DOI 10.52209/1609-1825_2021_4_286 UDC 621.31

Voltage Regulation As a Source to Increase the Quality of Electric Power

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Abstract. *The article provides an overview of the capabilities of a linear control transformer use. During the use of transformer nodes, the indicator mode changes, namely the network diagram, the load of the nodes and the composition of the generating equipment. Therefore, the regulation of voltage and reactive power in accordance with the planned schedules does not give the economic effect that can be achieved with the operational and automatic control of regulating devices (i.e. generators, synchronous compensators, transformers, etc.). It is necessary to regulate voltage in order to ensure the required technical and economic indicators of the operating modes of electrical networks. The function of a linear transformer is to regulate and maintain the supplied voltage at various points in the network. Linear devices change the circuit parameters of the network – transformation ratios, reactance. These are transformers, autotransformers with voltage regulation devices under load (OLTC), special control transformers, capacitor units for longitudinal compensation of the inductive resistance of the network. The main technical measures to improve the quality of electricity are considered. The issue of voltage regulation is discussed in detail.*

Keywords: *power quality, energy efficiency, linear control transformer, asynchronous motors, efficiency factor, transformer.*

Introduction

It is necessary to regulate the voltage in order to ensure the required technical and economic indicators of the operating modes of electrical networks. For different electrical networks, the purpose of voltage regulation varies. The main function of voltage regulation is to maintain voltage deviations within the limits established by GOST 13109-97 to ensure high-quality electricity. Currently, power systems use various devices to maintain the voltage regime, these are: generators of power plants, transformers with a load-controlled transformation ratio, capacitor banks, reactors, synchronous compensators and static valve sources of reactive power. Considering that most of these equipment are technically outdated, they cannot fully ensure the required voltage regulation range. Construction of new facilities or reconstruction of existing substations requires significant time and capital investment. It becomes necessary to look for other methods and means of voltage regulation. In this case, transformers of the linear three-phase transformer with natural circulation of oil and air, adjustable under load type can be used as a means of local voltage regulation.

According to Lin and Liu [1], electricity consumption is a direct reflection of the conditions of financial development in the economy. As it is known, in the Republic of Kazakhstan, the production of electrical energy is implemented by 138 power plants, where as of 01/01/2019 the installed total capacity of power plants is 21,901.9 MW, and the available capacity is 18,894.9 MW [2]. Control transformers are essential in the power distribution chain from the power plant to the consumers, as voltage deviations negatively affect the operation of induction motors (IM).

Linear transformers are installed in electrical circuits in order to regulate the supplied voltage when the operating power is reduced. The coils create an electromagnetic field that discharges when the current in the circuit decreases. Thus, the supply of stable electricity is ensured [3].

Research methodology

For induction motors (IM), a voltage change of 10% can result in changes of starting, operating and maximum torque by around 20% (see Table).

In addition, slip, efficiency, stator and rotor current, etc. also change. The service life of the motor insulation is thus cut in half. A 1% increase in voltage contributes to an increase in reactive power consumption by 3%. When installing IM in produc-

Changing the characteristics of an asynchronous electric motor due to voltage deviation from the nominal		
Motor characteristics	**Change in characteristic with voltage deviation, %**	
	-10	**+10**
Starting and maximum torque	-19	21
Synchronous speed	const	const
Slip,%	23	-17
Rotational speed at a rated load	-1,5	1
Efficiency under load:		
rated	-2	1
75% Pr	const	const
50% Pr	-1÷2	1÷2
Load power factor:		
100% Pr	1	-3
75% Pr	2÷3	-4
50% Pr	4÷5	-5÷-6
Rotor current at rated load	14	11
Stator current at rated load	10	-7
Starting current	-10÷-12	10-12
Winding temperature rise at rated load	5-6°C	does not change

tion lines, due to changes in the speed of rotation of the engine, productivity and quality may be affected. During welding, the quality of the seam deteriorates and the consumption of reactive energy increases [4].

Voltage oscillations increase the injury from the illumination point of view, as the fatigue of people is increasing dramatically. An increase in voltage can shorten the life of lighting fixtures, so when the voltage rises by 5%, it will halve the service life of fixtures, and if it rises by 10%, the service life is shortened by a factor of four. Decreasing the voltage reduces the luminous flux, thereby worsening the comfort conditions for people and may cause injury.

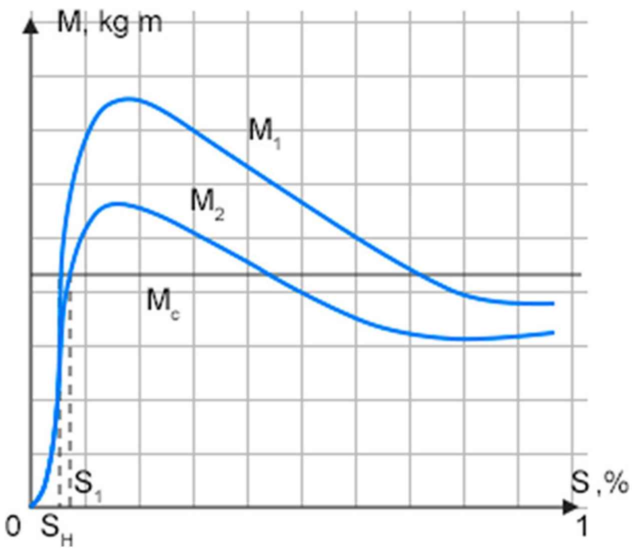

Figure 1 – Mechanical indicator of the motor at rated (M1) and reduced (M2) voltages

From the curves in Figure 2, it can be seen that, with the decrease in voltage, the most noticeable decrease is in the luminous flux. Accordingly, with an increase in the voltage above the nominal, the lamp power P, the luminous flux F and the luminous efficiency h increase, but at the same time the service life of the T lamps is drastically reduced and contributes to a quick burnout and excessive consumption of electricity [5].

Thus, in the case of voltage fluctuations, they lead to changes in luminous flux and illumination, thereby affecting labor productivity and human fatigue. When the voltage is reduced, the operation conditions of fluorescent lamps deteriorate, so that their service life, determined by spraying the oxide coating of the electrodes, is reduced at both negative and positive voltage deviations. For example, when the voltage fluctuates by 10%, the service life of fluorescent lamps is reduced on average by 20-25%.

Furthermore, a lot of industrial equipment are sensitive to voltage fluctuations. Valve converters usually have a DC automatic control system by means of phase control. With an increase in the voltage in the network, the regulation angle automatically changes in the direction of increase, and with a decrease in the voltage, the opening angle to the load is not fully supplied. It is necessary to take into account the fact that with an increase in voltage by only 1%,

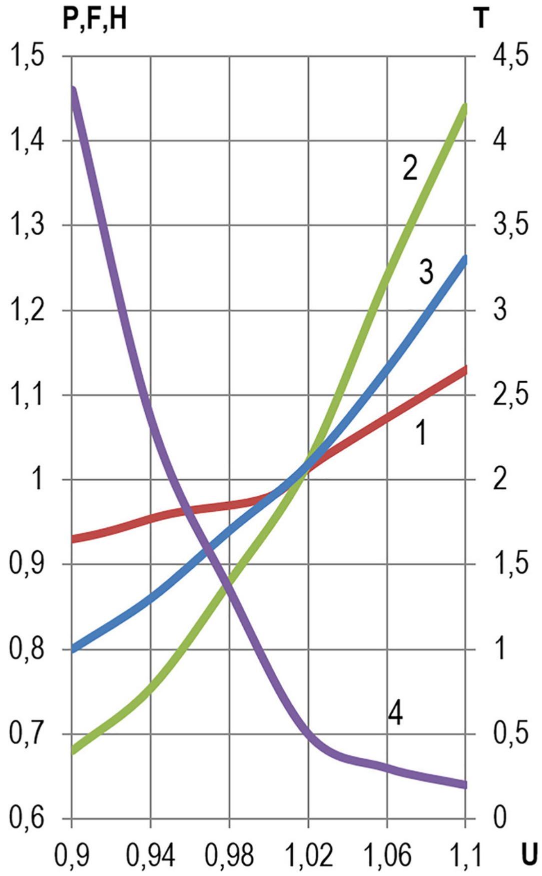

Figure 2 – Dependences of the characteristics of incandescent lamps on voltage: 1 – power consumption, 2 – luminous flux, 3 – luminous efficacy, 4 – service life

it contributes to an increase in the consumption of reactive power by the converter by about 1-1.4%, thereby deteriorating the power factor.

Experience has shown that a decrease in voltage on electric arc furnaces, for example, by 7% leads to an increase in the duration of the steel melting process by 1.5 times and to an increase in electricity consumption [5].

Voltage fluctuations negatively affect the operation of electric welding machines: for instance, for electric spot welding machines with a voltage deviation of 15%, it contributes to obtaining 100% product rejects [6].

Research findings

Considering the above, maintaining the required voltage level is becoming a very important component of power supply systems, which makes the development of linear control transformers topical.

Research and development of linear regulating transformers has been going on since the middle of the last century. The research was based on changes in the quality characteristics of transformers: size, winding material, design, etc.

Federal State Budgetary Educational Institution of Higher Professional Education «Rostov State Transport University» (RSTU), a science and research unit (SRU), has patented the design of a regulated transformer [7]. The aim of the work is to reduce the no-load loss and increase the efficiency of the linear control transformer by changing the magnetic fluid in the cores of the magnetic circuit.

In 1997, an adjustable transformer with a reduced space occupied by the regulating windings was patented in the USA [8]. The objective of the invention was to create a transformer with compact control windings. This task was achieved by using a flexible conductor with a mechanism containing an electric field. A flexible conductor presents itself as a flexible cable for even distribution of electricity. The flexible cable has a conductive core and a first semiconductive layer around the core. A solid insulating layer around the first semiconducting layer and the second semiconducting layer around the insulating layer. Provided that the second semiconducting layer is grounded, the cable has the ability to accommodate the electric field generated by the current in the conductive core. Thus, the electric voltage is absorbed in the solid insulation of the cable, and there is practically no electric field outside the second semiconducting layer, which makes it possible to increase the efficiency of the transformer.

Since 1975, research has been carried out in the field of using various insulating materials to improve the efficiency of controlled transformers, reduce no-load losses and increase dielectric strength [9, 10]. The development of more efficient transformers is the main focus of research in the field of electrical engineering; they improve the quality of electricity [11, 12].

In recent times, there has been a growing interest in the automation of equipment and the development of automatic adjustable transformers. Members of the international non-profit association of specialists in the field of technology, development of standards for radio electronics, electrical engineering and hardware of computing systems and networks, Xu, Dominguez-Garcia and Sauer [13] proposed an algorithm for calculating the optimal setting of transformer voltage regulation taps. Thus, without changing the structure, design and materials of transformers (winding, core) only by selecting certain conditions without developing a prototype, it is possible to virtually simulate.

Conclusion

Nonetheless, the Republic of Kazakhstan lags behind both the world community and the CIS countries, in the development of standards for the quality of electrical energy in general-purpose power supply systems (GOST 13109-97), as well as in the development of general-purpose oil type power transformers with voltages up to 35 kV inclusive (GOST 11920-93). The latest updates to GOST regarding the power quality standard were introduced in 2013, but Kazakhstan had not yet signed the interstate standard. Quality standards for oil type power transformers have not been updated since the early 90's. However, the requirements for both the quality of electrical energy and the transformers themselves have been raised around the world.

One of the tasks of great significance in the production and operation of transformers is to increase the efficiency of operation of the device, i.e. reduction of idling losses. There are several ways to reduce losses in steel:

1. Decrease in the magnitude of the magnetic flux. However, this method is not acceptable, since it requires more copper wires to create an EMF (electromotive force).

2. The use of electrical steel, which has high resistance and low hysteresis losses.

3. The use of thin plates for the manufacture of the magnetic system. This will significantly reduce eddy current losses.

4. Use of structures of magnetic cores with oblique joints of plates according to the STEP-LAP scheme.

5. Automation of the process of cutting and blending of the magnetic circuit in order to reduce additional losses.

Taking into account the above advantages, to improve the quality of electricity and the efficient operation of transformers, to reduce no-load losses, jointly with the «Kentau Transformer Plant» JSC and «TRENCO R&D» LLP, work is being carried out to develop a linear regulating transformer of the LTMN 16000/10 type.

The advantage of the LTMN 16000/10 type transformer over the power transformer is in the increase of the voltage regulation limit to save electricity via introduction of additional voltage into the main winding of the transformer itself.

In conventional power transformers the windings of the primary and secondary voltage are placed in one common active part, however the LTMN-16000/10 transformer will consist of two separate active parts placed in one common tank:

the active part of the series transformer (with series and exciting windings) and the active part of the autotransformer (with a regulating winding and an on-load voltage control device (OLTC)), connection between which is carried out through the tap changer.

Acknowledgments

This research was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP09058053).The study was carried out by «TRENCO R&D» LLP, 010000, Nur-Sultan city, Kabanbay batyr ave., Buidling 53/1, Block 53 (S4).

REFERENCES

1. B. Lin and C. Liu, Why is electricity consumption inconsistent with economic growth in China? // Energy Policy. – Vol. 88. – 2016. – p. 310-316.
2. https://www.kegoc.kz/ru/elektroenergetika/elektroenergetika-kazahstana-klyuchevye-fakty
3. Ананичева С.С. и др. Качество электроэнергии. Регулирование напряжения и частоты в энергосистемах: учебное пособие – 3-е изд., испр. Екатеринбург: УрФУ. 2012. 93 с.
4. Лагутенков А.Г., С.В. Ершов. Анализ и оценка влияния колебания напряжения на качество электроэнергии в сети / Известия ТулГУ. Технические науки 2015. Вып. 12. Ч. 2. 154-157 с.
5. Умбеткулов Е.К., Сахариев Б.С., Амитов Е.Т. К вопросу обеспечения электроэнергией спасательных и других неотложных работ при землетрясениях // Вестник АУЭС, № 2 (49), 2020 г., 43-48 с.
6. Lebedev S.M., Gefle O.S. Amitov E.T. Thermally conductive polymeric materials and their usage in LED-devices // Appl. Mech. Mater. – Vol. 756. 2015. pp. 159-163.
7. А.С. 2 364 972 RU. Кл. C1 – Регулируемый трансформатор / Соломин В.А., Жарков Ю.И. и Костюков А.В.; опубл. 20.08.2009, Бюл. № 23. – 6 с.
8. А.С. 6995646 US. Кл. B1 – Трансформатор с регулировкой напряжения / Udo Fromm, Par Holmberg, Albert Jaksts и др.; опубл. 03.02.1997.
9. Wroblewski, T., & Kusko, A. High-Power Ferroresonant Voltage Regulating Transformers / International Telecommunications Energy Conference INTELEC 79, Nov. 26, 27, 28, 29, 1979, Sheraton Park Hotel, Washington, D.C., USA, pp. 371-375.
10. Arrillaga, J., Barrett, B., & Vovos, N.A. Thyristor-controlled regulating transformer for variable voltage boosting // Proceedings of the Institution of Electrical Engineers. Vol. 123, Issue 10. October 1976, pp. 1005-1009.
11. Волков Н.Г. Качество электроэнергии в системах электроснабжения: учебное пособие. – Национальный исследовательский Томский политехнический университет, Томск: 2010, 152 с.
12. Суднова В.В. Качество электрической энергии. – М.: ЗАО Энергосервис, 2000. – 80 с.
13. Жежеленко И.В. Показатели качества электроэнергии и их контроль на промышленных предприятиях. – М.: Энергоатомиздат, 1986. 168 с.

Электр сапасын арттыру көзі ретінде кернеуді реттеу

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Аңдатпа. *Мақалада сызықтық реттеу трансформаторын қолдану мүмкіндігі туралы шолу берілген. Трансформаторлық түйіндерді қолдану кезінде индикаторлық режим өзгереді, атап айтқанда желілік диаграмма, түйіндердің жүктемесі, генераторлық жабдықтың құрамы. Сондықтан жоспарлы кестелерге сәйкес кернеу мен реактивті қуатты реттейтін реттеуші құрылғыларды (яғни генераторларды, синхронды компенсаторларды, трансформаторларды және т.б.) жедел және автоматты басқару кезінде қол жеткізуге болатын экономикалық нәтиже бермейді. Электр желілерінің жұмыс режимдерінің қажетті техникалық-экономикалық көрсеткіштерін қамтамасыз ету үшін кернеуді реттеу қажет. Сызықтық трансформатордың функциясы-желінің әртүрлі нүктелерінде берілген кернеуді реттеу және ұстап тұру. Сызықтық құрылғылар желінің тізбек параметрлерін – трансформация коэффициенттері мен реактивті кедергілерді өзгертеді. Олар: трансформаторлар, жүктеме астында кернеуді реттеу құрылғылары бар автотрансформаторлар, арнайы реттеу трансформаторлары, желінің индуктивті кедергісін бойлық өтеуге арналған конденсаторлық қондырғылар. Электр энергиясының сапасын арттыруға мүмкіндік беретін негізгі техникалық іс-шаралар қаралды. Кернеуді реттеу мәселесі егжей-тегжейлі қаралды.*

Кілт сөздер: *электр энергияның сапасы, энерготиімділік, сызықтық реттегіш трансформатор, асинхронды қозғалтқыштар, пайдалы әсер коэффициенті, трансформатор.*

Регулирование напряжения как источник для повышения качества электроэнергии

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Аннотация. *В статье приведен обзор о возможности применения линейного регулировочного трансформатора. Во время использования трансформаторных узлов происходит изменение режима показателя, а именно схема сети, нагрузки узлов, состав генерирующего оборудования. Поэтому регулирование напряжения и реактивной мощности в соответствии с плановыми графиками не дает того экономического эффекта, которого можно достичь при оперативном и автоматическом управлении регулирующими устройствами (т.е. генераторами, синхронными компенсаторами, трансформаторами и т.д.). Для обеспечения требуемых технико-экономических показателей режимов работы электрических сетей необходимо регулировать напряжение. Функцией линейного трансформатора является регулирование и поддержание подаваемого напряжения в различных точках сети. Линейные устройства изменяют схемные параметры сети – коэффициенты трансформации, реактивное сопротивление. Это – трансформаторы, автотрансформаторы с устройствами регулирования напряжения (РПН) под нагрузкой, специальные регулировочные трансформаторы, конденсаторные установки для продольной компенсации индуктивного сопротивления сети. Рассмотрены основные технические мероприятия, позволяющие повысить качество электроэнергии. Подробно рассмотрен вопрос регулирования напряжения.*

Ключевые слова: *качество электрической энергии, энергоэффективность, линейный регулировочный трансформатор, асинхронные двигатели, коэффициент полезного действия, трансформатор.*

REFERENCES

1. B. Lin and C. Liu, Why is electricity consumption inconsistent with economic growth in China? // Energy Policy. – Vol. 88. – 2016. – pp. 310-316.
2. https://www.kegoc.kz/ru/elektroenergetika/elektroenergetika-kazahstana-klyuchevye-fakty
3. Ananicheva S.S., et al. Kachestvo elektroenergii. Regulirovanie napryazheniya i chastoty v energosistemah [Power quality. Regulation of voltage and frequency in power systems]: uchebnoe posobie [manual] – 3rd edition, Rev., Yekaterinburg: Ural Federal University, 2012. p. 93.
4. Lagutenkov A.G., S.V. Ershov. Analiz i ocenka vliyaniya kolebaniya napryazheniya na kachestvo elektroenergii v seti [Analysis and evaluation of the impact of voltage fluctuations on the quality of power in the network] / Izvestiya TulGU [Bulletin of TulSU]. Tekhnicheskie nauki [Technical Sciences] 2015. No. 12. Part 2. pp. 154-157.
5. Umbetkulov E.K., Sahariev B.S., Amitov E.T. K voprosu obespechenija jelektrojenergiej spasatel'nyh i drugih neotlozhnyh rabot pri zemletrjasenijah. [On the issue of providing electricity for rescue and other urgent work during earthquakes] // Vestnik AUJeS. [Bulletin of AUEC] 2020, No. 2 (49), pp. 43-48.
6. Lebedev S.M., Gefle O.S. Amitov E.T. Thermally conductive polymeric materials and their usage in LED-devices // Appl. Mech. Mater. – Vol. 756. 2015. pp. 159-163. [7] A.S. 2 364 972 RU. Kl. C1 – Reguliruemyj transformator [A.S. 2 364 972 RU. Cl. C1 – Regulated transformer]. Solomin V.A., Zharkov Yu.I. and Kostjukov A.V., publ. 20.08.2009, Bul. No. 23. – p. 6.
7. A.S. 6995646 US. Kl. B1 – Transformator s regulirovkoj naprjazhenija [A.S. 6995646 US. Cl. B1 – Voltage regulated transformer] Udo Fromm, Par Holmberg, Albert Jaksts, et al.; publ. 03.02.1997.
8. Wroblewski, T., & Kusko, A. High-Power Ferroresonant Voltage Regulating Transformers / International Telecommunications Energy Conference INTELEC 79, Nov. 26, 27, 28, 29, 1979, Sheraton Park Hotel, Washington, D.C., USA, pp. 371-375
9. Arrillaga, J., Barrett, B., & Vovos, N. A. Thyristor-controlled regulating transformer for variable voltage boosting // Proceedings of the Institution of Electrical Engineers. Vol. 123, Issue 10. October 1976, pp. 1005-1009.
10. Volkov N.G. Kachestvo jelektrojenergii v sistemah jelektrosnabzhenija: uchebnoe posobie. – Nacional'nyj issledovatel'skij Tomskij politehnicheskij universitet [Volkov N.G. The quality of electricity in power supply systems: manual. – National Research Tomsk Polytechnic University], Tomsk: 2010, p. 152.
11. Sudnova V.V. Kachestvo jelektricheskoj jenergii. [The quality of electrical energy]. Moscow: CJSC Energoservice, 2000 – p. 80.
12. Zhezhelenko I.V. Pokazateli kachestva jelektrojenergii i ih kontrol' na promyshlennyh predprijatijah [Power quality indicators and their control at industrial enterprises]. Moscow: Energoatomizdat, 1986 – p. 168.