UDC 621.314 **DOI:10.30724/1998-9903-2019-21-3-135-145**

METHOD FOR CONTROL OF THE START-UP REGULATING DEVICE FOR POWER TRANSFORMERS OF THE POWER SUPPLY SYSTEM

V.S. Klimash, B.D. Tabarov

Komsomolsk-na-Amure State University, Komsomolsk-on-Amur, Russia

Abstract: *Three-phase thyristor switches are designed for pulsed formation of inrush currents of electrical equipment with their subsequent shunting in steady state operation. In transformer substations, they perform a bumpless turning on of a power transformer by connecting its primary winding first to two phases of the network at the moment of zero crossing by the phase voltage of the network third phase, and then to the network third phase at the moment of zero crossing by the line voltage of the other two network phases. In this case, the starting currents of the transformer almost immediately enter the steady state without the appearance of constant components in the magnetization currents and voltage drop. To expand the functionality of thyristor switches, it is proposed, in addition to bumpless turning on of a power transformer, to disconnect it without arcing between the contacts of electrical equipment, as well as to carry out continuous voltage regulation for consumers when voltage in the network changes. The proposed method and structure for its implementation on the basis of two three-phase thyristor reactor keys and a capacitor bank make it possible while changing the network voltage to stabilize the generated reactive power at the input of the substation without creating the current distortions in the power transformer and power transmission simultaneously with stabilizing the substation output voltage. Modeling and research of the start-regulating device as part of a transformer substation was carried out in the MatLab environment. The results of numerical experiments in stationary and dynamic modes of the substation operation showed the feasibility of using the developed technical solutions for the industrial power supply system.*

Keywords: *three-phase network, transformer substation, dual-band regulation, thyristor-reactor regulator, capacitor bank, control method, control operations, consumer voltage stabilization, reactive power compensation of the network, mathematical model.*

For citation: Klimash VS, Tabarov BD. Method for control of the start-up regulating devicefor power transformers of the power supply system. *Power engineering: research, equipment, technology.*2019; 21(3):135-145. (In Russ). doi:10.30724/1998-9903-2019-21-3-135-145.

СПОСОБ УПРАВЛЕНИЯ ПУСКОРЕГУЛИРУЮЩИМ УСТРОЙСТВОМ ДЛЯ СИЛОВЫХ ТРАНСФОРМАТОРОВ СИСТЕМЫ ЭЛЕКТРОСНАБЖЕНИЯ

В.С. Климаш, Б.Д. Табаров

Комсомольский-на-Амуре государственный университет, г. Комсомольск-на-Амуре, Россия

Резюме: *Трехфазные тиристорные ключи предназначены для импульсного формирования пусковых токов электрооборудования с последующим их шунтированием в установившемся режиме работы. Применительно к трансформаторным подстанциям они выполняют безударное включения силового трансформатора за счет подключения его первичной обмотки сначала к двум фазам сети в моменте перехода фазного напряжения третьей фаза сети через ноль, а затем к третьей фазе сети в момент перехода линейного напряжения двух других фаз сети через ноль. При этом пусковые токи трансформатора практически сразу входит в установившиеся режим без возникновения постоянных составляющих в токах намагничивания и спада напряжения. Для расширения функциональных возможностей тиристорных ключей предлагается, кроме безударного подключения силового трансформатора, осуществлять его отключение без образования дуги между контактами электроаппаратуры, а также осуществлять непрерывное регулирование напряжения у потребителей при изменении напряжения в сети. Предложенный способ и структура его реализации на основе двух трехфазных реакторно-тиристорных ключей и конденсаторной батареи позволяют при изменении напряжения сети одновременно со стабилизацией выходного напряжения подстанции стабилизировать генерируемую реактивную мощность на входе подстанции без создания искажений тока в силовом трансформаторе и электропередаче. Моделирование и исследование пускорегулирующего устройства в составе трансформаторной подстанции проводилось в среде MatLab. Результаты численных экспериментов в стационарных и динамических режимах работы подстанции показали целесообразность применения разработанных технических решений для системы промышленного электроснабжения.*

Ключевые слова: *трёхфазная сеть****,*** *трансформаторная подстанция, двухподдиапазонное регулирование, реакторно-тиристорный регулятор, конденсаторная батарея, способ управление, операции управления, стабилизация напряжения потребителей, компенсация реактивной мощности сети, математическая модель.*

Introduction

The commercially available thyristor AC voltage regulators with natural switching (TRVN) have relatively small overall dimensions, high speed and operational reliability. They are used to start asynchronous motor, at the input of diode rectifiers, in heating installations, lighting systems and in other electrical technologies. According to individual projects, they are manufactured for a voltage of 35 kV and a current of 2 kA for static compensators of reactive power of electric steelmaking plants [1].

At the same time, experimental studies on the use of TRVN as start-regulating devices for power transformers (PT) of substations 6 (10)/0.4 kV did not find practical application. This is due to the fact that with an increase in the control angle of the thyristors, TRVN consumes additional reactive power and introduces distortions in the output voltage and input current of the substation [2-11].

Analytical study of appropriate literature, patents study, and survey of testing experience in industrial operation allowed creating new technical solutions for transformer substations (TS). This is a reactor-thyristor AC voltage regulator with natural switching (R-TRVN) [12, 13] specially designed for PT and its control method [14].

The proposed R-TRVN device is installed on the high side of the PT in the same manner as the mechanical on-load tap-changer, and under continuous regulation it provides stable voltage for consumers with voltage deviations from the nominal by ± 10%. At the same time, it provides a sinusoidal voltage at the input and output of PT for three values of voltage in the network (nominal value, increased and decreased relative to the nominal value by 10%). Between these sinusoidal levels, a continuous narrow-range regulation is carried out in two sub-bands: in the upper one it is with lowered network voltage, and in the lower one with increased network voltage. Regulation is performed with a harmonic composition of voltage, meeting the Russian State Standard requirements, and without distorting the shape and phase shift of the current network.

The R-TRVN control method, in addition to dual-band regulation, provides bumpless turning on PT under load, in which there are no shock electrodynamic forces on the transformer windings and voltage reduction, and shutdown is performed without arcing on the mechanical contacts of the high voltage switch [15].

The purpose and objectives of research

The purpose of this work is to study the adjusting properties and energy parameters of the substation according to the P-TRVN - PT scheme using a mathematical model.

To achieve this purpose, the following tasks were set and solved in the work.

1. Development of a software package for substation research according to the P-TRVN - PT scheme.

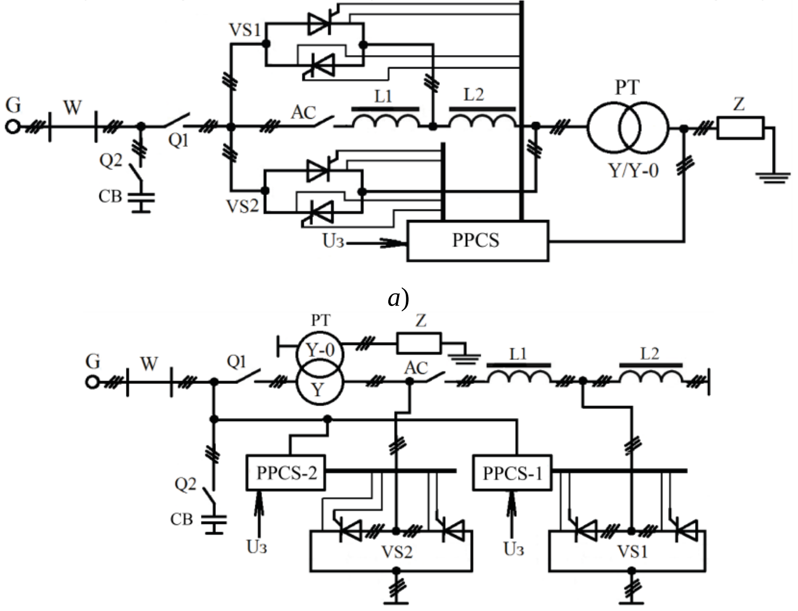
2. Study of voltage at the PT input and at consumers when the voltage deviation in the network is ± 10% of the nominal.

3. Study of current shape in the network, reactor, thyristor switches and at the PT input during the process of voltage stabilization at consumers.

4. Study of the current network phase when voltage deviates from the input of the substation, which includes P-TRVN and a block of capacitors.

Development of a specialized device for a transformer substation

Two schemes are proposed for connecting the P-TRVN device to the primary circuit of the PT substation. They are shown in fig. 1. In the first circuit (Fig. 1, a), the device is connected between the network and the primary PT winding connected in a star, and its pulse-phase control system (PPCS) is synchronized with the voltage of the secondary PT winding. In the second scheme (Fig. 1, b), the device is included in the cut of the star of the primary PT winding, and its pulse-phase control system is synchronized with the network. Both circuits perform regulation with identical physical processes and have their own advantages and disadvantages in the reconstruction of existing and newly designed TSs, taking into account the use of dry or oil PTs in them. At the same time, the advantage of the second circuit is that when a three-phase short circuit occurs in the primary winding of the PT, the thyristors are not exposed to emergency current.



a)

b)

Fig. 1. Schemes of a transformer substation with a reactor-thyristor voltage regulator

The circuits (Fig. 1) contain a three-phase network G, a power line W, an input high-voltage switch Q1, a high-voltage switch Q2 in the CB capacitor bank circuit, modules of the main VS-1 and additional VS-2 thyristor switches with a pulse-phase control system PPCS-1 and PPCS-2, AC contactor, main L1 and additional L2 reactors, power transformer PT and active-inductive load Z.

The device operates as follows.

The power transformer PT is turned on when the additional thyristor switches *VS-2* are completely turned off. In this case, firstly two main thyristor switches *VS-1* using an additional reactor *L2* connect two phases of its primary winding to the corresponding phases of the network *G* at the moment of zero crossing by the phase voltage of the network third phase G, then the third main thyristor switch *VS-1* connects the third phase of the primary winding of the power transformer PT to the network third phase at the moment the line voltage of the other two phases of the network is crossing zero. At the end of the process of turning on the PT power transformer while preparing the substation for voltage regulation, parallel to the fully open main thyristor switches *VS-1*, the main reactor *L1* is connected via a three-phase contactor *AC*. Further, when the conductive state of the thyristors changes, the process of voltage regulation starts both up and down as relating to the network voltage. The upper limit is set by the transformation ratio of the power transformer, and the lower limit is set by the resistance of the reactor.

The proposed R-TRVN control method provides voltage regulation at the input of the power transformer relative to the network voltage and among consumers between the specified regulation limits: the maximum and minimum divided by the nominal level.

The maximum limit of voltage regulation at the power transformer load is set by the transformation coefficient of the power transformer PT with the main switches *VS-1* completely turned off and the additional thyristor switches *VS-2* fully turned on at a reduced voltage in the network *G*. The additional thyristor switches *VS-2* at this moment bypass the main L1 and additional L2 reactors in the circuit primary winding of a power transformer PT.

The rated voltage level at the load is ensured when the main switches *VS-1*, which bypass the main reactor L1, are fully turned on, and the additional thyristor switches *VS-2* are completely turned off at the rated mains voltage *G* and the rated load *Z*.

The minimum regulation limit on the load is set by the total resistance of the main L1 and additional L2 reactor with completely closed main *VS-1* and additional *VS-2* thyristor switches with increased voltage in the network G and rated load Z.

A change in the network voltage affects the voltage of consumers and leads to a change in the reactive power of the capacitor bank and in the network.

The inductance and voltage drop are regulated using R-TRVN at the TS input. Depending on the positive and negative voltage deviations at the substation input, it is necessary to individually select the resistance of the primary and secondary reactors. This contributes to the achievement of high quality load voltage.

It should be noted that the reactive power of capacitors depends on the change in the supply voltage and that during the process of voltage stabilization for consumers, the conductive state of thyristors and inductance of R-TRVN in the PT primary circuit are regulated using a thyristor switch. An increase in inductance simultaneously with an increase in the generated reactive power of capacitors eliminates the deviation of the reactive power (deviation of the current phase) of the network according to the principle of indirect compensation.

The known devices built on the principle of indirect compensation of reactive power with parallel connection to the network and capacitors and a thyristor-reactor device [19] create current distortions in the network and can operate either in the mode of reactive power compensation, or in the mode of voltage maintenance.

For the proposed method and device [13, 14], the distinctive feature of the principle of indirect compensation of network reactive power with simultaneous compensation of voltage deviations at consumers without distorting the PT and network current is that the capacitor is connected to the network in parallel, and the reactor is connected in series between the network and TS .

An increase in the inductance in the PT circuit during the pulse-phase control of the alternating voltage at the reactors neutralizes the additional reactive power generated by the capacitors, providing a slight deviation of the network phase current from voltage and maintaining the maximum cosφ value. This is one of the great features of the proposed device.

Turning off the substation power transformer PT without the occurrence of an electric arc and switching overvoltages is conducted as follows.

Before turning off the power transformer, pulses are first removed from the additional thyristor switches *VS-2*. Then, the main thyristor switches *VS-1* are transferred to the fully open state and the current through the contacts of the three-phase contactor *AC* and the main reactor L1 is set to zero. After this, the three-phase contactor *AC* is used to disconnect the de-energized main reactor *L1* without arcing and overvoltage. At the final operation of the method, control pulses are removed from the main thyristor switches *VS-1* with natural switching and they are turned off without switching losses when phase currents are crossing zero.

Mathematical modeling of the reactor thyristor device

To study the regulatory properties and energy parameters of the substation according to the R-TRVN - PT scheme and physical processes in static and dynamic modes, a software package was developed in the Matlab environment [16]. The substation model is built for the circuit of Fig. 1b, and is shown in Fig. 2. It contains the following elements and modules: three single-phase sources forming a three-phase network (*Ua, Ub, Uc*); power line *W*; input high-voltage switch *Q1*; high-voltage switch *Q2* in the battery circuit of the capacitor bank CB; contactor *AC*; modules of the main *VS-1* and additional *VS-2* thyristor switches with a pulse-phase control system PPCS-1 and PPCS-2; main *L1* and additional *L2* reactors; power transformer PT; active-inductive load Z and other auxiliary elements.

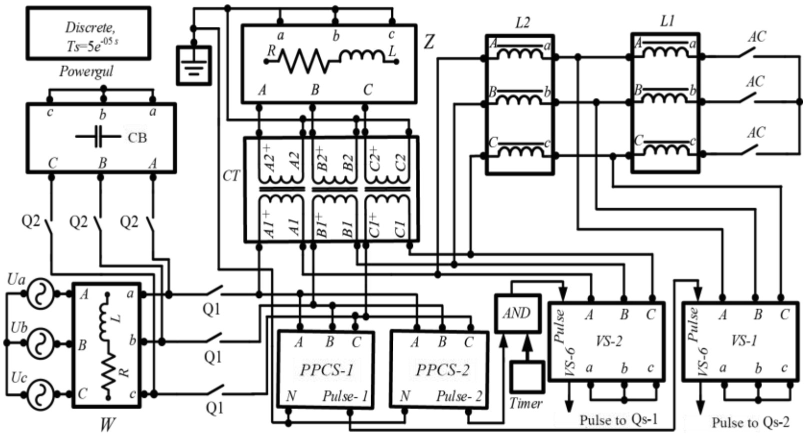
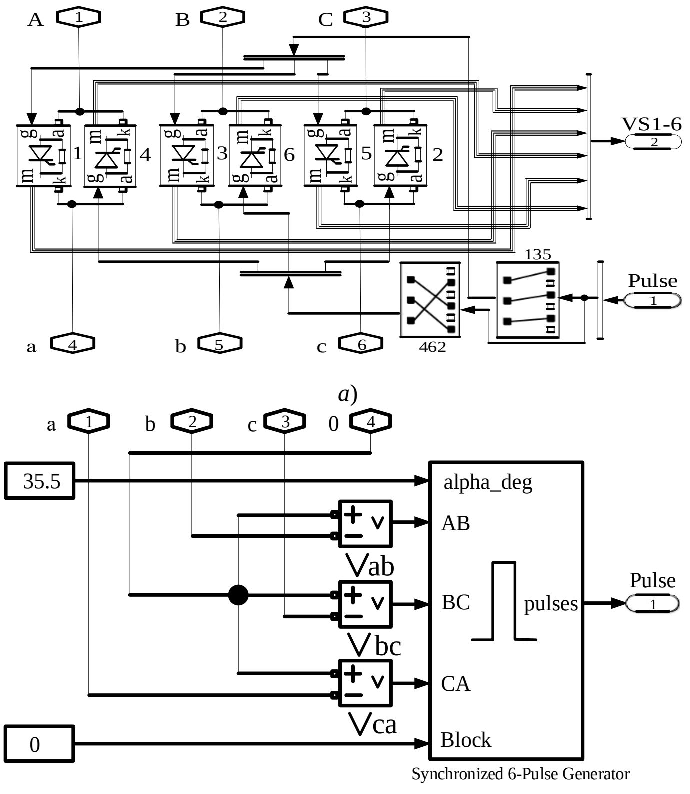


Fig. 2. Block-modular mathematical model of a transformer substation with a dual-band control device

Figure 3 shows detailed schemes of modules that have particular differential equations and, when joint, form a common system of differential equations of the object under study.



b)

Fig. 3. Detailed schemes of models of the software package:
a) - thyristor key; b) - control systems

Research results of a transformer substation with a start-regulating reactor-thyristor device

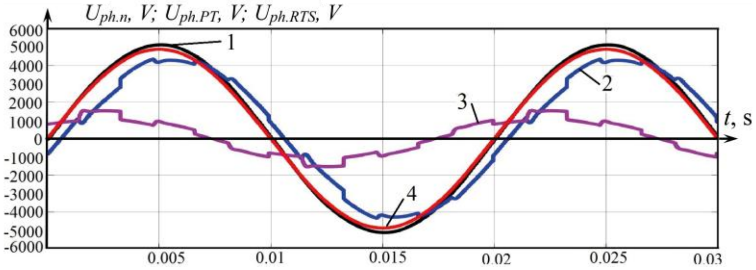
When modeling, the following physical processes of substation according to the *R-TRVN* - *PT* scheme were studied.

1. Study of voltages at the PT input and consumers with voltage deviations in the upper and lower sub-bands of regulation.

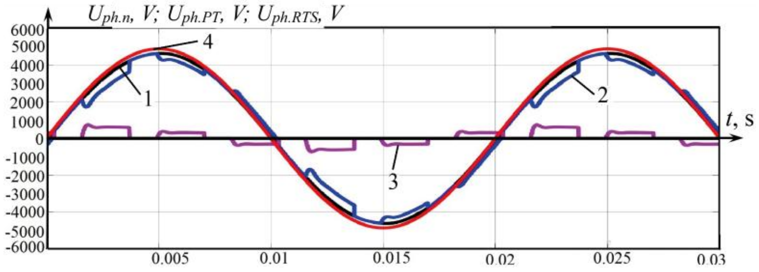
2. Study of voltages at *R-TRVN* at the PT input with respect to the network. The obtained oscillograms are shown in Fig. 4.

3. Study of the network current shape at that at the input of PT in the reactor and through the thyristors during voltage stabilization at the consumer when working from dual-band *R-TRVN.*

Further we analyze the results of TS numerical studies in *MatLab* using *the R-TRVN* scheme. Figure 4 shows voltage oscillograms at the TS elements using the R-TRVN scheme. They are obtained at rated load and network voltage deviations of ± 5% of the nominal level and are shown for one phase. It should be noted that when the regulation is shifted from the middle in one direction or another, the voltage shape improves and tends to be sinusoidal.



a)



b)

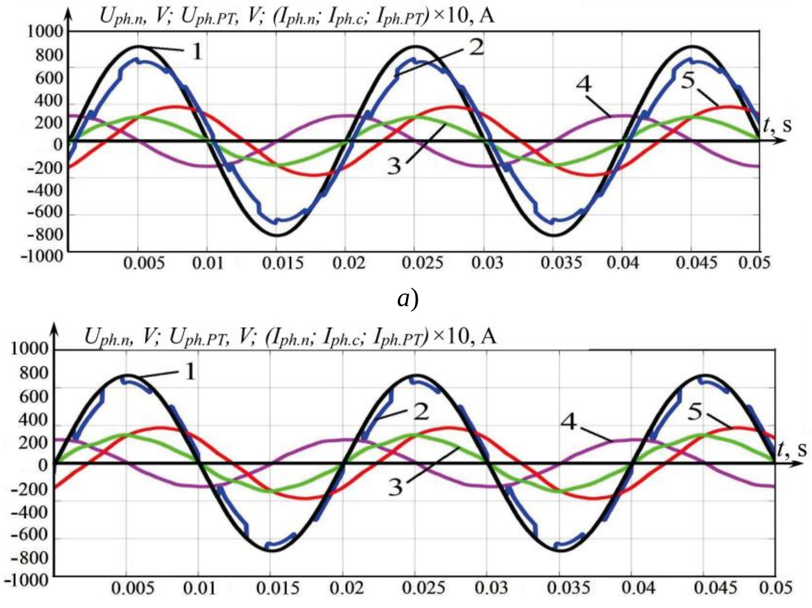
Fig. 4. Oscillograms of voltage drop in the network, transformer and device at the upper (a) and lower (b) voltage control sub-bands:
1, 2, 3 and 4 are the phase voltages in the network, at the PT input, at R-TRVN and phase voltage at the PT input at the network rated voltage

The device employs a narrow-range pulse-phase regulation of alternating voltage with a parallel connection of reactor and thyristor switch [17]. This three-phase device is included in the primary circuit of the PT connected to a star without a neutral wire. Such an inclusion creates an interphase voltage interaction [18], as a result of which the voltage modulation frequency increases three times with respect to the switching frequency of the phase thyristor switches (Fig. 4).

When the network voltage is increased by the deviation $+\Delta U$, the device, increasing the control angle α, reduces the conductive state of the thyristors and, increasing the inductance on the high side of TS, creates a voltage drop $-\Delta U$ on it, while maintaining the required voltage at consumers. With a decrease $-\Delta U$, the device reduces the control angle α, increases the thyristors conductive state and, reducing the inductive resistance on the high side of TS, creates a voltage drop of $+\Delta U$ on it.

Thus, during stabilisation of load voltage, the X_L of reactor thyristor device is regulated, providing the principle of indirect compensation of reactive power [19].

The oscillograms in Fig. 5 illustrate voltage regulation in the upper and lower sub-bands.

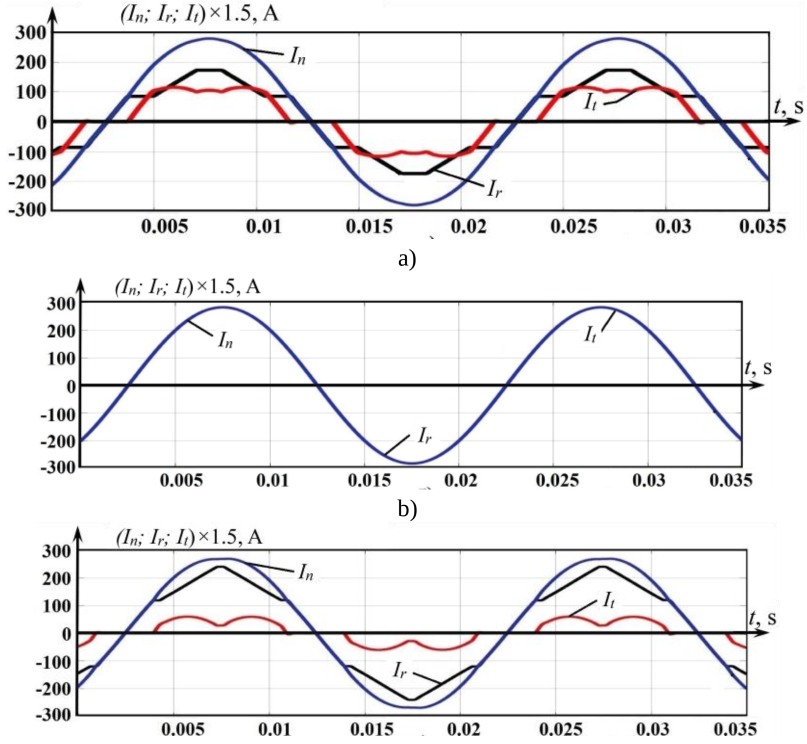


b)

Fig. 5. Oscillograms of currents and voltages in the upper (a) and lower (b) sub-bands of voltage regulation: 1 and 2 - phase voltages of the network and PT input;
3, 4 and 5 - phase currents of the network, capacitor and *PT* input

Analysis of these oscillograms shows that the shape of the network current is distorted slightly, and its phase coincides with the network voltage, which determines high efficiency of electricity consumption of the transformer substation.

R-TRVN studies have revealed that voltage regulation on the TS high side does not adversely affect the shape of the network current. The results of this study are illustrated by the following figures.



a)

b)

c)

Fig. 6. Oscillograms of currents at different angles of thyristor control:
Ic and *Ip* are the phase currents of the network and additional reactor; *It* is the phase current of the main thyristor switch

Oscillogram in Fig. 6b, illustrates the PT operation at its rated mode and characterizes that, at rated PT operation, the currents of network, additional reactor, and main thyristor switch are equal. It can be seen from the oscillogram (Fig. 6, a and c) that the thyristor and reactor currents are distorted, and their sum, being the network current and the current of the power transformer, retains a sinusoidal shape at any control angles. This is another remarkable property of the device, which does not create additional losses in the power transformer and in the network during regulation [20].

Conclusions

Studies of a mathematical model of dynamic and quasi-stationary processes of a dual-band reactor-thyristor AC voltage regulator with natural switching as part of a transformer substation allowed us to draw the following conclusions:

1. The use of a reactor-thyristor device of continuous operation allows one to release a mechanical switching device with a current-limiting reactor of on-load tap changing type, to simplify the PT design and the technology for production of complete transformer substations.

2. When the voltage deviation in the network is ± 10% of the nominal value, the device maintains the voltage at consumers at a given level with an accuracy of not more than ± 1%.

3. The device, together with a capacitor bank, simultaneously with voltage stabilization at the transformer substation output provides stabilization of the generated reactive power at the substation input.

4. During the process of continuous regulation of voltage at the input of substation under load, the reactor-thyristor AC voltage regulator with natural switching does not create current distortions in the power transformer and in the network.

5. When applying a special control that takes into account electromagnetic processes, the device produces bumpless turning on the power transformer under load without phase currents exceeding their established values and turning it off without arcing at the contacts of high-voltage switching devices.

References

1. Klimash VS., Tabarov BD. Principy postroeniya puskoreguliruyushchego ustrojstva dlya transformatornyh podstancij. *Omsk scientific Bulletin. Ser. Electrical engineering.* 2017; 155(5): 55-60. (In Russ).

2. Panfilov DI, ELGebaly AE. and Astashev MG. Topologies of thyristor controlled reactor with reduced current harmonic content for static VAR compensators.17th EEEIC conference, Milan, Italy, 6–9 June. 2017.

3. Panfilov DI, Gebaly EL AE and Astashev MG Design and Optimization of New Thyristors Controlled Reactors with Zero Harmonic Content. 18th International Conference of Young Specialists on Micro. Nanotechnologies and Electron Devices, June 29–July 3, 2017.

4. DI. Panfilov, AE. ELGebaly and MG. Astashev, “Thyristors Controlled Reactors for Reactive Power Control with Zero Harmonics Content”, 17th IEEE International Conference on Smart Technologies IEEE EUROCON 2017, Ohrid, Macedonia, 6 - 8 July 2017.

5. Yakimov IA, Nikolaev AA., Barabash RO., Anohin VV Issledovanie raboty tiristornogo regulyatora napryazheniya pechnogo transformatora v rezhime stabilizacii pervichnogo toka dugovoj staleplavil'noj pechi // *Elektrotekhnika: setevoj elektronnyj nauchnyj zhurnal Russian Internet Journal of Electrical Engineering*. 2016; 3(4): 3-10. (In Russ).

6. Dionise TJ., Morello S. “Comprehensive Analysis to Specify a Static Var Compensator for an Electric Arc Furnace Upgrade”, *IEEE IAS Annual Meeting Conference Record,* Oct 2014.

7. Dionise TJ., “Assessing the Performance of a Static Var Compensator for an Electric Arc Furnace“, IEEE Industry Applications Society Annual Meeting, Las Vegas, NV, October 2012.

8. Kawamura A. “An Optimal Control Method Applied for the Compensation of the Fundamental

Литература

1. Климаш В.С., Табаров Б.Д. Принципы построения пускорегулирующего устройства для трансформаторных подстанций // Омский научный вестник. Серия «Электротехника». 2017. № 5 (155). С. 55–60.

2.Panfilov D.I., ELGebaly A.E. and Astashev M.G. Topologies of thyristor controlled reactor with reduced current harmonic content for static VAR compensators.17th EEEIC conference, Milan, Italy, 6-9 June 2017.

3. Panfilov DI, ELGebaly AE and Astashev MG Design and Optimization of New Thyristors Controlled Reactors with Zero Harmonic Content. 18th International Conference of Young Specialists on Micro / Nanotechnologies and Electron Devices, June 29–July 3, 2017.

4. Panfilov D.I., ELGebaly A.E. and Astashev M.G. “Thyristors Controlled Reactors for Reactive Power Control with Zero Harmonics Content”, 17th IEEE International Conference on Smart Technologies IEEE EUROCON 2017, Ohrid, Macedonia, 6 - 8 July 2017.

5. Якимов И.А., Николаев А.А., Барабаш Р.О., Анохин В.В. Исследование работы тиристорного регулятора напряжения печного трансформатора в режиме стабилизации первичного тока дуговой сталеплавильной печи // Электротехника: сетевой электронный научный журнал. 2016. Т.3, №4 (3). С. 3–10.

6. T.J. Dionise, S. Morello, “Comprehensive Analysis to Specify a Static Var Compensator for an Electric Arc Furnace Upgrade”, IEEE IAS Annual Meeting Conference Record ;Oct 2014.

7. T.J. Dionise, “Assessing the Performance of a Static Var Compensator for an Electric Arc Furnace“, IEEE Industry Applications Society Annual Meeting, Las Vegas, NV, October 2012.

8. Kawamura A. IEEE Transactions of Industry Applications. 1983. Vol. 1A-19, iss. 3. pp. 414-423.

9. Якимов И.А. Обоснование тиристорного

VAR Fluctuations in the Arc Furnace," IEEE Transactions of Industry Applications. 1983. Vol. 1A-19, iss. 3. pp. 414-423. doi: 10.1109/TIA.1983.4504217.

9. Yakimov IA. Obosnovanie tiristornogo regulirovaniya napryazheniya transformatora dugovoj staleplavil'noj pechi . *Elektrotekhnicheskie sistemy i kompleksy*. 2017; 2 (35): 41-48. (In Russ).

10 Panfilov DI., Elgebaly AE., Astashev MG. Design and Assessment of Static VAR Compensator on Railways Power Grid Operation under Normal and Contingencies Conditions2016, 16th EEEIC conference, Florence7-10 June;Italy.

11. Panfilov DI., ELGebaly AE., "Modified Thyristor Controlled Reactors for Static VAR Compensators" 2016 IEEE 6th International Conference on Power and Energy (PECON 2016), Melaka, Malaysia, November 2016.

12. Getopanov AYu, Tabarov BD, Klimash V.S. Issledovanie regulirovochnyh svojstv i vliyaniya na set' reaktorno-tiristornogo ustrojstva na vysokoj storone pechnogo transformatora // *Elektrotekhnicheskie sistemy i kompleksy* 2018; 39(2):49-56. (In Russ).

13. Klimash VS, Tabarov BD .Ustrojstvo dlya vklyucheniya, vyklyucheniya i regulirovaniya napryazheniya transformatornoj podstancii. Patent RUS 2667481 №2667481 RF. H02P 13/00 (2006.01). №2017143967; Appl. 14.12.2017;, Byul. №26.Accesed :20 Sep 2018.

14. Klimash S, Tabarov BD. Sposob vklyucheniya, viyklyucheniya i regulirovaniya napryaweniya transformatornoy podstansii [A method for switching on and off and regulate voltage transformer substation]. Patent RUS №2667095 RF. H02M 5/25 (2006.01); G05F 1/30 (2006.01). №2017147194; Appl. 29.12.2017; publ. 14.09.2018, Byul. №26

15. Klimash VS, Tabarov BD. *Issledovaniya transformatornoj podstancii s puskoreguliruyushchim ustrojstvom v avarijnyh rezhimah raboty* // 3 Povolzhskaya nauchno-prakticheskaya konferenciya. «Priborostroenie i avtomatizirovannyj elektroprivod v toplivno-energeticheskom komplekse i zhilishchno-kommunal'nom hozyajstve., 7–8 dec Kazan, 2017. pp. 118-123. (In Russ).

16 Klimash VS., Tabarov BD. Programmnyj kompleks matematicheskih modelej magnitno-tiristornogo puskoreguliruyushchego ustrojstva dlya silovogo transformatora v srede MatLab. Patent RUS .Svidetel'stvo o gosudarstvennyj registracii

регулирования напряжения трансформатора дуговой сталеплавильной печи // ЭЛЕКТРОТЕХНИЧЕСКИЕ СИСТЕМЫ И КОМПЛЕКСЫ. 2017.Т 35. № 2. С. 41–48.

10. Panfilov D.I., Elgebaly A.E. and Astashev M.G., Design and Assessment of Static VAR Compensator on Railways Power Grid Operation under Normal and Contingencies Conditions2016, 16th EEEIC conference, Florence7-10 June;Italy.

11. Panfilov D.I., ELGebaly A.E. Modified Thyristor Controlled Reactors for Static VAR Compensators 2016 IEEE 6th International Conference on Power and Energy (PECON 2016), Melaka, Malaysia, November 2016.

12. Гетопанов А.Ю., Табаров Б.Д., Климаш В.С. Исследование регулировочных свойств и влияния на сеть реакторно-тиристорного устройства на высокой стороне печного трансформатора // Электротехнические системы и комплексы. Серия «Электротехника». 2018. №2 (39). С. 49–56.

13 Климаш В.С., Табаров Б.Д. Пат. 2667481 Российская Федерация, МПК H02P 13/00 (2006.01). Устройство для включения, выключения и регулирования напряжения трансформаторной подстанции. № 2017143967; 14.12.2017; Бюл. № 26.Ссылка активна на. 20сентября.2018,

14.Климаш В.С., Табаров Б.Д. Пат. 2667095 Российская Федерация, МПК H02M 5/25 (2006.01); G05F 1/30 (2006.01). Способ управления пускорегулирующим устройством силового трансформатора № 2017147194; 29.12.2017. Бюл. № 26. Ссылка активна на: 14.09.2018

15. Климаш В.С., Табаров Б.Д. Исследования трансформаторной подстанции с пускорегулирующим устройством в аварийных режимах работы // 3 Поволжская научно-практическая конференция. «Приборостроение и автоматизированный электропривод в топливно-энергетическом комплексе и жилищно-коммунальном хозяйстве». 7–8 декабря 2017. С. 118–123.

16. Климаш В.С., Табаров Б.Д. Программный комплекс математических моделей магнитно-тиристорного пускорегулирующего устройства для силового трансформатора в среде MatLab. Патент РФ.Свидетельство о государственный регистрации программы для ЭВМ № 2017613852,. Бюл№4.Ссылка активна на:03

programmy dlya EVM
№ 2017613852 Byul№4 Accessed:03 apr 2017.
17.Zharsky BK, Golubev VV. *Impul'snoe regulirovanie peremennogo napryazheniya.* Kiev: Institut elektromekhaniki AN USSR 1975. (In Russ).
18. Klimash V.S. *Vol'todobavochnye ustrojstva dlya kompensacii otklonenij napryazheniya i reaktivnoj energii s amplitudnym, impul'snym i fazovym regulirovaniem:* Vladivostok, 2002. (In Russ).
19. Solodukha YaYu. *Sostoyanie i perspektivy vnedreniya v elektroprivod staticheskih kompensatorov reaktivnoj moshchnosti (obobshchenie otechestvennogo i zarubezhnogo opyta). Reaktivnaya moshchnost' v setyah s nesinusoidal'nymi tokami i staticheskie ustrojstva dlya eyo kompensacii*. Moskva: Informelektro, 1981. (In Russ).
20. Klimash VS, Tabarov BD. Issledovanie vhodnogo toka transformatornoj podstancii pri rabote ot magnitno-tiristornogo puskoreguliruyushchego ustrojstva. // *Mezhdunarodnyj centr nauchnogo sotrudnichestva «Nauka i prosveshchenie». 9 Mezhdunarodnoj nauchno - prakticheskoj konferencii "World Science: Problems and Innovations"*, Penza, April 30, 2017. P. 167-170. (In Russ).
апреля 2017
17. Жарский Б.К., Голубев В.В. Импульсное регулирование переменного напряжения. Киев: Институт электромеханики АН УССР, 1975.
18. Климаш В.С. Вольтодобавочные устройства для компенсации отклонений напряжения и реактивной энергии с амплитудным, импульсным и фазовым регулированием: Владивосток, 2002. 141 с.
19. Солодуха Я.Ю. Состояние и перспективы внедрения в электропривод статических компенсаторов реактивной мощности Реактивная мощность в сетях с несинусоидальными токами и статические устройства для её компенсации. Москва: Информэлектро, 1981.
20. Климаш В.С., Табаров Б.Д. Исследование входного тока трансформаторной подстанции при работе от магнитно-тиристорного пускорегулирующего устройства. // Международный центр научного сотрудничества «Наука и просвещение». 9 Международной научно - практической конференции «World Science: Problems and Innovations». Пенза, 30 апреля 2017. С. 167–170.

Authors of the publication

Vladimir S. Klimash - doctor of technical Sciences, Professor, Professor of the Department of "Industrial electronics". E-mail: klimash@yandex.ru.

Bekhruz D. Tabarov – post-graduate student of the Department "Industrial electronics", E-mail: behruz.tabarov@mail.ru.

Received ***April 02, 2019***