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ELECTRICAL POWER UNIT OF THE TRANSFORMER OIL CENTRIFUGAL CLEANING UNIT

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Abstract. Problem. *Cleaning transformer oil is one of the important engineering tasks, whose solution is associated with significant material and energy expenditure. Due to the increase in electricity consumption at modern automobile companies (firms, organizations, service stations, etc.), the load on transformer substations increases and the requirements for reliability of electrical and electronic devices become more complicated. This, in turn, leads to the problem of cleaning and recycling of transformer oil.* ***Goal****. The goal is the research and development of an efficient unit for centrifugal cleaning of transformer oil with a drive control system that provides automation of the start and braking mode of the drive.* ***Methodology****. Analytical methods of research, methods of the theory of electric machines and electric drives are used, as well as the methods of calculating electric circuits. Also, methods of analysis of circuits and control of power electronics devices, principles of operation and methods of control of static converters are used.* ***Results****. The structural scheme of the unit for cleaning transformer oil is developed. The calculations of the main elements of the power block of the transformer oil cleaning unit are performed. The block diagram of the voltage converter with frequency $f = 50$ Hz to alternating voltage with frequency $f = 400$ Hz is developed. Control circuits of the electric drive of the centrifugal separator are chosen. The analysis of operation of electric drive control circuits is carried out and the principles of their work concerning two components are considered: the regulated rectifier and the inverter.* ***Originality****. The scheme of the converter of alternating three-phase current with voltage of 220 V and frequency of 50 Hz, into alternating three-phase current with voltage of 220 V and frequency of 400 Hz is developed. This frequency, in addition to providing the necessary characteristics of the oil separator, allows you to develop a converter device of a relatively small weight and volume, and also provides its high reliability.* ***Practical value****. Utilizing the used transformer oil in this way will solve several problems at once. It is possible to reduce the initial production of transformer oil. The issue of waste oil disposal is being resolved leading to the solution of the environmental aspect of this problem. All this will reduce the cost of oil poured into transformers and the operating cost of transformer substations.*

Keywords: *power supply system, power transformer, transformer oil, oil separator, electric power, transformer substation.*

Introduction

The transformer operating time is largely determined by the insulation system operating time. This is due to the fact that almost 85 % of transformer failures are caused by insulation damage [1–4]. This refers to both liquid insulation (transformer oil) and solid insulation (paper, cellulose products, etc.). Transformer oil (TO) accounts for almost 80 % of the transformer electrical strength. Thus, TO purification is one of the most important technical tasks, the solution of which is associated with significant material and energy resources costs.

Due to the increase in electricity consumers number, in particular, in motor carriers, the load on transformer substations is increasing. At the same time, it is increasingly difficult to comply with the requirements to ensure the reliability and fail-safe operation of electrical and electronic devices. Cleaning and recycling of TO plays an important role in solving these problems. In addition, the use of waste transformer oil allows one to:

– reduce the TO production volume;

– reduce the volume of waste oil recycling, which is one of the steps to solve environmental problems [5–7];

– reduce the cost of oil poured into transformers, and thus reduce operating costs at transformer substations.

Analysis of publications

Currently, several methods are used to purify the waste TO [1–4, 8–15]:

– purifying using the oil separators with an operating frequency of 50 Hz;

– settling of oil with the subsequent drain of the top (purified) layer;

– purification of oil followed by draining of the upper (purified) layer and carrying out chemical reactions to restore its properties.

Each of these methods has practical application with its advantages and disadvantages. If special chemical reagents are used to improve the electrical properties of transformer oil and to better purify it, this increases the purification time and dramatically increases the cost per liter of TO.

TO is chiefly purified by settling and filtration. But this method has its shortcomings:

– large quantities and sizes of devices used;
– inconvenience of operation;
– long purification time;
– low productivity;
– low purification quality.

One of the promising methods to clean TO at present is using oil separators [2–4, 9, 16, 17].

Productivity, purification quality, and convenience of operation increases when using centrifugal separators. Centrifugal purification with a separator allows to continuously dispose of waste, which is very convenient, since there is no need to disassemble or stop the separator. The efficiency of the separators is most affected by their drive, which is powered by AC 220/380 V, with frequency 50 Hz. The block diagram of such a drive includes a reducer, a friction clutch and an asynchronous motor (AM).

The presence of the intermediate links in the drive circuit of the oil separator, and especially the step-up gear, necessitates the installation of high-power drive motors.

The intense dynamic mode of operation of all parts of the high-speed machines drive leads to intensive wear of the starting clutch, and worm gearbox. This reduces the quality of purification and the level of safe maintenance of the separators and increases electricity specific losses. Replacement and repair of the drive worn parts leads to downtime, increased production costs and the cost of purified TO.

In addition, the drive motor, whose power is selected under the conditions of permissible heating during start-up, is underloaded in the separator rated mode and, accordingly, is characterized by low energy performance (efficiency, load factor), thus irrationally consuming electrical energy [5, 18–20].

One of the ways to eliminate the noted shortcomings may be the use of electric motors with industrial frequency powered by semiconductor converters [21, 22].

Moreover, given that the start-up and braking processes for separators with periodic manual unloading of sludge are an integral part of their production cycle, as well as the fact that the drum inertia moment is ten times higher than the moment of the motor rotor, the significant impact of specified modes on power selection and block diagrams of the drive and its power supply source, becomes evident.

An analytical review of the literature sources [1–4, 8–16, 21, 22] indicated that currently an alternating current with an industrial frequency (50 Hz) is used to power the separators the general purpose electric drives. But when using this current, the advantages of this purification method are not significant.

Therefore, a power supply with a higher current frequency is needed. Increasing the speed of the separator drum reduces the imbalance that is necessarily present due to the imperfection of the production process and the separator assembly. The transition to an increased operating frequency (f_{op} = 400 Hz) is also promising in terms of improving the separator weight-and-dimensional characteristics [9, 16, 23].

Therefore, for such separators it is offered to use asynchronous motors with operating frequency f_{op} = 400 Hz that allows:

– to facilitate the asynchronous motor start-up conditions;

– to improve the transient process when starting the asynchronous motor;

– to improve operating conditions for relay protection and automation equipment.

Thus, the justification for creating an effective installation for TO centrifugal purification is actually a justification for the possibility of using electric drive equipment with a frequency of
f_1 = 400 Hz [23, 24].

Purpose and objective

The aim of the work is to study and develop an effective installation for centrifugal purification of transformer oil with a drive control system that ensures automation of the drive start-up and braking mode.

To achieve this goal the following tasks shall be solved:

– to develop the structural diagram of TO purification installation;

– to carry out the necessary calculations of its basic elements;

– to develop a structural diagram of the voltage converter with a frequency of f = 50 Hz into a voltage with a frequency of f = 400 Hz;

– to choose elements schemes of the electric drive of the centrifugal separator.

Structural diagram of the electric power circuit of the TO purification system

The structural diagram of the power circuit (with the control circuit) of TO purification system is provided in Fig. 1.

The main elements of the circuit are, Fig. 1:

a) adjustable bridge-circuit rectifier of three-phase alternating current with a voltage of 380 V, with a frequency of $f = 50$ Hz;

b) three-phase voltage inverter (current), which converts the DC voltage at the output of the controlled transformer-rectifier unit (TRU) into three-phase AC with a frequency of $f = 400$ Hz.

The inverter output is connected to the winding of start-up stator and the working motor of centrifugal separator of TO purification. The main parts of this diagram are discussed in more detail below.

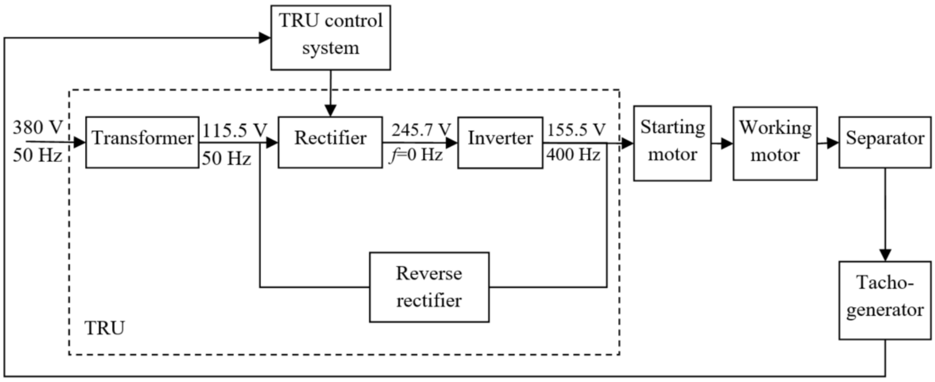


Fig.1. Structural diagram of the electric power circuit of the TO purification system

Rectifier

To adjust the speed of an asynchronous motor, the method of changing the average value of the supply voltage of an asynchronous motor is used.

This change is carried out by means of a thyristor regulator (TR), which is a set of six thyristors (VS1, VS2, ... VS6), which are connected in pairs – counter-parallel in each phase of the AM stator winding and thyristor control system (CS).

The diagram of the power circuit of the thyristor regulator is provided in Fig. 2 [24, 25].

The diagram shows:

Tr – power transformer;

U_{2ph} – output voltage of the phase of the transformer winding;

U_d – output voltage of the rectifier;

I_1 – current of the transformer primary winding;

I_2 – current of the transformer secondary winding;

I_d – current rectifier valve;

VS1, ... VS6 – control valves (thyristors).

The complete diagram of the adjustable rectifier is provided in Fig. 3. In this diagram, the control system provides the generation of pulses for the thyristor control current, as well as a smooth change of the delay angle for the valves opening to the angle α, which provides a change in the average value of the rectified voltage U_d, Fig. 4, 5 [25].

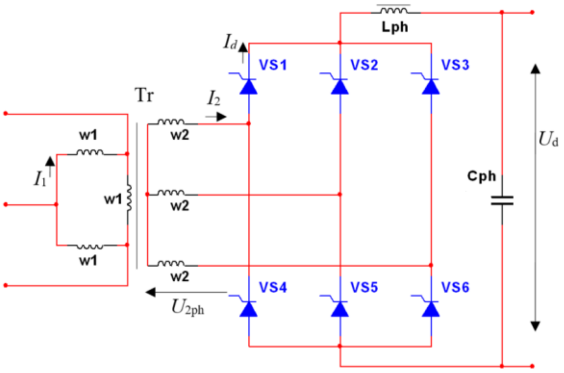


Fig. 2. Diagram of the power circuit of the thyristor regulator

At a delay angle α = 0, there is no delay in thyristors opening, i.e., thyristors open with the beginning of the growth of the supply voltage sine wave $U = 380$ V. In this case, the output voltage of the nonlinear element U_{NE} at the output of the regulator is maximum and equal to the input voltage $U_{in} = 380$ V. This mode is shown by a graph of the output voltage U_{NE} at a delay angle α = 0, Fig. 4.

At values of the delay angle to open thyristors which lie within $0 < \alpha < 180^o$, they are open within an angle $\beta < 180^o$. Based on this, the average value of the regulator output voltage will decrease.

The shape of the output voltage is not sinusoidal, but is a sine wave segments, as shown in the graph of the regulator output voltage at a delay angle $\alpha \neq 0$, Fig. 5.

At a delay angle of thyristors opening, with the angle being equal $\alpha = 180^o$, thyristors do not open, proceeding from this, the output voltage of the regulator $U_{NE} = 0$.

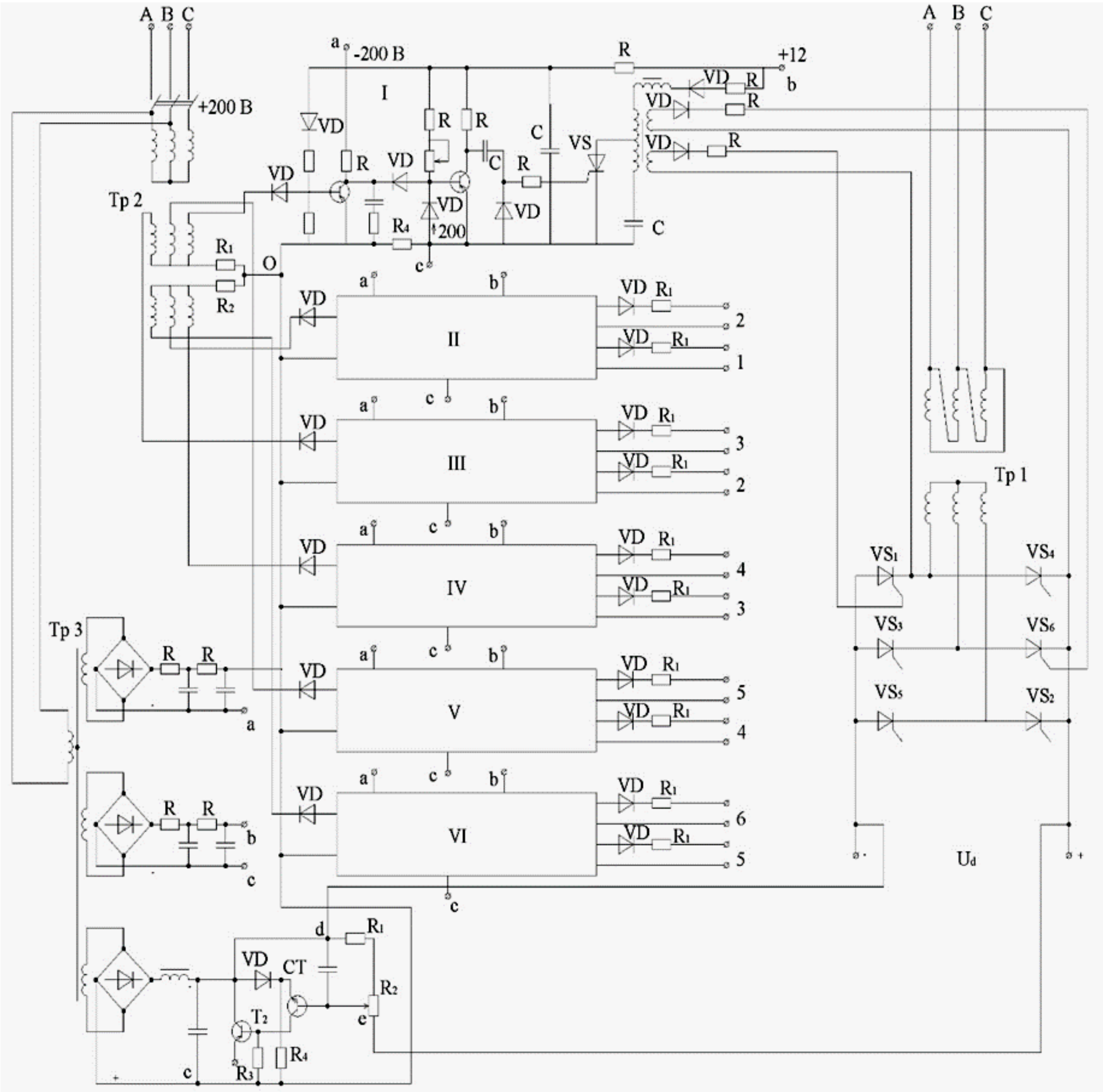


Fig. 3. Wiring diagram of the adjustable rectifier

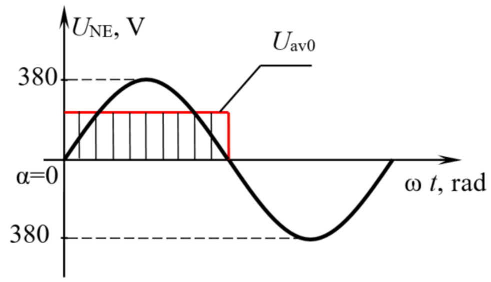


Fig. 4. Graph of the output voltage U_{NE} at a delay angle $\alpha = 0$

The dependence of the output voltage U_{NE} average value on the angle α is calculated according to the formula:

$$U_{NE} = U_{av0} \cdot \frac{1+\cos\alpha}{2}, \tag{1}$$

where (U_{av0}) – the maximum value of voltage for an angle $\alpha = 0$ and $U_{in} = 380$V:

$$U_{cpo} = \frac{2 \cdot \sqrt{2} \cdot U_{вх}}{\pi} = \frac{2 \cdot \sqrt{2} \cdot 380}{3{,}14} = 342 \text{ V}.$$

Table 1 shows the dependence of the nonlinear element U_{NE} voltage on the angle α.

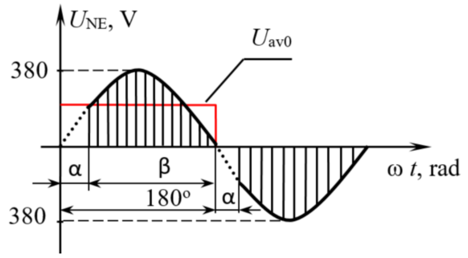


Fig. 5. Graph of the controller output voltage for a delay angle α ≠ 0

Table 1 – The dependence of the nonlinear element U_{NE} voltage on the angle α

α °	0	30	60	90	120	150	180
U_{NE}, V	342	319	257	171	86	23	0

The graph of the dependence of the average value of the thyristor regulator voltage on the thyristors opening delay angle α, built based on table 1 data, is provided in Fig. 6.

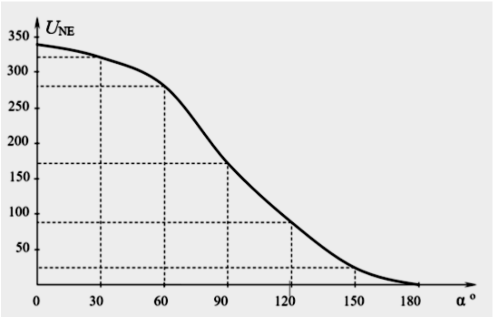


Fig. 6. The graph of the dependence of the average value of the thyristor regulator voltage on the thyristors opening delay angle α

The functional diagram of one channel of the control system controller (SC) is provided in Fig. 7.

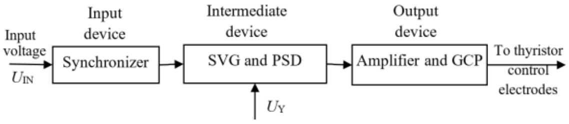


Fig. 7. Functional diagram of one regulator channel of the regulator control system

The control scheme includes:

– input device (synchronizer);

– intermediate device (sawtooth voltage generator (SVG) and phase-shifting device (PSD));

– output device (amplifier and generator of control pulses (GCP));

– U_C – control voltage for regulating the regulator output voltage;

– U_{IN} – input voltage to power the control system.

Since 6 thyristors (VS1… VS6) are installed in the regulator, for their normal operation in the three-phase regulator the control system (SC) shall have 6 channels of the six-phase voltage system required to control the thyristors of the three-phase regulator.

These channels should be shifted relative to each other at an angle of 60°, as shown in Fig. 8.

To create such a six-phase controlled voltage system, an input device (synchronizer) synchronized with the supply voltage shall be installed. The easiest way to achieve this is to use three single-phase transformers connected according to the scheme provided in Fig. 9.

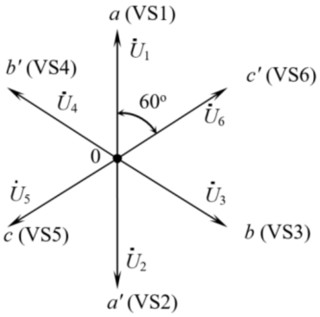


Fig. 8. A six-phase voltage system is required to control the thyristors of a three-phase regulator

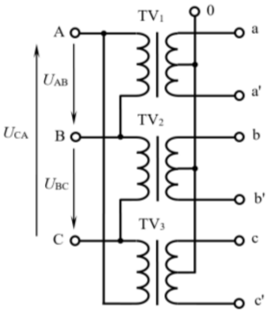


Fig. 9. The diagram to create a six-phase controlled voltage system

The given diagram of the input device is simple and reliable in operation. Its main shortcoming is that the output voltages U_{A0}… $U_{C'0}$ have the shape of a sinusoid, which complicates their use to control the transistors of the following amplifiers in their key operation mode, which requires rectangular control voltages.

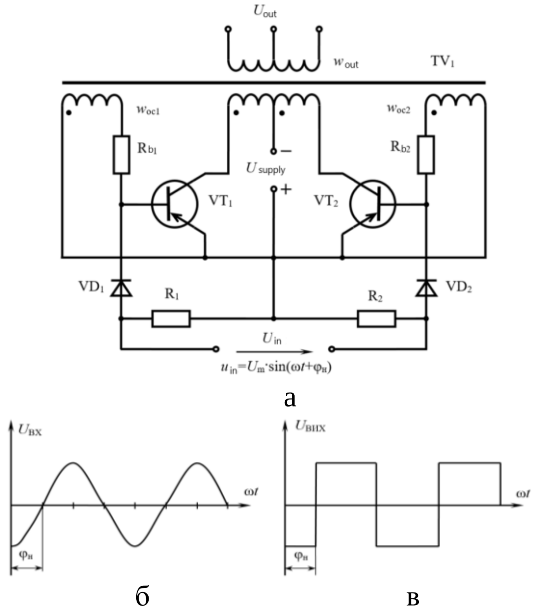
To create a synchronizer with a rectangular output voltage using magneto-transistor generators made in the form of a DC-AC converter according to the Royer diagram.

Fig. 10,a shows a diagram of the input device (for one phase), made based on the Royer converter, which provides a rectangular output voltage.

The graph of the input voltage is shown in Fig. 10,б, and the output voltage – in Fig. 10,в.

A three-phase controller requires three input devices to obtain a six-phase control voltage system. The input control circuits of the autogenerators are supplied with voltages that are shifted in phase by ±120^o, i.e. with a three-phase voltage system. The output circuits are connected according to the scheme (Fig. 9), which provides the creation of a controlled six-phase rectangular voltage system.

A three-phase three-winding transformer with six transistors (VT1… VT6) is very often used as a synchronizer, the electrical circuit of which is provided in Fig. 11.



a

б

в

Fig. 10. Input device: a – diagram; б – input voltage graph; в – output voltage graph

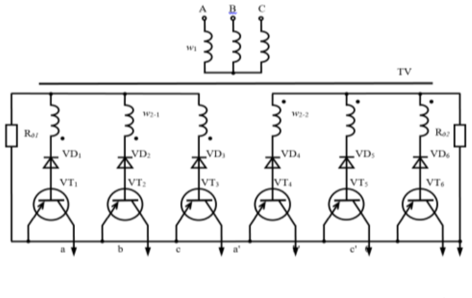


Fig. 11. Three-phase three-winding transformer with six transistors

The primary winding of a three-phase transformer (with the number of turns w_1) is connected to the three-phase supply network. The secondary three-phase windings $w_{2\text{-}1}$ and $w_{2\text{-}2}$ are connected relative to each other in the antiphase.

In total, a 6-phase voltage system is created at the output of these windings. Switching diodes VD1… VD6 and transistors VT1… VT6 on the transformer output provides obtaining rectangular voltage at the output.

The intermediate device is a combination of a sawtooth voltage generator and a phase-shifting device (PSD). This device is often called a pulse generator (PG).

It generates the pulses needed to open the thyristors and change the phase of the control pulse relative to the reference voltage, i.e. creates the required length of delay time for the pulse generation that opens the thyristor (creates the required delay angle α).

To change the delay angle, a control voltage U_C is supplied to the pulse generator, which is compared with the voltage of the sawtooth voltage U_{S1}. An amplifying device is installed at the sawtooth voltage generator output (SVG) to ensure the required control pulse strength.

The wiring diagram of pulses generator (PG) which includes the sawtooth voltage generator (SVG) and the phase shifting device (PSD) with vertical control, is provided in Fig. 12, and voltage graphs – in Fig. 13.

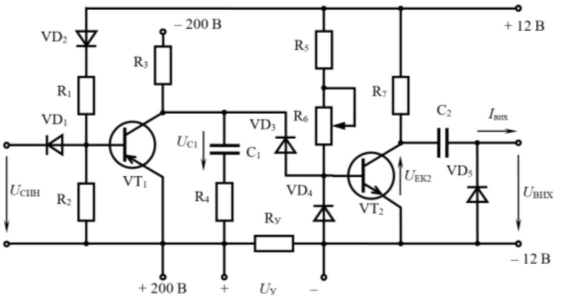


Fig. 12. The wiring diagram of the pulses generator

The input of the pulse generator is connected to the synchronizer output, receiving from it the control voltage U_{SIN} in the form of a sequence of pulses of rectangular shape, which follow the power supply frequency (Fig. 13).

This voltage is applied to the input of the sawtooth voltage generator made on the transistor VT_1. The duration of the timing pulse is set by an angle of 2π/3 rad (Fig. 13), the sawtooth voltage U_{C1} on the capacitor C_1 is formed at intervals when the transistor VT_1 is closed, i.e. within an angle of 4π/3 rad.

Capacitor C_1 should be selected of such a capacity that the voltage on it would increase linearly in the range of 4π/3 rad.

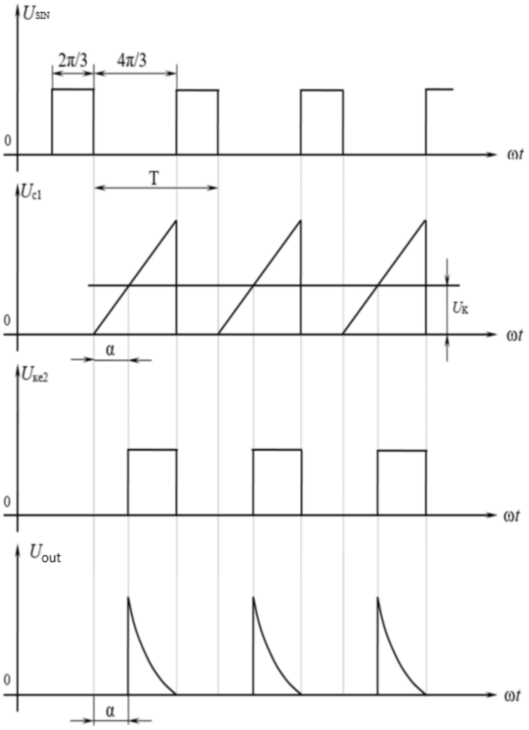


Fig. 13. Pulse generator voltage graphs

Transistor VT_2 (Fig. 12) in the initial position it is open by the displacement current, which is determined by the resistance values of resistors R_5 and R_6. The sawtooth voltage is a locking voltage for VT_2 transistor.

Therefore, as soon as this voltage exceeds the voltage U_C which is supplied to R_C resistor, VT_2 transistor will be cutoff.

Thus, the transition of the transistor VT_2 from saturation mode (opening) to cut-off mode (closing) is determined by the value of the control voltage U_C and can be adjusted in phase in the range from $\varphi_0 = 0$ to $\varphi_{max} = 4\pi/3$ rad, (i.e. from $\varphi_0=0^o$ to $\varphi_{max} = 240^o$) relative to the front of the timing pulse U_{SIN}.

VD_4 diode serves to limit the negative voltage based on VT_2 transistor, VD_3 diode prevents a short circuit of the power supply through an open transistor VT_1 or a discharged capacitor C_1.

Reliable locking of VT_1 transistor at the moment when the timing pulse U_{SIN} is absent, is performed by a positive displacement, which is removed from the voltage divider R_1–R_3.

The rectangular pulse U_{KE2}, which is removed from the collector of the transistor VT_2, is differentiated by the leading edge of the circuit voltage $R – C_2$ (R – input resistance of the transistor VT_2), and the obtained voltage pulse, which is removed from the diode VD_5 – is fed to the output device as the end stage amplifier (A) of control pulses generator (GCP).

The output end stage pulse amplifier (A) can be made on both transistors and thyristors. One of the possible diagrams of the end stage pulse amplifier (A), which is most often used in control pulse generators, made in the form of a two-stage amplifier on transistors, is provided in Fig. 14.

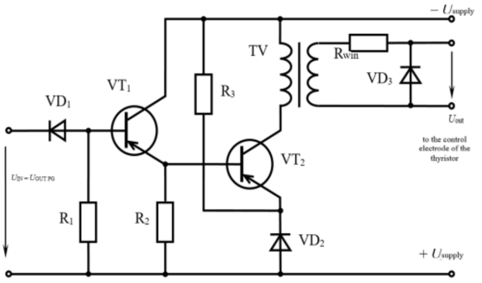


Fig. 14. Two-stage transistor amplifier

The first stage of the amplifier is made on VT_1 transistor. It works as an emitter repeater. The second stage (VT_2 transistor) works as a pulse amplifier. In the interval between pulses, VT_1 transistor is further locked by the displacement voltage, which is removed from the VD_2 diode. The pulse supplied from the pulse generator ($U_{OUT PG}$) is amplified by the current of the first stage and is supplied to VT_2 transistor, which opens when the potential of its base becomes lower than the potential of the cathode of VD_2 diode.

The control pulse is transmitted to the control electrode of the thyristor of the regulator via the isolating pulse transformer TV and the current-limiting resistor R_{LIM}, thus causing its opening.

At the end of the control pulse, the electrical energy accumulated in the transformer is dissipated in the secondary circuit (R_{LIM}-VD_2), which eliminates the possibility of overvoltage on the control electrode of the thyristor and the transformer winding.

The inverter used is a voltage inverter. It converts DC voltage to a voltage with 400 Hz. To control the inverter, a control system is installed using capacitors to increase operating reliability.

Capacitors are separated from the power circuit by diodes (the circuit is called 'with load-separated capacitors'). The voltage to which the capacitors are charged, is not immediately applied to the load supports, but is supplied through thyristors.

This ensures their reliable operation. Let's consider a practical diagram of a frequency converter with a DC link and an automatic voltage inverter.

Currently, there are various wiring diagrams that allow to make the necessary transformations, for example, the diagram shown in Fig. 15 [23].

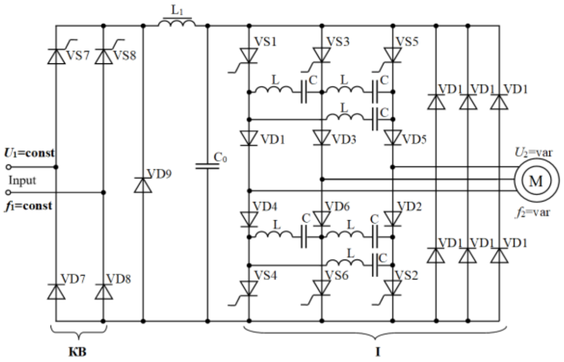


Fig. 15. FC diagram with a link of an autonomous voltage inverter

Two thyristors VS7 and VS8 and two diodes VD7 and VD8 included in the so-called semi-controlled bridge circuit are used as a controlled rectifier to obtain a full-wave rectified voltage, the average value of which can be adjusted conventionally by influencing the voltage phase of control electrodes VS7 and VS8. The inverter consists of six thyristors VS1–VS6, six diodes VD1–VD6 connected with them in series and six diodes connected in a three-phase bridge circuit VD10–VD15 and, finally, six oscillating circuits LC.

The conversion of DC voltage into a three-phase variable is carried out by switching thyristors VS1–VS6, operating in a certain sequence. The time of open state of each thyristor corresponds to 120° of the output frequency; the sequence of thyristors opening corresponds to their numbering according to the diagram, i.e. VS1 opens first, VS2 opens after 60°, etc. – up to VS6.

After VS6, VS1 opens again, etc. every 60° of the output frequency.

When switching at any time, two thyristors are open simultaneously.

The thyristors are opened by applying a positive pulse to the control electrode from the invertor control unit (ICU). To close the thyristors, the current flowing through it shall be reduced to zero. This is achieved using switching circuits LC; for example, when VS3 is turned on, the capacitor C is discharged through the previously opened VS1 and VS1 is closed.

The circuit is used in electric drives that operate with frequent transients, and in cases where AM braking with heat recovery to the network is needed.

It should be noted that there are some features of the elements calculation:

1 estimated transformer power $S_{\text{т}}=P_{\text{т}}=P_{\text{r-out}}$, W. $P_{\text{r-out}}$ – rated output power of TRU;

2 the voltage on the primary winding of $U_{1\text{ph}}$ transformer is assumed to be by 9…12 % less than the rated voltage of the supply network. This is due to the need to have a reserve to maintain the voltage U_{d} constant and to reduce the level of primary voltage;

3 the current value of current in thyristors is calculated according to the formula:

$$I_{\text{a}} = \frac{0.817 I_{\text{r-out}} \cdot w_2}{w_1};$$

4 the average value of the current in a valve is determined as:

$$I_{\text{av}} = \frac{0.33 I_{\text{r-out}} \cdot w_2}{w_1};$$

5 the maximum value of current in thyristors is determined using the formula:

$$I_{\text{v max}} = I_{\text{v max}} \frac{w_2}{w_1};$$

6. maximum voltage value on control thyristors:

$$U_{\text{contr.max}} = 1.05 \cdot U_d \frac{w_2}{w_1};$$

7 protection of valves – thyristors from switching overvoltages is carried out by installation of a circuit $R – C$;

8 circuits $R – C$, used for protection against switching overvoltages, may not be installed only in the case of using diodes in the circuit of a three-phase rectification circuit, if it uses diodes VL-200 or VL5-200;

9 if TRU output uses electric filters of "Г"- or "T"-shape type, the resulting electromagnetic constant of the filter time can be calculated by the formula:

$$T_{\text{e}} = T_{\text{e}1} + T_{\text{e}2} + \ldots = L_1 C_1 + L_2 C_2 + \ldots + L_n C_n,$$

where L is the inductance of one filter arm, Gn;

C is the capacity of one filter arm, F;

10 the transfer function of such a multi-link filter is defined as:

$$W(p) = \frac{U_{\mathrm{OUT}}(p)}{U_{\mathrm{IN}}(p)} = \frac{\kappa_{\mathrm{e}}}{T_{\mathrm{e}} p + 1},$$

where $\kappa = \kappa_1 + \kappa_2 + \ldots + \kappa_n$ – equivalent filter transfer coefficient (κ_1, κ_2, … κ_n – transfer coefficients of individual filters).

Conclusions

The structural diagram of the power circuit of the transformer oil purification unit is developed. The operating frequency of this installation is $f = 400$ Hz.

Ukrainian industry does not mass-produce frequency converters from 50 Hz to 400 Hz. Currently, there are only some samples and designs for low-power sources. That is why it was necessary to develop a circuit for 220 V alternating three-phase current converter with a frequency of 50 Hz (f_1), into 220V alternating three-phase current with a frequency of 400 Hz (f_2). This frequency, in addition to providing the necessary characteristics of the oil separator, allows to develop a converter device of a relatively small weight and volume, which, in addition, provides high operating reliability.

The diagrams and the operating principle of its two constituent parts are considered: the adjustable rectifier and the inverter.

According to the calculations results and literature sources analysis [1–4, 9–17] we can make a conclusion as to the expediency of using this installation for centrifugal cleaning of transformer oil.

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Електрична силова частина приладу відцентрового очищення трансформаторної оливи

Анотація. Проблема. *Очищення трансформаторної оливи є одним із важливих технічних завдань, вирішення якого пов'язано зі значними витратами матеріальних і енергетичних ресурсів. У зв'язку зі збільшенням споживачів електроенергії, зокрема на автотранспортних підприємствах, збільшується навантаження на трансформаторні підстанції та ускладняється дотримування вимог щодо забезпечення надійності та безвідмовності роботи електричних та електронних пристроїв. Важливим чинником для вирішення цих проблем є очищення та вторинне перероблення трансформаторної оливи.* ***Метою*** *роботи є дослідження та розроблення ефектив-*

ного приладу для відцентрового очищення трансформаторної оливи з системою керування приводом, що забезпечує автоматизацію режиму запуску й гальмування приводом. ***Методологія.*** *Використовуються аналітичні методи дослідження, методи теорії електричних машин та електроприводів, методи розрахунку електричних кіл, методи аналізу схем та керування приладами силової електроніки, принципи роботи та методи керування статичними перетворювачами.* ***Результати.*** *Розроблено структурну схему обладнання для очищення трансформаторної оливи. Здійснено розрахунки основних елементів силової частини приладу очищення трансформаторної оливи. Розроблено структурну схему перетворювача напруги з частотою f = 50 Гц на змінну напругу з частотою f = 400 Гц. Вибрано схеми керування електропривода відцентрового сепаратора. Здійснено аналіз роботи схем керування електропривода та проаналізовано принципи їхньої роботи щодо двох складових частин: випрямляча, що регулюється, та інвертора.* ***Оригінальність****. Розроблено схему перетворювача змінного трифазного струму, напругою 220 В з частотою 50 Гц, на змінний трифазний струм, напругою 220 В з частотою 400 Гц. Така частота, крім забезпечення необхідних характеристик нафтового сепаратора, дозволяє розробити перетворювальний пристрій порівняно невеликої ваги і об'єму, а також забезпечує високу надійність роботи.* ***Практичне значення****. Використання відпрацьованої трансформаторної оливи у зазначений спосіб дозволить вирішити декілька питань. З'являється можливість знизити об'єм первинного виробництва трансформаторної оливи. Вирішується питання утилізації відпрацьованої оливи, що дозволить вирішити екологічний аспект цієї проблеми. Все це призведе до зниження вартості оливи, що заливається до трансформаторів, тобто до зниження експлуатаційної вартості трансформаторних підстанцій.*

Ключові слова: *система електропостачання, силовий трансформатор, трансформаторна олива, нафтовий сепаратор, електроенергія, трансформаторна підстанція.*

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