Торайғыров университетінің хабаршысы
ҒЫЛЫМИ ЖУРНАЛЫ

НАУЧНЫЙ ЖУРНАЛ
Вестник Торайгыров университета

Торайғыров университетінің ХАБАРШЫСЫ

Энергетикалық сериясы

1997 жылдан бастап шығады

ВЕСТНИК Торайгыров университета

Энергетическая серия

Издается с 1997 года

ISSN 2710-3420

№ 3 (2025)

ПАВЛОДАР

НАУЧНЫЙ ЖУРНАЛ
Вестник Торайгыров университета

Энергетическая серия
выходит 4 раза в год

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания, информационного агентства и сетевого издания
№ 14310-Ж
выдано
Министерство информации и общественного развития Республики Казахстан

Тематическая направленность
публикация материалов в области электроэнергетики, электротехнологии, автоматизации, автоматизированных и информационных систем, электромеханики и теплоэнергетики

Подписной индекс – 76136

https://doi.org/10.48081/TPDW7598

SRSTI 44.29.29

https://doi.org/10.48081/GPVK4034

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ANALYSIS OF SWITCHING MODES TRANSIENT PROCESSES IN HIGH-VOLTAGE ELECTRICAL NETWORKS

The article is devoted to the analysis of transient processes in high-voltage electric networks under various switching modes. The parameters of this process are individual for each object and, moreover, even for each specific switching. Transient processes in switching modes create electromagnetic fields that cause interference and overvoltage in the secondary network and even in the internal circuits of the power supply system. This can lead to failures in operation and damage to electrical equipment. To assess the impact of switching processes on the operation of electrical equipment, a single-line diagram is considered and the characteristics of the electrical equipment included in the power supply system of the «Yuzhnaya» substation of «Shubarkol Komir» JSC are given. The switching processes that occur when turning on/off the feeder, turning on the load, emergency load shedding, as well as emergency disconnection of the feeder under load are considered. The parameters of the processes under consideration are calculated based on the switching processes. To analyze the characteristics of these transient processes, a mathematical model of the power supply system is developed and its modeling is carried out. Time diagrams of voltage on the feeder are given. Based on the data obtained, switching modes in electrical networks were determined that had *the most negative impact on the operation of electrical equipment, both as a whole and on its various parts.*

Keywords: Power supply system, electrical networks, switching modes, transient processes, high-frequency overvoltages, mathematical model.

Introduction

Switching interference is caused by changing the load. In electrical networks, distribution devices and electrical equipment chains the causes of electromagnetic effects that have a detrimental effect on automatic and automated systems for technological control of electrical facilities are [1]:

– transients in high-voltage circuits, which occur when switching of circuit breakers and disconnectors, short circuits, and when overcurrent limiters are activated;

– electrical and magnetic fields of industrial frequency generated by power equipment of stations and substations;

– transient processes in substation grounding devices caused by industrial short-circuit currents and lightning currents;

– fast transition processes in low voltage inductive circuits; transition processes in chains of different classes of voltage when lightning strikes directly into or near the object;

– static electricity discharge;

– electromagnetic disturbances in the operational current circuits.

– Investigation of switching interference is possible by experimental way, as well as by mathematical or simulation modelling methods.

Materials and methods

To simulate the operation of transition processes occurring in the substation «Yuzhnaya» JSC «Shubarkol Komir», figure 1 presents a single-line power supply scheme of the substation.

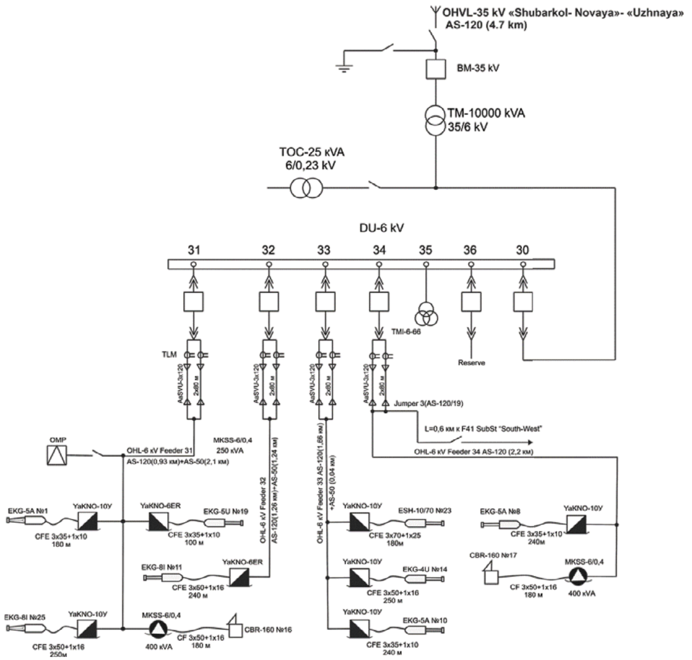

Figure 1 – Single line substation power supply circuit.

The «Yuzhnaya» substation has one incoming feeder and 5 waste feeders, one of which is in reserve. The remaining 4 provide electricity to various electrical equipment along the power lines. The 35 kV voltage is supplied to the substation via a high-voltage overhead power line. The voltage conversion from 35 kV to 6 kV is produced by a transformer of the TM-10000 kVA 35/6.

The application programming package MATLAB SIMULINK is used to create a simulation model of substation's electricity supply [2].

The method was used to calculate the parameters of the TM-10000 kVA 35/6 transformer [3]. Based on reference data, calculated using the mathematical software MathCad [4]. The calculation results are shown in table 1.

Table 1 – Calculation data of the transformer TM-10000 kVA 35/6

Transformer parameter	Estimated for TM-10000 kVA 35/6
Active resistance of windings. Ohm	0.398/0.012
Full resistance to wrapping. Ohm	4.594
Inductive winding resistance. Ohm	4.576
Inductance of windings. Road	0.015

Full power loss in transformer idle mode. kVA	80
1No-magnetizing transformer power. kVar	78,670
Active resistance of the magnetization circuit. Ohm	84480
Inductive resistance of the magnetization circuit. Ohm	15570
Inductance of the magnetization circuit. Hn	49.565

For the construction of model cable lines and overhead power lines used ready-made units [2]. Active resistance and specific inductive resistance, taken from reference data [3; 4; 5].

Inductance values of cable and overhead power lines are found from the expression:

$$L_0 = \frac{x_0}{2\pi f}, \text{Hn} \tag{1}$$

where: x_0 -the specific inductive resistance, Ohm;

f – power frequency, Hz.

The capacity of the overhead power line is defined by the expression:

$$C_0 = \frac{b_0}{2\pi f}. \text{ F} \tag{2}$$

where b0 – specific capacitive conductance, Sm/km.

The capacity of cable lines is selected according to the voltage and cross-sectional area of the conductor. The capacitance conductivity of overhead cable lines is in the range (2,6 … 2,8) 10-6 cm/km [6]. The capacity of overhead cable lines is therefore 8.28·10-9 F/km [6]. Parameters required for the cable line model are presented in table 2.

Table 2 – Cable Characteristics

Line Options	AaSVU-3x120	AS-120	AS-50	C F E 3x35	CAE 3x50	CO 3 x70
Resistance of the direct and zero sequence line, Ohm/km	0,258	0.2440	0.5951	0,54	0.39	0,28
The inductance of the direct and zero sequence line, Hn/km	0,191 ·10‘3	1,162 ·10-3	1,216 ·10-3	0,277 ·10-3	0,264 ·10’3	0,255 ·10-3
Direct and zero line sequence capacity, F/km	8,28 ·10-9	8,28 ·10-9	8,28 ·10-9	0,31	0,36	0,40

The availability of different electrical equipment connected to the substation allows modelling with different load parameters. As the electric excavator motors are connected directly to the high voltage, the corresponding electric motors are used as loads.

The reference data is used for calculation of parameters of electric motor replacement scheme [7; 8; 9]. The input data for building the modelled electric motors are presented in table 3.

Table 3 – Input data for the construction of electric motor models

Electrical equipment name	ECG-5A	ECT-8I	ECG-4U	ESH-10/70
Motor type	AE-4001-4U2	SDEO-14-29-6	AE113-4M	SDE2-16- 46-6U2
Rated power, kWt	250	560	250	1250
Nominal linear voltage. V	6000	6000	6000	6000
Magnetic field rotation speed, rpm	1500	1000	1480	1000
Efficiency factor, %	94.5	93.8	92	96
Rated power factor	0.89	0,9	0.905	0,9
Maximum moment fraction	2,7	2	2,7	2.1
Trigger moment multiplicity	1.2	0.7	1.2	0.8
Starting current ratio	6.5	6.5	6.5	6.2
Moment of inertia, кg·м2	400	P0	400	370
Active resistance of the seed layers of the stator winding, Ohm	3,014	1,631	1,754	0,184

Simulation of the switching interference modelling under different operating modes of electrical equipment. For investigation of switching interference arising from high-voltage circuit breakers, a substation simulation model (figure 2) was developed using MatLab Simulink software based on the single-line supply scheme shown above (figure 1).

For easy viewing of the model as a whole, we have developed the following model blocks:

– substation unit (35/6) containing the vacuum circuit breakers of the substation;

– unit of high-voltage lines (Line), containing in itself overhead power lines, with parameters selected according to reference data;

– electrical equipment unit (ECG, ECT, ESH (Table 3)) containing models of electric motors excavators serving as a main load.

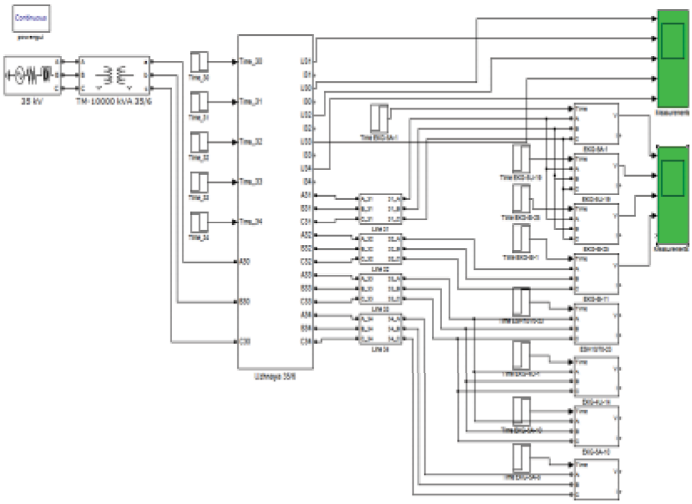

Figure 2 – Substation Simulation Model

The voltage to the feed transformer is supplied by a three-phase AC voltage source. Next, the substation unit whose switches are controlled by single step effects (Time), which are started at a certain time. The voltage is transmitted on power lines (Line), to the corresponding YaKNO (cell of the quarry outdoor installation). The control of the cell switches is also done with the help of single step effects (Time). The voltage is then applied to electrical equipment (EKG, ESH) whose main power consumers are asynchronous or synchronous motors [10; 11].

Results and Discussion

To evaluate the impact of switching processes on electrical equipment, consider the following modes: switching processes occurring when the feeder is turned on/ off, load switching (including simultaneous switching of different loads connected to one feeder), the accidental load-off and the accidental off of the loaded feeder. The switching of electric motors is considered as a load.

Figure 3 shows a stress oscillation showing the mutual effect of the feeders on each other when load is switched on.

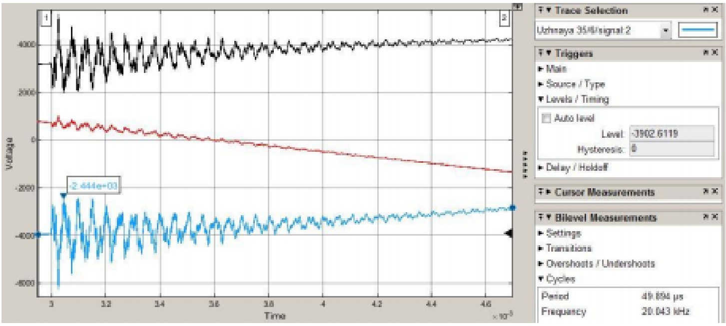

Figure 3 – Transition Process Occurring On The Feeder When Another Feeder Is Switched On Within A Substation

As shown by the presented oscillation and calculations, the change in signal amplitude at the feeder of the substation is about 1458 V and is represented as fading vibrations with a frequency of about 20 kHz. However, when zoomed in you can see the high frequency component (figure 4). The signal frequency on the feeder under load when another feeder is switched on is 595 kHz.

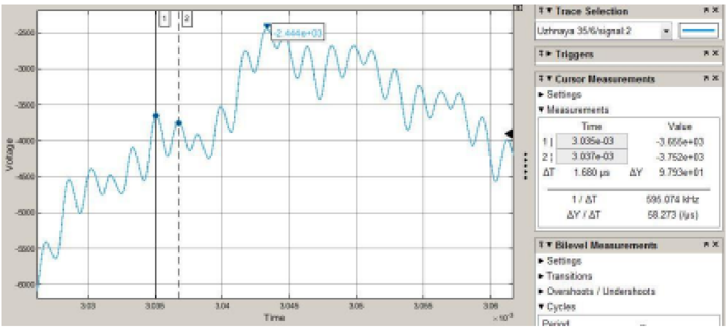

Figure 4 – Form of the signal for overvoltage

Figure 5 shows the oscillation of the load on the feeder when the load is connected.

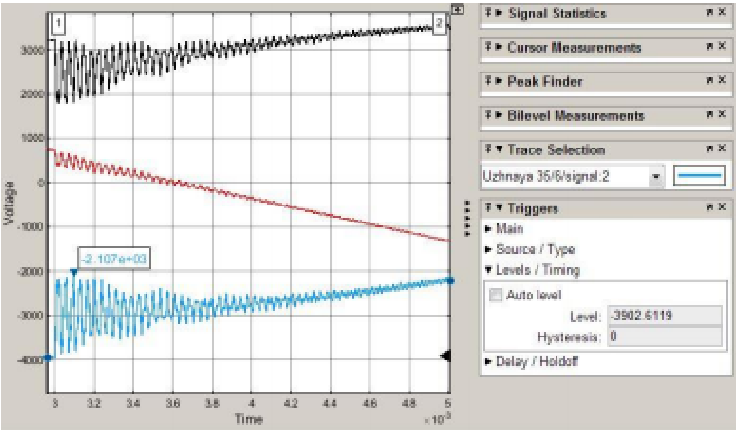

Figure 5 – Transition process occurring on the feeder at load connection

The presented oscillation shows a change in signal amplitude at the feeder of the substation, which is about 1795 V and is represented as fading oscillations with a frequency of about 20 kHz.

Figure 6 shows a stress oscillation showing the effect of the switching process on the feeder while simultaneously including different loads.

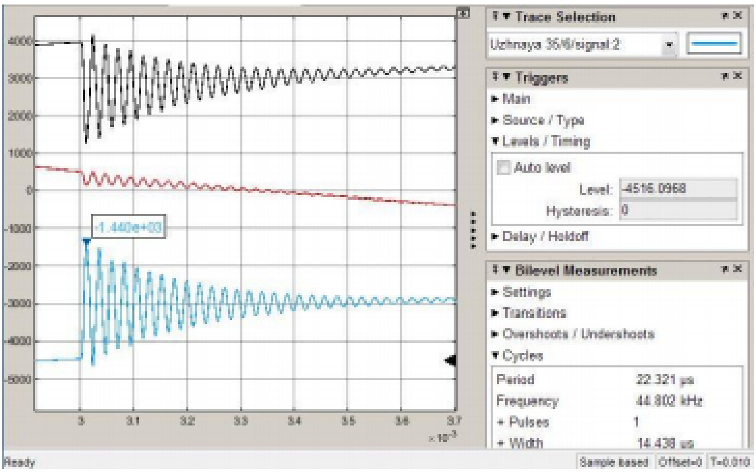

Figure 6 – Transition process occurring on the feeder when switching on different loads

As shown by the presented oscillation, the change of voltage on the feeder of the substation is the fading of initial amplitude oscillations around 3000 V with a frequency around 45 kHz.

Figure 7 shows the oscillation of voltages, in case of an emergency disconnection of one of the feeders of the substation under load.

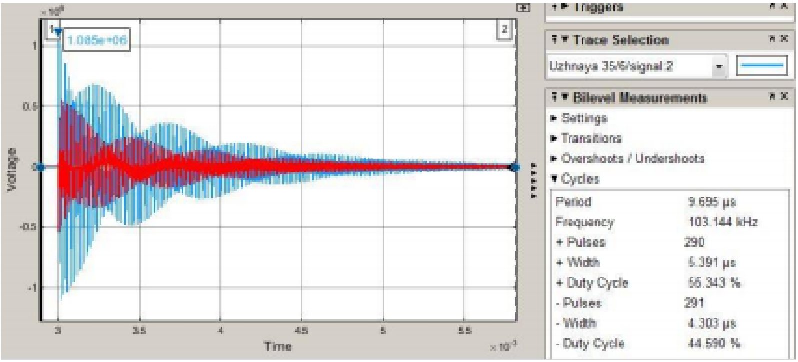

Figure 7 – Transition process occurring on the feeder at time of emergency shutdown

When the load is switched off, as in previous experiments, a switching overvoltage due to inductive currents occurs. Overvoltage is manifested as fading oscillations with a frequency of about 20 kHz. Based on the first law of switching current in the circuit can not be changed in a leapfrog, that is, the current before switching is equal to the current after switching [12; 13]. Also, according to the law of electromagnetic induction, the proportion of the network voltage that balances electromotive force self-induction is determined by the expression [14; 15]:

$$U = L\frac{di}{dt}, \tag{3}$$

where L – Inductance of the circuit, Hn;

di/dt – Current change rate.

It follows that even with small currents, dangerous overvoltages can occur due to very short transition time or current change rate (figure 8).

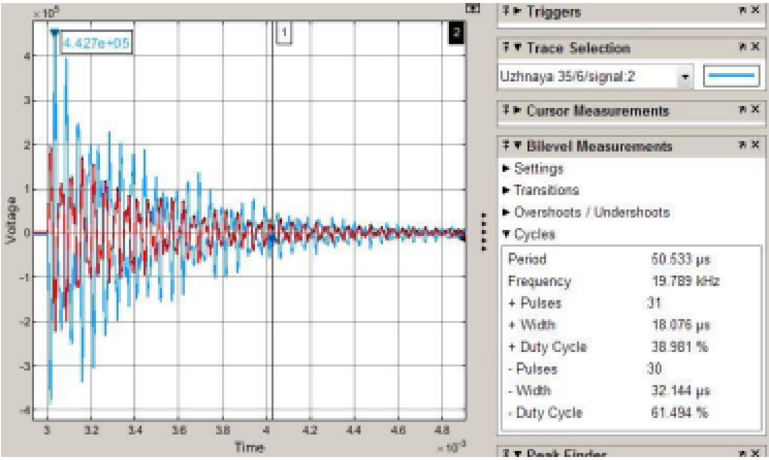

Figure 8 – Transition process occurring on the feeder at the moment of load disconnection

As shown in Figure 8, at the beginning of the transition process, voltage amplitude on one of the phases reaches a value of 442.7 kV, with a transition time of about 2 milliseconds. You can also see that different phases show different voltage amplitude. There is no phase shift on two phases due to load asymmetry and different time of switching off individual phases (this property is inherent in vacuum circuit breakers).

The main results of the modelling are presented in table 4.

Table 4 – Effect of switching processes on the state of the feeder

Mode of operation	Voltage amplitude, kV	Frequency. kHz
Feeder Switching On	1,458	595
Load Switching On	1,795	20
Two Types of Load Switching On	3,000	45
Feeder Emergency Shutdown	1,000	1200
Load Emergency Shutdown	442,7	20

Based on the data of table 4, a histogram of the influence of different switching modes on the state of the feeder is constructed, shown in figure 9. By the histogram it can be seen that the most negative effect is caused by the accidental disconnection of both the feeder and the load.

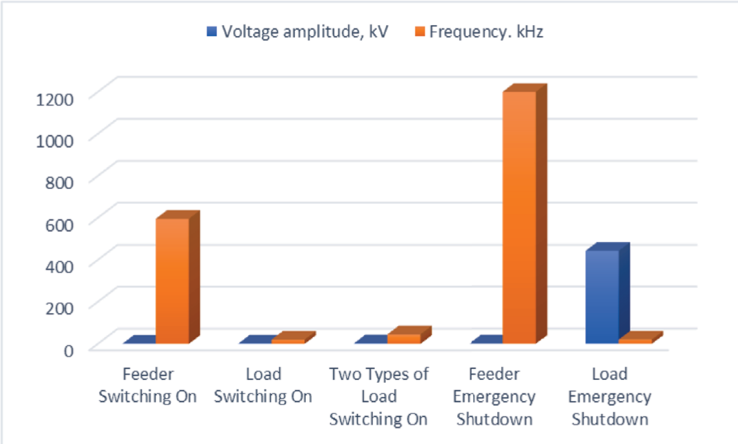

Figure 9 – Diagram of the effect of switching modes on the feeder

Conclusions

Based on the obtained data, the greatest influence on the processes occurring in electrical equipment is emergency shutdowns. Switching overvoltages, resulting from the occurrence of a transient process in the electrical network, have a detrimental effect on the operation of electrical equipment, both as a whole and on its various parts.

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Received 15.04.25.
Received in revised form 01.08.25.
Accepted for publication 05.09.25.

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15.04.25 ж. баспаға түсті.
01.08.25 ж. түзетулерімен түсті.
05.09.25 ж. басып шығаруға қабылданды.

ЖОҒАРЫ ВОЛЬТІ ЭЛЕКТР ЖЕЛІЛЕРІНДЕГІ АУЫСУ ПРОЦЕСТЕРІН ТАЛДАУ

Мақала әртүрлі коммутация режимдеріндегі жоғары вольтты электр желілеріндегі өтпелі процестерді талдауға арналған. Бұл процестің параметрлері әрбір объект үшін жеке болып табылады *және оның үстіне, тіпті әрбір нақты коммутация үшін. Коммутация режимдеріндегі өтпелі процестер қайталама желіде және тіпті электрмен жабдықтау жүйесінің ішкі тізбектерінде кедергілер мен асқын кернеу тудыратын электромагниттік өрістерді жасайды. Бұл электр жабдығының бұзылуына және зақымдалуына әкелуі мүмкін. Коммутация процестерінің электр жабдығының жұмысына әсерін бағалау үшін бір сызықты диаграмма қарастырылып, «Шұбаркөл Көмір» АҚ «Южная» қосалқы станциясының электрмен жабдықтау жүйесіне кіретін электр жабдықтарының сипаттамалары келтірілген. Фидерді қосу/өшіру, жүкті қосу, жүктемені авариялық ажырату және жүктеме кезінде фидерді авариялық ажырату кезінде болатын коммутация процестері қарастырылады. Қарастырылып отырған процестердің параметрлерін есептеу коммутация процестері негізінде жүргізілді. Көрсетілген өтпелі процестердің сипаттамаларын талдау үшін электрмен жабдықтау жүйесінің математикалық моделі жасалып, оны модельдеу жүргізілді. Фидердегі кернеудің уақытша диаграммалары келтірілген. Алынған мәліметтер негізінде электр жабдығының жұмысына тұтастай алғанда да, оның әртүрлі бөліктерінде де ең жағымсыз әсер ететін электр желілеріндегі коммутация режимдері анықталды.*

Кілтті сөздер: электрмен жабдықтау жүйесі, электр желілері, коммутация режимдері, өтпелі процестер, жоғары жиілікті асқын кернеулер, математикалық модель..

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Поступило в редакцию 15.04.25.
Поступило с исправлениями 01.08.25.
Принято в печать 05.09.25.

АНАЛИЗ ПЕРЕХОДНЫХ ПРОЦЕССОВ РЕЖИМОВ КОММУТАЦИИ В ВЫСОКОВОЛЬТНЫХ ЭЛЕКТРИЧЕСКИХ СЕТЯХ

Статья посвящена анализу переходных процессов в электрических сетях высокого напряжения, при различных коммутационных режимах. Параметры этого процесса индивидуальны для каждого объекта и, более того, даже для каждой конкретной коммутации. Переходные

процессы в коммутационных режимах создают электромагнитные поля, вызывающие наводки и перенапряжения во вторичной сети и даже во внутренних цепях системы электроснабжения. Это может привести к отказам в работе и повреждению электрооборудования. Для оценки влияния коммутационных процессов на работу электрооборудования рассмотрена однолинейная схема и приведены характеристики электрооборудования, входящего в систему электроснабжения подстанции «Южная» АО «Шубарколь комир». Рассмотрены коммутационные процессы, возникающие при включении/отключении фидера, включении нагрузки, аварийное отключение нагрузки, а также аварийное отключении фидера, находящегося под нагрузкой. Расчет параметров рассматриваемых процессов осуществлен на основании процессов коммутации. Для анализа характеристик указанных переходных процессов разработана математическая модель системы электроснабжения и проведено ее моделирование. Приведены временные диаграммы напряжения на фидере. На основании полученных данных, определены режимы коммутации в электрических сетях, оказывавшие наиболее негативное влияние на работу электрооборудования, как в целом, так и на различные ее части.

Ключевые слова: система электроснабжения, электрические сети, коммутационные режимы, переходные процессы, высокочастотные перенапряжения, математическая модель.

Теруге 09.09.2025 ж. жіберілді. Басуға 30.09.2025 ж. қол қойылды.
Электронды баспа
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Шартты баспа табағы 22,2. Таралымы 300 дана. Бағасы келісім бойынша.
Компьютерде беттеген: А. К. Мыржикова
Корректор: А. Р. Омарова, Д. А.Кожас
Тапсырыс № 4447

Сдано в набор 09.09.2025 г. Подписано в печать 30.09.2025 г.
Электронное издание
29.9 Mb RAM
Усл. печ. л. 22,2. Тираж 300 экз. Цена договорная.
Компьютерная верстка: А. К. Мыржикова
Корректор: А. Р. Омарова, Д. А. Кожас
Заказ № 4447

«Toraighyrov University» баспасынан басылып шығарылған
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140008, Павлодар қ., Ломов к., 64, 137 каб.

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