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THE MEASURES FOR SUPPRESSION APERIODIC CURRENT COMPONENT IN EXTRA-HIGH VOLTAGE LINES 750 kV

At present, the networks of extra-voltage received the SF_6 switches with the auto-compression principle of extinguishing the arc. The experience of operation showed the inability of these switches to perform commutation-type quick "on/off" for lines with a high degree of compensation of charging power due to the existence of a long durable aperiodic component in the current flowing in the switch. The results of investigation of the causes of accidents of SF_6 circuit breakers during commutation of compensated transmission lines of 750 kV are presented. In the article have been reported, that the presence of a large aperiodical component of current prevent the current from crossing zero for several milliseconds, resulting in serious damage to one pole of circuit breaker.

In the work the analysis of abnormal modes of extra high voltage transmission lines with different measures is performed. The article deals with the cycle of three-phase automatic re-inclusion on the 750 kV line with two groups of shunt reactors installed. Electromagnetic processes in compensated transmission lines depending on parameters of the line are investigated. The moments of a sharp change in parameters of transient processes during switching in extra-high voltage lines are revealed. Measures to limit the duration of the existence of the aperiodic component of the current are considered.

In the main power Ukrainian grids have replaced air switches for SF_6 gas switches. This upgrade was caused by the fact that modern electrical industry does not produce air switches and in the event of damage to repair and restore power would be impossible. Compared to SF_6 gas air circuit breakers have certain advantages, the main ones are speed and high breaking capacity, and the possibility of an extra device controlled switching. This upgrade was carried out from 2010 year to 2014.

Nevertheless new SF_6 breakers have a lot advantages, but some nuances were discovered in the process of using 750 kV on long overhead power lines with shunt reactors installed on them, due to which there were several accidents at the substations. Damage 750 kV circuit breakers, which in recent years have occurred on several foreign substations and also in Ukraine, served as an excuse for starting the necessary development of normative documents, establishing regulations and norms of operation.

Keywords: short circuit, three-phase automatic reclose, aperiodical current component, pre-insertion resistor, damping constant, total current of electromagnetic transient.

General characteristics of the problem.

In main power electrical networks of Ukraine, the replacement air circuit breakers on sulfur hexafluoride (SF_6) circuit breakers were implemented. This modernization is due to the fact that the modern electrotechnical industry does not manufacture air switches and, in case of accident, repairs these breakers and renewals electrical supply will be impossible. In comparison with air circuit breaker, the SF_6 has certain advantages, the main ones being the speed and high switching power, as well as the possibility of installing an additional control switching device and pre-insertion resistors. The switching point of an SF_6 circuit breaker is a probabilistic parameter and it is impossible to perform switches at the required moment without the use of controlled switching. Such a disadvantage during the operation led to emergency situations, including the appearance of aperiodic (AP) current component at electromagnetic transients [1-5].

So the presence of a significant aperiodic component in the current through the switch leads to the fact that the current passing through zero can happen only after a certain time (up to several sentiseconds) after switching on. For asymmetric faults in damaged phases, the damping rate of the aperiodic component is rather high, and the amplitudes of the aperiodic component and the periodic current of the steady-state regime are approximately equal. Therefore, in the damaged phases the problem of a long non-transient current through zero is absent. In undamaged phases, the amplitude of the aperiodic component is several times greater than the amplitude of the periodic current of the steady-state regime. Therefore, when reclosing of the line (planned or in the three phase auto-reclose cycle (TPAR)) in the case of an asymmetrical short circuit on this line, it can be difficult to disconnect its undamaged phases.

Therefore, in design practice to ensure reliable operation of overhead lines equipped with SF_6 circuit breakers with an intensive arc suppression system, it is necessary to perform calculations related to the analysis of the switching capacity of such at commutations.

The aim of article is to study the conditions for the appearance of unacceptable values and the duration of the AP current component of the transition process to avoid damage of the poles SF_6 circuit breakers. This goal implies developing measures to prevent possible emergency situations in extra-high voltage lines 750 kV.

Proposed approach to problem solving.

As design commutations on overhead lines, at which dangerous values of the aperiodic component of the current in the circuit breaker can occur, it is necessary to consider:

a) re-closing of the unsuccessful TPAR in the cycle with a short-circuit in the pause, which occurred again or taking into account the possible false operation of the relay protection;

b) re-closing in the cycle of an unsuccessful TPAR with non-stopping short-circuit on the power line;

c) re-closing in the cycle of a successful single phase auto-reclose (SPAR) with a short-circuit fault on the line, taking into account possible false protection relay operation.

A single-line scheme of extra-high voltage line is shown on (Fig.1). The structure of the circuit consists of the following elements: L_M – the inductance of the groups of the shunt reactors for the compensation of the mutual capacitance C_M, L_E - the inductance of the groups shunt reactors which compensate for the capacitance on the ground C_E, L_L - inductance phase of the line, L_{S1}, L_{S2} - inductance of the power systems, L_M - phase-to-phase inductance of the air line, R_M - active resistance of component shunt reactor, that compensate C_E, R_E - active resistance of component shunt reactor, that compensate C_M, R_{Eqv} - equivalent active resistance of systems and overhead line.

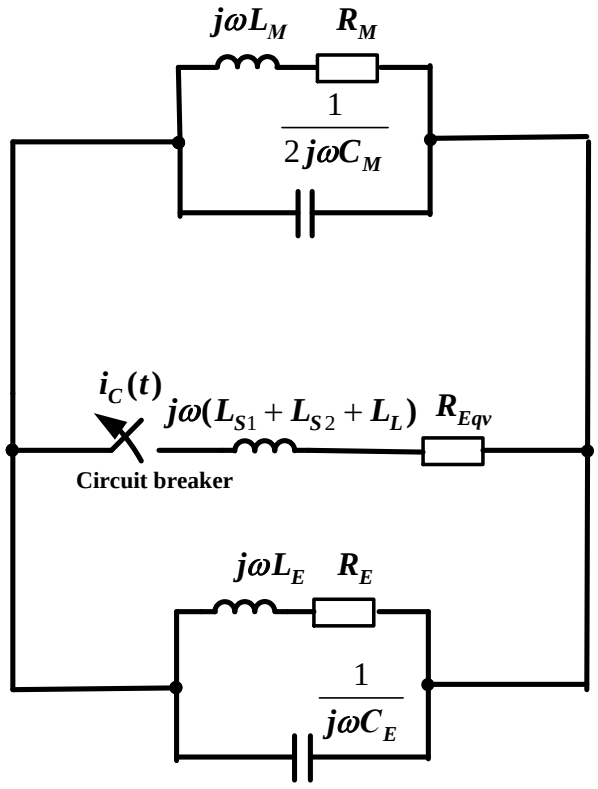


Figure 1 – The single-line scheme of extra-high voltage line

On (Fig.2) are shown the total current of electromagnetic transient at reclosing TPAR undamaged phase. We can see that the value of the AC of the current determines the moment of the transition of current through zero. Accordingly, the larger this component of the current of the transient process, the longer the arc will burn in the arc-camera, which will damage the switch's pole. Prolonged burning of the arc in the interconnecting gap of an SF_6 switch leads to burning of contacts, overheating of the arc gas and extreme pressure increase in the chamber. In this case there is an explosive breakdown of the switch's pole.

The total current value in the switch $i_C(t)$ is determined by the expression:

$$i_C(t) = i_{inv}(t) + i_{ap}(t) + i_{osc}(t)$$

where

$i_{inv}(t) = I_{inv}\cos(\omega t + \Psi)$ involuntary component voltage in circuit breaker; ω - angular velocity; I_{inv} and Ψ - amplitude and phase of involuntary value of current.

$i_{ap}(t) = I_{ap}e^{-t/\tau}$ aperiodical component in circuit breaker; I_{ap} - amplitude of aperiodical component; t - time of electromagnetic transient; τ - the damping constant of the AC.

$i_{osc}(t) = I_{tr}e^{-t/\tau_{osc}}\cos(\omega t + \Psi_{tr})$ decaying current transient component in circuit breaker. I_{tr} and Ψ_{tr} - amplitude and phase of decaing transient component; τ_{osc} - the damping constant of decaying current transient component.

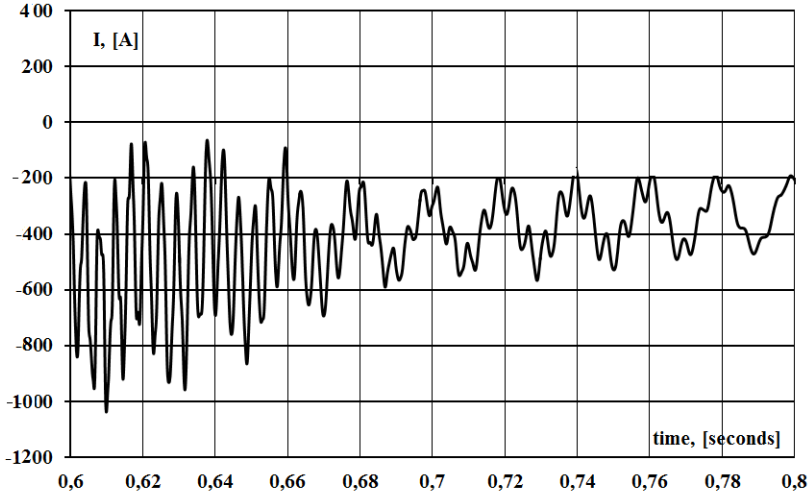


Figure 2 – The total current of electromagnetic transient

The time constant of the damping of the aperiodic component of the current can be determined from the ratio of the active resistance and the inductive current in the flow circuit. The damping constant of the AC of the current in the switch when the line is switched on with shunt reactors, is determined by the expression:

$$\tau = \frac{L_M + L_E + L_{S1} + L_{S2} + L_L}{R_{Eqv} + R_M + R_E} \quad (1)$$

In this work, the modes of operation of switch are considered in the fast "on/off" cycle of the pause a TPAR cases a-c) of extra high voltage line 750 kV, when at the moment of connection in the current of the switch there is mainly AP component whose value is more than several hundred amperes. Also it should be noticed, that active resistance of the line and equivalent active resistance of systems are neglected due to small value relative to inductance resistance of shunt reactors and other power equipment.

So, the initial value of the AP current component depends of values (1).On (Fig.3) are shown AP in phase A in cycle of TPAR. The permissible value of AP component for SF_6 circuit breakers 750 kV is 58% of total current at the transition process.

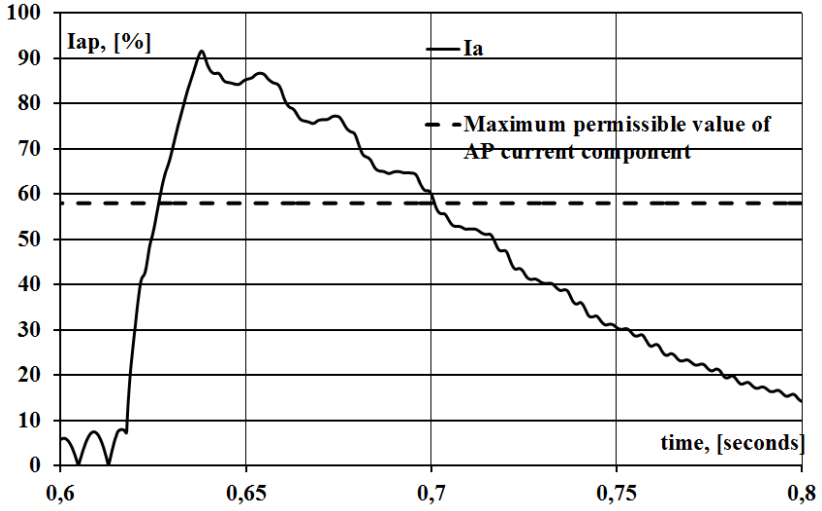


Figure 3 – Excess the current AP component the maximum permissible value

One way for suppression AP is growing active resistance. So, one of the solutions to mitigate the risk related to the magnitude and duration of AP component is pre-insertion resistors (PIR). There are basically two different PIR configurations: parallel and series. In parallel PIR configuration, the resistor switch is in series with the resistor bank, and both are in parallel with the circuit breaker interrupter, where the interrupter operation follows the PIR switch operation. In a series PIR configuration, the resistor switch is in series with the circuit breaker interrupter but in parallel with an overhead line.

The second traditional measure to reduce the magnitude and duration of AP component is energizing overhead line by controlling the closing moments of the circuit breaker poles [3]. The controlled commutation is used to eliminate undesirable effects of transients during scheduled switching of capacitor banks, shunt reactors, overhead lines and power transformers. The purpose of this device is to close and/or unlock the terminals of the switch at the required point of the sinewave of the current or voltage. It should be noted that ABB (Asea Brown Boveri Ltd.) has developed switching device SwitchSync F236 [3-5], which is intended for SF_6 switches with polar control. The moments of disconnection for phases control switch device are shown on figure 4.

All circuit breakers are equipped controlled switching device SwitchSync F236. The main advantages of the SwitchSync F236 in comparison with other devices are shown in Table 2. Among them there are application area and breaker operation. The SwitchSync F236 can be used for commutation of all power equipment unlike others.

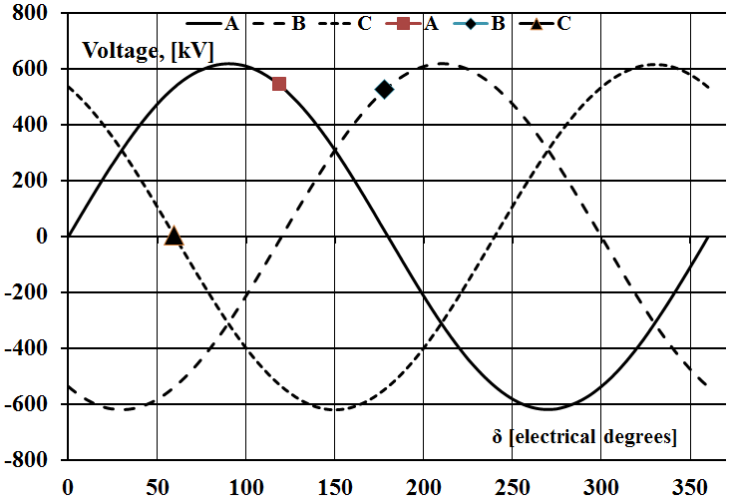
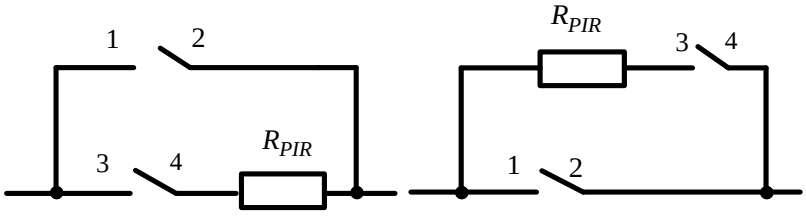


Figure 4 – Sine wave voltage phases A, B. C with designated switching points

The application of PIR can reduce (1) and, consequently reduce amplitude and duration AP in circuit breaker. When using the PIR for a certain period of time before closing the main contacts of the circuit breaker, auxiliary contacts are switched on, in series with the active contacts resistance (Fig. 5 a)) for series and (Fig. 5 b)) for parallel connection. Due to this, at the first moment of time after the contacts are closed, an intensive damping of the electromagnetic transient is carried out. Used in modern switches, the pre-activation time of the resistors varies within 8-12 ms. In the present work, the pre-connection time is assumed equal to 10 ms.

On (Fig. 5 a and b) is shown the connection diagram of the PIR to the switch. Main contacts 1, 2 of circuit breaker can be locked with springs after their unlocking. In all circuits, the main contacts 1 and 2 are disconnected before the auxiliary 3 and 4, and switched on later (unless, of course, contacts 1 and 2 remained disconnected).



a) Series connection OF PIR b) Parallel connection OF PIR

Figure 5 – Connection of pre-insertion resistor

When installing switches with PIR on the overhead line, the AP in the current arises both at the first stage of switching on- when arcing contacts are switched on, and in the second stage of switching on-when the main contacts shunt resistors. At the first stage of reclose AC due to PIR, included in the circuit, that fades faster than in the circuit without a resistor. At the second stage of the re-closing, an AC appears again, the initial value of which is much smaller than in the first stage (the amplitude of the aperiodic component in the second stage of the

inclusion may be zero, and maybe about 30% less than at the first switching stage, depending on the moment including the main contacts).

Therefore, not for all values of the resistance and not in all circuit-mode situations, the current transition through the zero value is guaranteed by the time when the breaker contacts begin to break. Solving the issue of reliability of arc extinction in the switch when installing on lines switches with PIR should be taken after the carefully exact selection of the value of the resistance and the time it is in the circuit and check the efficiency of the selected resistor for all possible commutations

It should be noted that nowadays don't exist studies in which compare the effectiveness of the PIR using of different designs in combination with a controlled switching device for suppressing the AP current component. The (Fig. 6) shows the results of comparing the efficiency of the application of two designs of PIR in combination with a control switching device. As can be seen from (Fig. 6), when using a PIR connected in 6series to the circuit breaker, it will be possible to suppress the AP component and, consequently, such a measure can be recommended for installation on extra-high voltage lines.

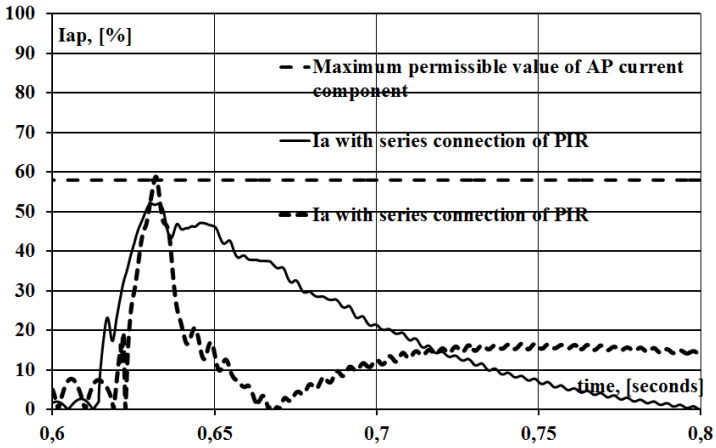


Figure 6 – Comparison the effectiveness of the PIR using of different designs in combination with a controlled switching device

The total current value in the switch $i_C(t)$ at using combined measure is shown on Fig. 7. As can be seen from the figure, the aperiodic component in the current of the intact phase is absent.

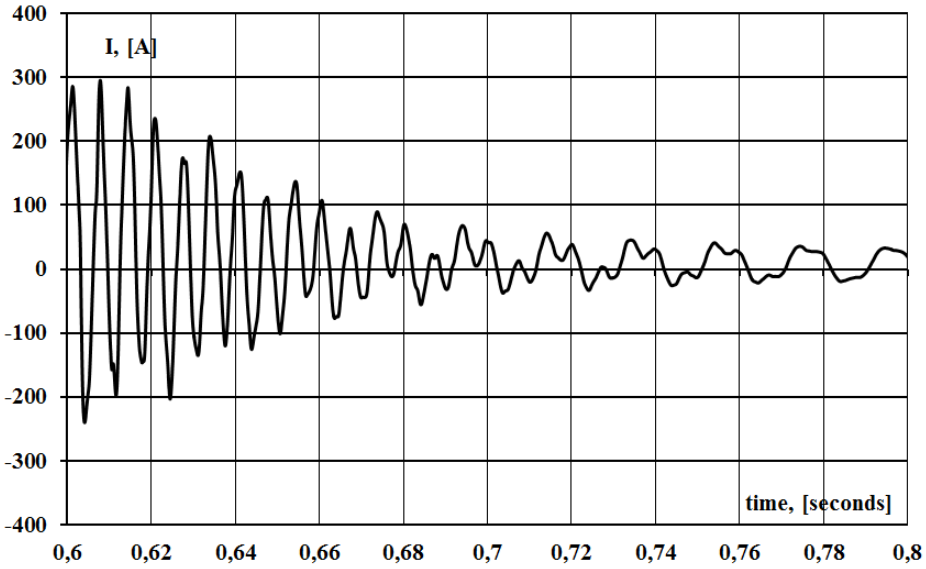


Figure 7 – The total current of electromagnetic transient at using PIR connected in series with with designated switching points

Conclusions.

Thus, although the replacement of the traditional air circuit breakers on SF_6 as rule, leads to an increase reliability of electrical supply, nevertheless, it can be concluded that it is necessary to perform before the modernization the preliminary analysis of transient processes arising from switching, in particular the value of the

current aperiodic component. The measure for preventing failures caused by the inability of the SF_6 circuit breaker poles to interrupt current that does not cross zero for a long period of time due to the presence of large aperiodic component is suggested.

Present work contains an analysis of the conditions for the onset of an aperiodic component of the current in circuit switching by SF_6 circuit-breakers with installed shunt reactors. When the charging power of the line is close to unity, during fast on / off cycles, the aperiodic component value cannot change instantaneously, which, together with the structural features of the gas-insulated circuit breakers, leads to emergencies.

The inclusion of a transmission line 750 kV in the absence of a zero crossing is a dangerous phenomenon that can occur when operating modern circuit breaker. The use of the PIR, together with the corresponding settings of the controlled switching device in the circuit breaker, is an effective measure for prevention the presence of the AC in the current. In addition, the use of the PIR should not introduce any undesirable consequences for the system. Since the value of the resistor depends on the moment of switching the switch it is impossible to determine for all possible cases of exploitation of transmission lines. But regardless of the moment of turning on, the use of such a resistor significantly reduces the aperiodic component of the current that occurs when the line is turned on.

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УДК 621.315.1

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ЗАХОДИ ОБМЕЖЕННЯ АПЕРІОДИЧНОЇ СКЛАДОВОЇ СТРУМУ ПРИ КОМУТАЦІЯХ ЛІНІЙ ЕЛЕКТРОПЕРЕДАЧІ НАДВИСОКОЇ НАПРУГИ 750 КВ

В даний час в мережах надвисокої напруги отримали розповсюдження елегазові вимикачі з автокомпресійним принципом гасіння дуги. Досвід експлуатації показав нездатність даних вимикачів виконувати комутацію по типу «включення-швидке відключення» для ліній з реакторами при високому ступені компенсації зарядної потужності внаслідок існування тривалої затухаючої аперіодичної складової в струмі, що протікає в вимикачі. Наведено результати дослідження причин аварій лінійних елегазових вимикачів при комутаціях компенсованих ліній електропередачі 750 кВ. Сформульовано рекомендації по запобіганню аварій через тривале невідключення полюсом елегазового вимикача струму, що не переходить через нуль внаслідок наявності в ньому великої аперіодичної складової. В роботі виконано аналіз анормальних режимів ліній електропередачі надвисокої напруги. Досліджені електромагнітні процеси в компенсованих лініях електропередачі в залежності від моментів комутації. Виявлені моменти різкої зміни параметрів перехідних процесів під час комутації в лініях надвисокої напруги. Розглянуто заходи обмеження існування тривалої аперіодичної складової струму.

Ключові слова: коротке замикання, трифазне автоматичне повторне включення, аперіодична складова струму, передвключений активний опір, постійна затухання, повний струм електромагнітного перехідного процесу.

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МЕРЫ ОГРАНИЧЕНИЯ АПЕРИОДИЧЕСКОЙ СОСТАВЛЯЮЩЕЙ ТОКА ПРИ КОМУТАЦИИ ЛИНИЙ ЭЛЕКТРОПЕРЕДАЧИ СВЕРХВЫСОКОГО НАПРЯЖЕНИЯ 750 кВ

В настоящее время в сетях сверхвысокого напряжения получили распространение элегазовые выключатели с автокомпресионным принципом гашения дуги. Опыт эксплуатации показал неспособность данных выключателей выполнять коммутацию по типу «включение-быстрое отключение» для линий с реакторами при высокой степени компенсации зарядной мощности вследствие существования длительной затухающей апериодической составляющей в токе, протекающем в выключатели. Приведены результаты исследования причин аварий линейных элегазовых выключателей при коммутации компенсированных линий электропередачи 750 кВ. Сформулированы рекомендации по предотвращению аварий из-за длительного неотключении полюсом элегазового выключателя тока, не переходит через ноль вследствие наличия в нем большой апериодической составляющей. В работе выполнен анализ ненормальных режимов линий электропередачи сверхвысокого напряжения. Исследованы электромагнитные процессы в компенсированных линиях электропередачи в зависимости от моментов коммутации. Выявлены моменты резкого изменения параметров переходных процессов при коммутации в линиях сверхвысокого напряжения. Рассмотрены меры ограничения существования длительной апериодической составляющей тока.

Ключевые слова: короткое замыкание, трехфазное автоматическое повторное включение, апериодическая составляющая тока, предвключенное активное сопротивление, постоянная затухания, полный ток электромагнитного переходного процесса.

Надійшла 17.04.2018
Received 17.04.2018