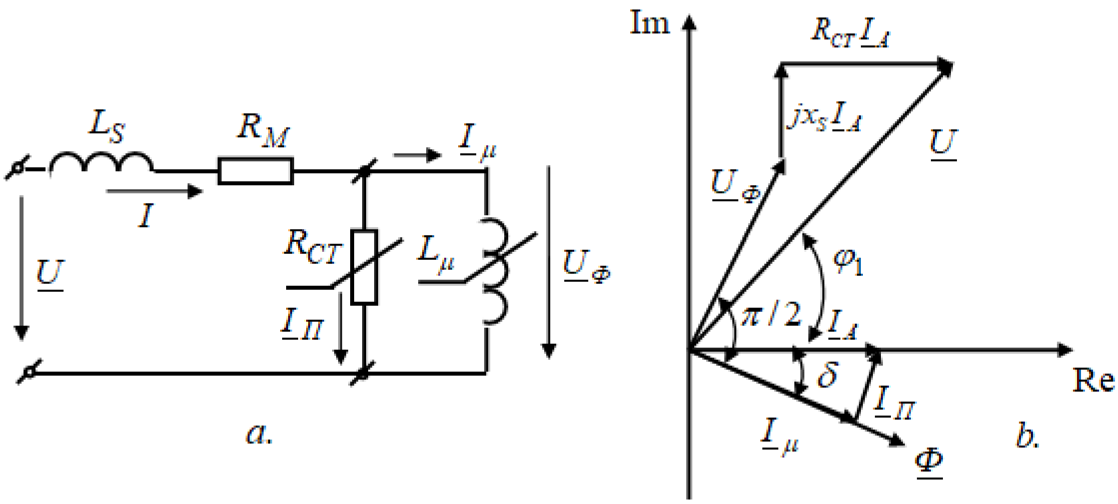

Figure 2.4 - Parallel equivalent circuit (a) and its vector diagram (b) of the coil with steel core

The approximate significance of coil reactive resistance

$$x'_{\mu} = \omega L'_{\mu} = \frac{Q}{I^2},\ \Omega.$$

The approximate significance of coil inductance

$$L'_{\mu} = \frac{x'_{\mu}}{\omega},\ \text{H}$$

where $\omega=2\pi f$ – the cyclic frequency of feeding voltage, f=50 Hz – angular frequency.
To the stage 5. The calculation of the specified parameters of the replacement scheme.
The calculation is made by taking into account inductance from the leakage fluxes. We accept the significance of the leakage flux equal to 10% from main flux which is closed at the magnetic core. In such assumption the leakage inductance is found as

$$L_S = 0{,}1L'_{\mu}, \text{ H.}$$

Reactive resistance from the leakage fluxes

$$x_S = \omega L_S, \ \Omega.$$

From the power triangle we find the angle of lag φ input equivalent current from input voltage

$$\varphi = \arccos\frac{P}{S}, \text{ rad.}$$

Let us determine the phasor significances of input voltage $\underline{U}$ and equivalent current $\underline{I}$

$$\underline{U} = Ue^{j\psi_U}; \underline{I} - Ie^{j\psi_I},$$

where U, I – the indications of apparatuses;

ψ_u, ψ_i – the phases of voltage and current which are connected by relation between each other

$$\psi_u - \psi_i = \varphi.$$

One of the phases (ψ_u or ψ_i) is accepted as initial (for example equal to zero).

We compute voltage on magnetization loop

$$\underline{U}_{\phi} = \underline{U} - \underline{I}(R_M + jx_S) = U_{\phi}e^{\psi_U}, \text{ V.}$$

In the sequel the specified calculation is being conducted for the parallel replacement scheme (Fig.3).

Active losses in the coil (in the resistance of the coil copper)

$$P_M = R_M I^2, \text{ Wt.}$$

Active losses for remagnetization of steel magnetic conductor (in the conductions of steel magnetic conductor)

$$P_C = P - P_M, \text{ Wt.}$$

Conductance of the steel of magnetic conductor core

$$G_{CT} = \frac{P_C}{U_{\phi}}, \text{ Sm.}$$

Current in the loop of losses which is conditioned by losses in the steel

$$I_{\Pi} = U_{\phi} \cdot G_{CT}, \text{ A.}$$

Losses current coincides in phase with voltage in magnetization loop that is why its phasor value is

$$\underline{I}_{\Pi} = I_{\Pi}e^{j\psi_U}, \text{ A.}$$

The phasor current significance of the main flux magnetization magnetic conductor loop is

$$\underline{I}_{\mu} = \underline{I} - \underline{I}_{\Pi} = I_{\mu}e^{j\psi_{\mu}}, \text{ A.}$$

The specified significance of inductive conduction of the magnetization loop

$$L_{\mu} = \frac{1}{\omega \cdot b_{\mu}}, \text{ H.}$$

Reactive losses in magnetization loop

$$Q_{\mu} = \frac{I_{\mu}^2}{b_{\mu}}, \text{ var.}$$

Reactive losses in inductance of dissipation flux

$$Q_S = x_S I^2, \text{ var.}$$

The value modulus of magnetic flux

$$\Phi = \frac{U_\phi}{4{,}44 \cdot f\omega}, \text{ Wb,}$$

where ω=100 – quantity turns of coil.

The magnetic flux lags behind from voltage in magnetization loop by angle $\frac{\pi}{2}$, that is why its phasor value is

$$\underline{\Phi} = \Phi \cdot e^{j(\psi_U - \frac{\pi}{2})}, \text{ Wb.}$$

Result of calculation to put down in table 1.

Analogously calculations can be made for the consecutive replacement scheme, Figure 2.

To Stage 7. Plotting of voltage phasor diagram combined with current phasor diagram and magnetic flux.

As initial vector there is chosen one of parameters: vector input current, input voltage or magnetic flux. All the rest of the vectors are drawn in scales according to the found phasor significances. Basic data for plotting phasor diagram are taken from table 1.

Questions for check knowledge

1. What does nonsinusoidality of current of the inductance coil with steel core depend on?
2. What harmonic components are present in the curve of nonsinusoidal current?
3. Explain the notion of equivalent sinusoid?
4. How should one calculate the significance of equivalent sinusoid current?
5. How will be changed the reactive resistance of inductance coil with increasing saturations magnetic core?
6. Why is the loop of the decapitation fluxes not saturated with the increasing of input voltage?
7. By what phenomenon is described the saturation steel of magnetic core?
8. Explain what is understood under the phenomenon of the steel resistance?
9. Explain what is understood under the phenomenon of the copper resistance?
10. What a method of calculation can be applied in replacement of the initial nonsinusoidal current curve by equivalent sinusoid?

Laboratory Work TFEE – 3/3

EXPERIMENTAL STUDY OF VOLTAGES PHENOMEN RESONANCE IN SERIES CIRCUIT

Objective

Experimental determination of the conditions of appearance and the peculiarities of voltage ferroresonance phenomenon in the consecutive connection of coil with steel core and capacitor

Work program

1. Assembling of the study circuit.
2. Experimental determination of the volt-ampere characteristic of coil with steel magnetic conductor.
3. Determining of the value of capacity which is necessary for the appearance of voltage ferroresonance phenomenon in the investigated loop.
4. Experimental determination of volt-ampere characteristic of the consecutive connection of coil with steel and capacity.
5. Plotting the volt-ampere characteristics of the whole loop and composing elements.
6. Analysis of results. Conclusions.

Work Stages

Stage 1. Assembling of the study circuit.

1.1. To assemble the electric scheme mentioned in Figure 3.1.

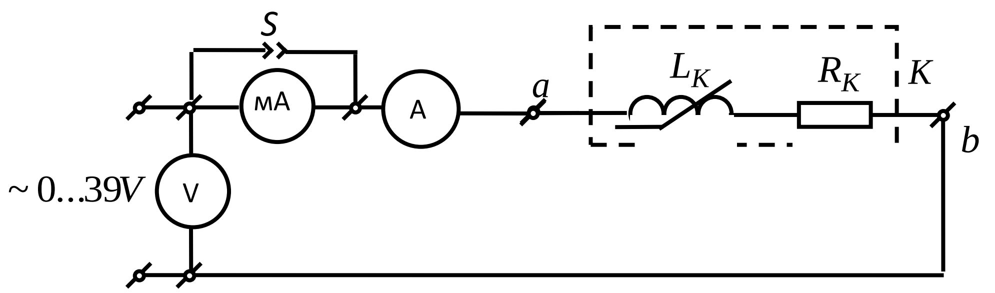

Figure 3.1. - The circuit of experimental study of volt-ampere characteristics of a nonlinear coil

On the scheme there are used elements:

– feed source – the single phase voltage from the bloc of three-phase voltage (50 Hz, 0 .. .39, 9 V);

– coil with steel magnetic conductor situated below of switchboard panel (for the experiment realization is taken the coil with is steel core which situated in the lower left corner of switchboard panel).

Stage 2. Experimental determination of the volt-ampere characteristic of coil with steel magnetic conductor.

After the verification of electric scheme to switch feed voltage, and take off dependence of current on the voltage. Results of measurements to put down in Table 3.1. If the currents exceed the limit of measurement of milliammeter it is necessary to shunt one by exterior short.

Table 3.1.

Measured values of voltage drop and current of the coil with steel core

№ order	1	2	3	4	5	6	7	8	9	10
U_K, V	4	8	12	16	20	24	28	30	32	34
I_K, mA										

Stage 3. Determining of the value of capacity which is necessary for the appearance of the voltage ferroresonance phenomenon in the investigated loop.

3.1. To plot the dependence $U_K = f(I_K)$ according to the data of Table 3.1.

3.2. Using the curve $U_K = f(I_K)$ and assuming $U_K = U_{LK}$, to determine the value of capacity C that is necessary for the appearance of voltage ferroresonance (current in the circuit should not be above 1 A).

3.3. To determine the greatest significance of capacity C_{KP} in which there is still possible ferroresonance phenomenon.

Stage 4. Experimental determination of volt-ampere characteristic of the consecutive connection of coil with steel and capacity.

4.1. To assemble the scheme that is mentioned in Figure 3.2.

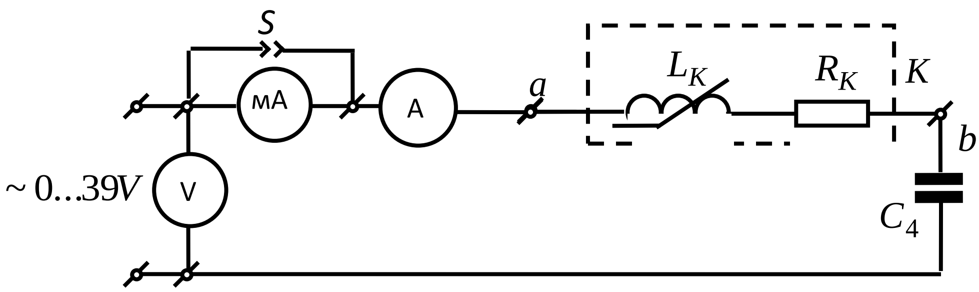

Figure 3.2. - Circuit of experimental study of volt-ampere characteristics of the phenomenon of voltage ferroresonanc

4.2. By means of decade switches to set up the value of capacity $C = C_4$ well-calculated as to Stage 3.2 which is necessary for the appearance of the voltage ferroresonance phenomenon.

4.3. To determine experimentally the volt-ampere characteristic, including the section after current step, of all the circuit consisting of coil with steel core and capacity. The results of observation to enter in to Table 3.2.

4.4. The growing branch of volt-ampere characteristic is taken off in increasing supply voltage till value not exceeding of the voltage step.

4.5. Before measuring the growing branch of volt-ampere characteristic at the large currents the milliammeter is short.
4.6. The decreasing branch of volt-ampere characteristics to take off in the decrease of supply voltage.

Table 3.2.

№ order	1	2	3	4	5	6	7	8	9	10
U, V										
U_K, V										
U_C, V										
I_K, mA										

4.7. Growing branch of volt-ampere characteristic is taken off in increasing supply voltage till value not exceeding of the voltage step.
4.8. Before taking off the growing branch of volt-ampere characteristic at the large currents the milliammeter is short.
4.9. The decreasing branch of volt-ampere characteristics to take off in the decrease of supply voltage.

Stage 5. Plotting the volt-ampere characteristics of all the circuit and composing elements.

5.1. In the general system of coordinates and in one and the same scale to draw the graphs of the circuit current dependences:
– supply voltage $U = f_1(I_K)$;
– coil voltage $U_K = f_2(I_K)$;
– capacity voltage $U_C = f_3(I_K)$.
5.2. As to graphs $U_K = f_2(I_K)$ and $U_C = f_3(I_K)$ to draw the computative curve of supply voltage $U' = F_1(I_K)$ and compare it with curve $U = f_1(I_K)$.

The Report must contain

1. The number and name of the laboratory work.
2. Ojective.
3. The work program.
4. Fig. 3.2, Tables 3.1, 3.2.
5. Graphic dependences $U = f_1(I_K)$, $U_K = f_2(I_K)$, $U_C = f_3(I_K)$, $U' = F_1(I_K)$.
6. The analysis of results and conclusions of the laboratory work.

Methodical direction

On the consecutive connection of coil with ferromagnetic core and capacitor is seen particular phenomenon connected with the nonlinear characteristic of this circuit named as ferroresonance. In difference from circuits with permanent parameters, resonance phenomenon in circuit with ferromagnetic coil is achieved not by the change of the frequency of supply voltage, but it value. This is connected with what of coil inductance

with ferromagnetic core is directly dependent on current value and consequent variate in the change of supply voltage to scheme.
For the experimental studies of phenomenon voltage ferroresonance is necessary to provide the conditions of it appearance which is achieved by fitting the choice of the significances of the reactive circuit elements. With this end in view on the first stage of researches it is necessary to determine the volt-ampere characteristic of investigated nonlinear inductance coil $U_K = f_2(I_K)$. This characteristic is credible curve magnetization core. On the second stage of researches choose characteristic linear capacitor.
Capacitor is the linear element, that is why it volt-ampere characteristic $U_C = f_3(I_K)$ presents direct line. If both characteristics $U_K = f_2(I_K)$, $U_C = f_3(I_K)$ to reduce in one coordinate system that point of their intersections uniquely will determine ferroresonance point.
Selected the point of the intersection of volt-ampere characteristics $U_K = f_2(I_K)$, $U_C = f_3(I_K)$ thereby assign the parameters of elements. If parameters in this laboratory work inductance coil unchanged, then significance capacitor element we can choose in acceding with calculation. For the reception the physically of actualized significance of capacitor choose the point of resonance directly for curve knee $U_K = f_2(I_K)$. Chosen point *N* is determined by coordinates, (Fig. 3) who belong the as unlinear characteristic of spool with steel $U_K = f_2(I_K)$ to so and characteristic linear capacitor$U_C = f_3(I_K)$. Hence cubic content $U_C = f_3(I_K)$ should be

$$C = I_N / (U_{N} . \omega),$$

where ω – angular frequency compliance to industrial voltage with cyclic frequency f=50 Hz.
If volt-ampere characteristics $U_K = f_2(I_K)$, $U_C = f_3(I_K)$ are not crossed that in the circuit the ferroresonance phenomenon does not appear. In extreme case the graph of characteristics $U_C = f_3(I_K)$ is tangent to the characteristic $U_K = f_2(I_K)$ at the origin of coordinates. To this case corresponding critical capacity C_{KP}. If value of capacity is equal or less of critical capacity C_{KP}, then the ferroresonance phenomenon does not appear. Namely for the appearance of the ferroresonance phenomenon in investigated circuit is it necessary and sufficient that significance of capacitor capacitance was not less critical capacity C_{KP}.

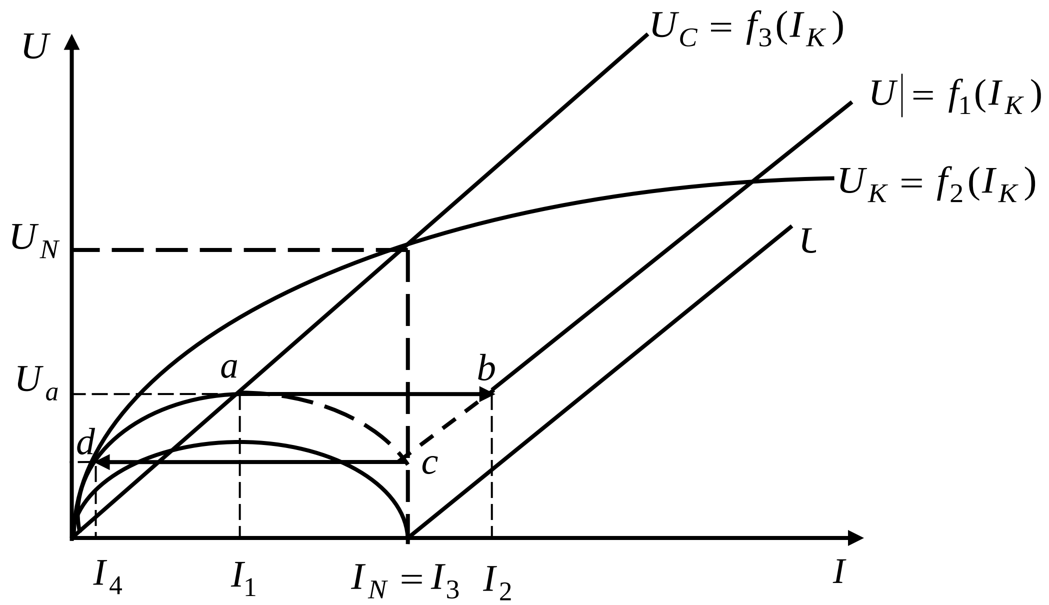

Figure 3.3. - Volt-ampere characteristic of the ferroresonance voltages phenomenon

If the ohmic resistance of coil inductance with steel core is negligible with reference to the reactive resistance of this spool that voltage on capacity element phase shift on corner 180^0. In such correlation the supply voltage of all circuit equal to of algebraic difference voltage on inductance and capacitance. Ordinaty of graphic dependence find as ordinate difference $U_K = f_2(I_K)$ and $U_C = f_3(I_K)$

$$U_P = U_K - U_C.$$

As far as consider voltage effective values on circuit, volt-ampere characteristics are considered irrespective from signs in the first quadrant, namely part of characteristic $U = f_1(I_K)$ which appear at fourth quadrant is considered in the first quadrant. With this end in view take its mirror reflection relatively of axis abscissa, namely take the characteristic modulus $U = f_1(I_K)$.

If it is impossible to neglect the omit resistance of inductance coil with steel core with reference to the reactive resistance of this coil, then resulting characteristic $U = f_1(I_K)$ will not drop till zero in voltage ferroresonance phenomenon and supply current will be deffer from zero

$$U = \sqrt{(U_K - U_C)^2 + U_A^2},$$

where U_A – the voltage drop on the ohmic resistance of inductance coil with steel core.

The slow increasing of voltage supply from 0 till U_a brings to smooth increment circuit current (Fig. 3) which practically on $\pi/2$ lags behind from voltage. In point *a* arises step current from significance I_1 till significance I_2 in point *b* on unchanged voltage U_a. Step current arises with the change of current phase. The current begins to lead the voltage practically on corner $\pi/2$. Such phenomenon of the step phase change in technique name phase reversal. The further increasing of tension brings to increasing circuit current.

The voltage decrease brings to decrease circuit current till significance I_2 in point *b* (Fig. 3). In later the voltages and current continue smooth to change till point *c* with where current accepts significance I_3, voltage – significance U_c. In point *c* with arises step current from significance I_3 till significance I_4 in point *d*. On this district of volt-ampere characteristic likewise arises the phenomenon of phase reversal. The further decrease of voltage supply brings to decrease circuit current and system returns in starting point.

Questions for check knowledge

1. Explain the phenomenon of phase reversal.
2. It is like to change summary volt-ampere characteristic in increasing of the ohmic resistance of nonlinear inductance coil?
3. Why in real electric circuits at the moment of resonance the current is not equal to zero?
4. In what cases, and in what points of the circuit volt-ampere characteristic arises step change of current and it phase?
5. For account of what effect is achieved voltages ferroresonance phenomenon?
6. It is like to change voltage on inductance coil in the decrease voltage supply, if till this in circuit predominated capacitance resistance?
7. On what district of the circuit volt-ampere characteristic is seen negative dynamic resistance?
8. Point on volt-ampere characteristic point of voltages ferroresonance phenomenon?
9. In known the volt-ampere characteristics of ohmic resistance, capacities and coils with steel core how to find resulting the volt-ampere characteristic of all circuit?
10. Why not is considered resulting volt-ampere characteristic in fourth quadrant?

Laboratory Work TFEE – 3/4

THE EXPERIMENTAL THE PHENOMENON OF RELAXATION SELF-EXCITED OSCILATIONS IN NONLINEAR CIRCUIT

Objective

Experimental determination on nonlinear circuit parameters which appears self-oscillation regime

Work program

1. Acquaintance with the circuit model.
2. Measurement of significances ohmic resistances.
3. Measuring of volt-ampere the characteristic of the nonlinear element.
4. Experimental determination voltage in which is generated self-oscillation mode.
5. Analysis of the influence of the significance of capacitance on frequency and amplitude self-oscillation mode.
6. Analysis of the influence of the significance of resistance on frequency and amplitude self-oscillation rmode.
7. Calculation of the relaxation oscillations frequency.
8. Analysis of results. Conclusions.

Work Stages

Stage 1. Acquaintance with the circuit model.

The circuit dummy is shown on Fig. 4.1.

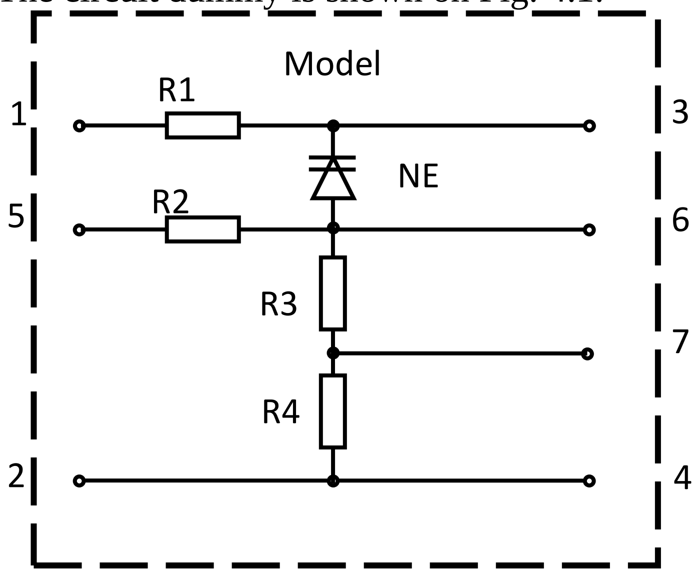

Figure 4.1. - Model scheme of the research circle

Direct voltage is given on the scheme clamps 1, 2. Polarity is shown on Fig.4.1 necessary to keep.
Exterior capacitor is connected to clamps 3, 4.

Stage 2. The measurement of significances ohmic resistances.

To measure by multimeter significance of ohmic resistances which are on dummy, results to put down in Table 4.1.

Table 4.1.

Numerical parameters of ohmic resistances of the circuit model

R1, kΩ	R2, kΩ	R3, kΩ	R4, kΩ

Stage 3. Measuring of volt-ampere the characteristic of the nonlinear element.

3.1. To gather scheme as to Fig.4.2. The voltage of the feed source to do equal to zero.

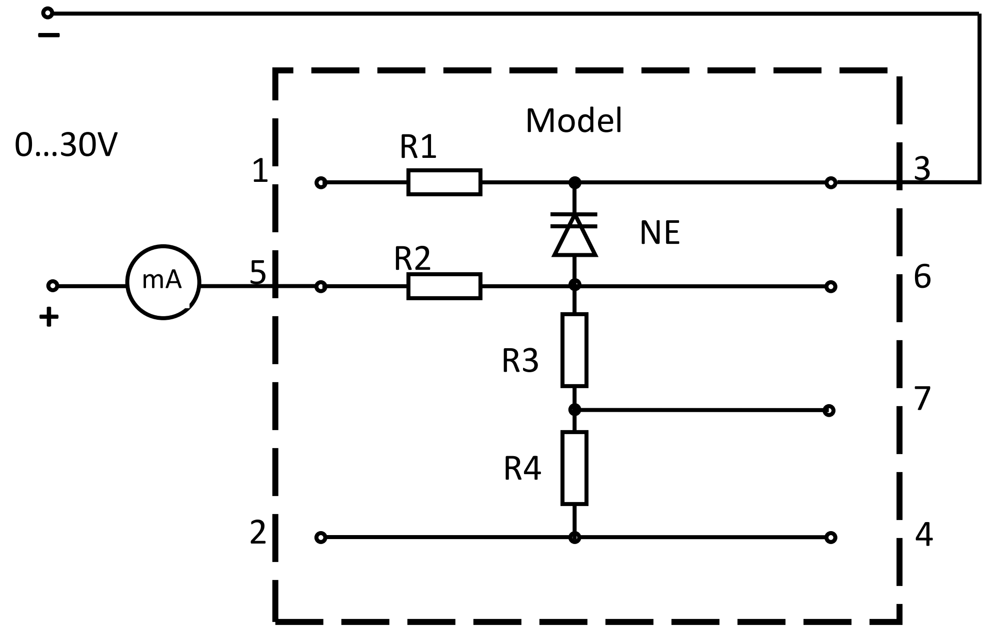

Figure 4.2. - Scheme of research of volt-ampere characteristic of nonlinear element

3.2. As the feed source to use of the supply voltage of the adjust source of direct voltage.
3.3. Slowly increase output voltage from null significance to find current the inclusions of nonlinear element I_{inp}.
3.4. To gather scheme as to Fig.4.3. The voltage of the source of feed to do equal to zero.
3.5. Slowly increase input voltage to determine the voltage of opening of nonlinear element U_0.
3.6. Slowly decreasing input voltage to determine the voltage of shutdown of nonlinear element U_3.

<u>Stage 4.</u> <u>The experimental determination voltage in which is generated self-oscillation mode</u>.

4.1. Asemble circuit according to Fig.4.4.

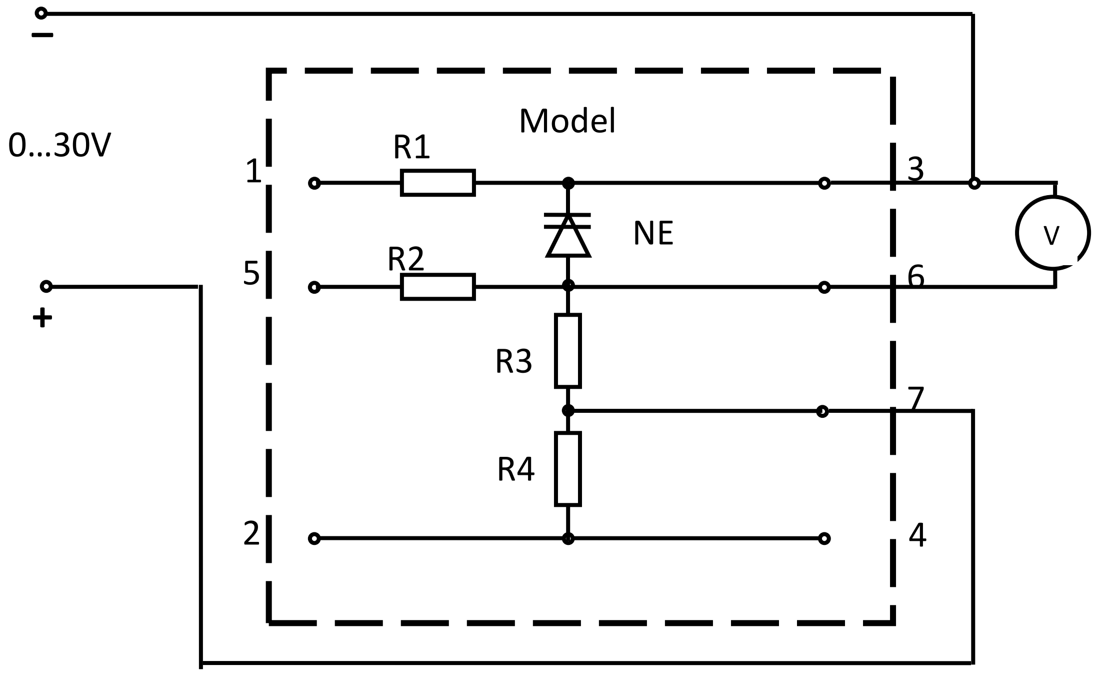

Figure 4.3. - Scheme of research of opening voltage of nonlinear element

4.2. As the feed source use series connected adjustable and nonadjustable the DC sources from bloc directly voltages.

4.3. As capacitor C_4 to use adjustable capacitor from the bloc of variable capacitor (C_4=5 μF).

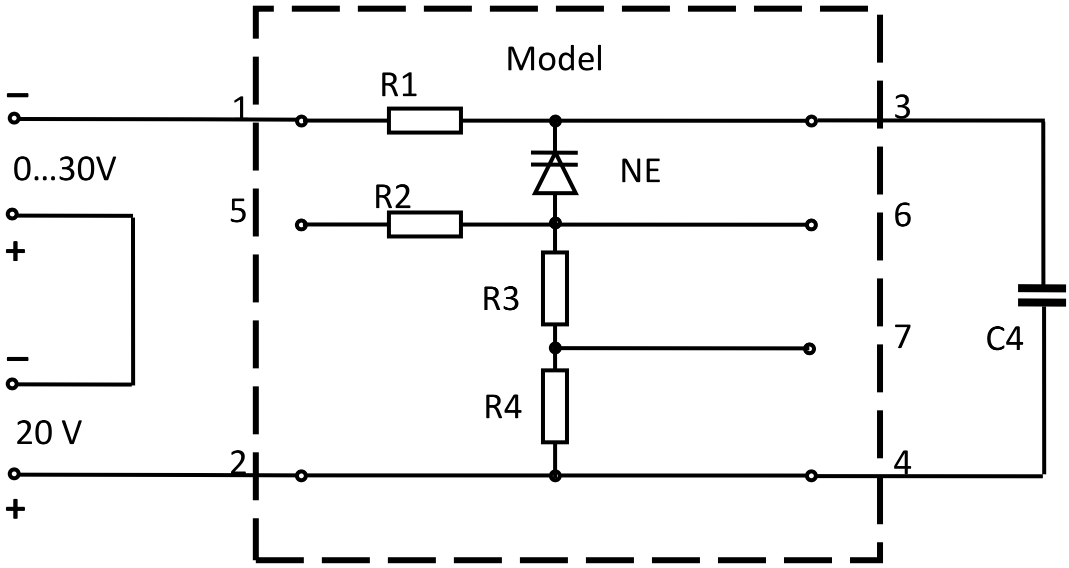

Figure 4.4. - Scheme of research of stable self-oscillations in a nonlinear circuit with negative dynamic resistance

4.4. The voltage oscillogram on capacitances $C_{4\,t}$ to take.
4.5. Changing the output source voltage to attain the appearance of stationary voltage self-excited oscillation on capacitances C_4.
4.6. From the screen of oscillograph to take the voltage curve.

Stage 5. The analysis of the influence of the significance of capacitance on frequency and amplitude self-oscillation mode.

5.1. The capacitor C_4 to increase till significance 10 μF .
5.2. On oscillograph screen to observe the changes of parameters self-oscillation mode.
5.3. The capacitor C_4 to decrease till significance 1 μF .
5.4. On oscillograph screen to observe the changes of parameters self-oscillation regime.

Stage 6. The analysis of the influence of the significance of resistance on frequency and amplitude self-oscillation mode.

6.1. The capacitor C_4 to set equal to 5 μF .
6.2. On the oscillograph screen to observe voltage curve on capacitor C_4.
6.3. By jumper (or by wire) the resistor R_3 to shunt.
6.4. On oscillograph screen to observe the changes of parameters self-oscillation regime.

Stage 7. Calculation of the relaxation oscillations frequency.

7.1. The period of charge and discharge of capacitor C_4 to calculate.
7.2. The period and the frequency of relaxation oscillations to find.

The Report must contain

1. The number and name of the laboratory work.
2. Objective.
3. The work program.
4. Fig. 4.4, Table 4.1.
5. The calculation of the relaxation oscillations frequency.
6. The voltage oscillograms on capacitances C_4.
7. Analysis of results and conclusions of the laboratory work.

Methodical direction

To the stage 1. The model is assembled on separate electric board. The scheme of connections is shown on the face panel of dummy. As nonlinear element is used diode thyristor (dinistor) KH102A owning negative dynamic resistance. Volt-ampere dinistor characteristic is shown on Fig.4.5.

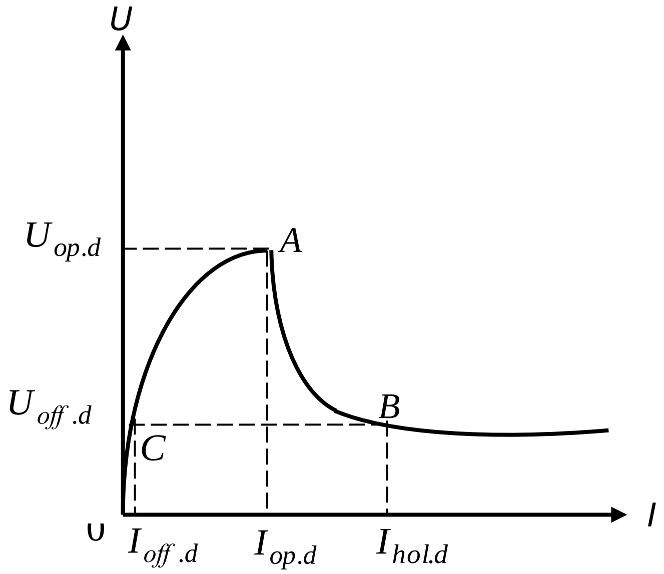

Figure 4.5. - Volt-ampere characteristic of a nonlinear element

In the voltage increase on diode thyristor current at the beginning small and practically does not grow that corresponds the district of OA volt-ampere characteristic. In this mode is supposed that dinistor is locked. In some voltage significance Uop.d named by the voltage of opening (point A) in dinistor appears avalanche-like process and dinistor current bounce grows till inclusion current Iop.d (point A) in the sharp decrease of resistance dinistor and voltage drops on it. Dinistor in point B is open, resistance little, current substantially limited by the significance of resistance included series with semiconductor device.

In decrease of current diode thyristor less significance holding current Ihol.d dinistor by bounce locks. Arises transition as to volt-ampere characteristic from point B in point C. Uoff.d – the dinistor out-off voltage.

To stage 3. The dinistor volt-ampere characteristic is determined as to three characteristic points A, B, C (Fig.4.5). For characterization point B is used the voltage source. For characterization points A is used current source.

To stage 4. On Fig.4.6 are show the volt-ampere characteristics of investigated circuit. The dinistor characteristic is presented by the intervals of lines OAB and CB. Series with dinistor is included resistor R_3 with characteristic as direct line OD. Summary the volt-ampere characteristic of nonlinear element and resistor R_3 is described broken by line $OA'D'B'C'O$. This characteristic owns negative dynamic resistance on district $A'B'$. If summary the volt-ampere characteristic of the source of supply source and resistor R_1 ($U_0 - IR_1$) crosses volt-ampere dinistor characteristic and resistor R_3 on unsteady district $A'B'$ in point G, then in circuit appear stationary self-excited oscillation. Increasing or decreasing voltage U_0 we can fall outside the limits district with negative dynamic resistance (point G is transfered for the limits of interval $A'B'$) and self-excited oscillation in circuit are derangement that can be observed on oscillograph screen.

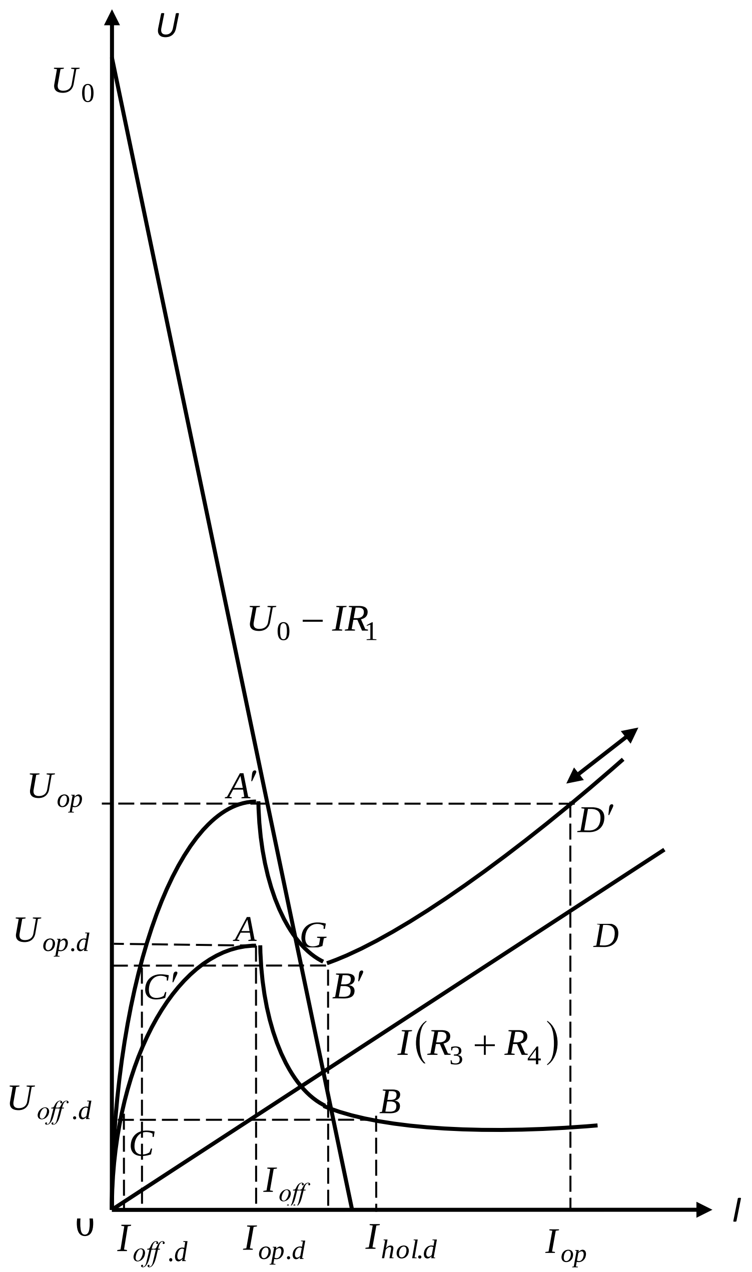

Figure 4.5. - Volt-ampere characteristic of a nonlinear circuit

<u>To stage 5.</u> Changing significance connected to dummy capacities to be sure that voltage amplitude of self-excited oscillation does not change. With increasing capacity enlarges period and decreases frequency self-excited oscillation.

To stage 6. With the decrease of the significance of resistance connected by series with dinistor enlarges the length of district $A'B'$ which brings to the growth of the voltage amplitude of self-excited oscillation. With increasing of resistance by series connected with nonlinear element, the voltage amplitude of self-excited oscillation decreases. Point G can appear for district $A'B'$ and self-excited oscillation are derangement at that. For resumption self-excited oscillation in augmented resistance is necessary to decrease tension U_0.

To stage 7. The approximate type of oscillogram transient processes is shown on Fig.4.7.

Capacitor charging time

$$t_1 = \tau_1 \ln \frac{U_0 - U_{вкл}}{U_0 - U_{отк}},$$

$$\tau_1 = R_1 \cdot C_4.$$

Capacitor discharge time

$$t_2 = \tau_2 \ln \frac{U_{отк}}{U_{вкл}},$$

$$\tau_2 = C_4 (R_3 + R_4).$$

Relaxation oscillations period

$$T = t_1 + t_2, \text{ s.}$$

Relaxation oscillations frequency

$$f = \frac{1}{T}, \text{ 1/s.}$$

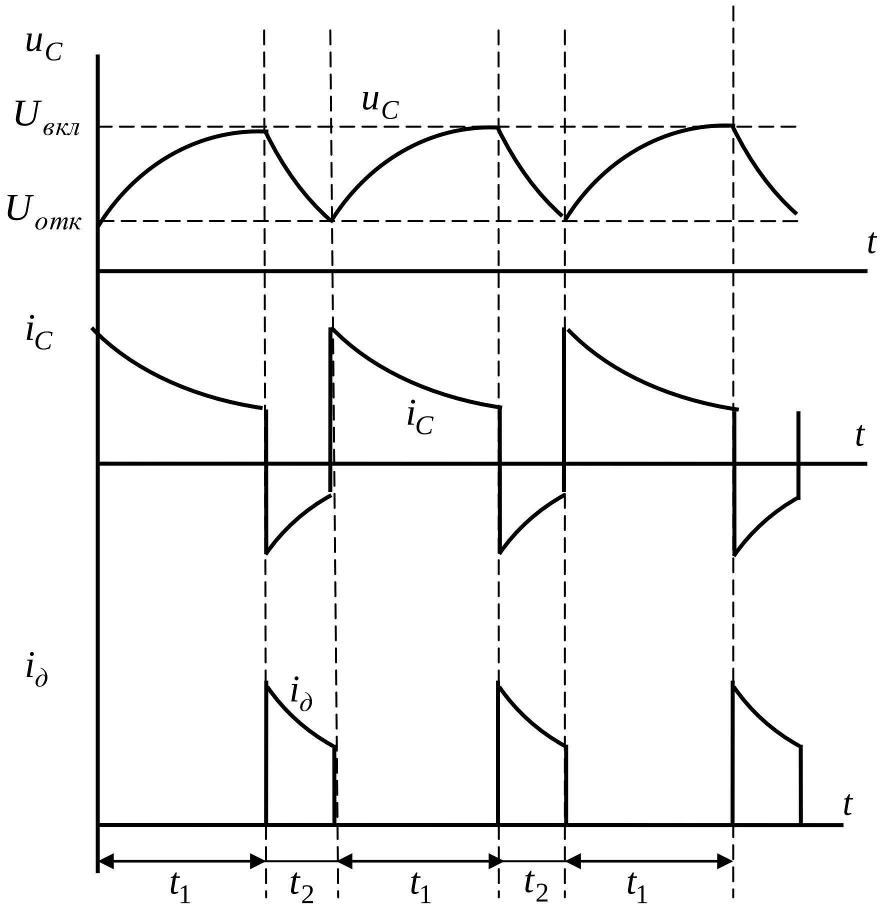

Figure 4.6. - Transient voltages and currents in self-oscillating nonlinear circuit

Questions for check knowledge

1. Will carry out analytical dependences for the calculation of the time of the voltage increasing on capacitor and the time of capacitor discharge.
2. Write down the instability condition for investigated scheme.
3. Carry out the condition of instability work for investigated scheme.
4. Determine the resistance significance R_1 in which is seen extreme oscillation process if the source voltage is 20 V.
5. Draw the scheme and choose devices for characterization volt-ampere characteristic of nonlinear element.
6. In what way to receive curve close to direct line?
7. Show as influent the value of resistance R_1 on frequency and the value of the voltage self-excited oscillation?
8. How influent capacity value on frequency self-excited oscillation?
9. Draw the equivalent schemes for calculation current on csrcuit of capacitor and nonlinear element.
10. Show as influent the value of ohmic resistance on frequency self-excited oscillation.

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CONTENT

Автор

Хілов Віктор Сергійович

Методичні вказівки англійською мовою до лабораторних робіт з дисципліни
ТЕОРЕТИЧНІ ОСНОВИ ЕЛЕКТРОТЕХНІКИ, ЧАСТИНА 1
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"Магнітні кола", "Перехідні процеси в колах з нелінійними елементами"
для студентів спеціальності
141 – Електроенергетика, електротехніка та електромеханіка

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