ABOUT TENSOR ANALYSIS APPLICATION TO THE STEADY-STATE STABILITY ESTIMATION TASKS OF POWER SYSTEMS WITH DISTRIBUTED GENERATION SOURCES

The aim of this paper is to analyze possibility of tensor methodology application to the stability estimation tasks. This study reviews components of mathematical model, which describes specifics of distributed generation sources. According to trend of share of distributed generation, some of them have an effect on stability. The moment of inertia is quite important value, it was caused by design and generator capacity. Therefore, lack of information is cause necessity of identification models for small capacity generators. Such model obtained by turbogenerator design procedure. Also, this study examines possibility of clarification identifying components of tensor model. References 6, figures 3.

Key words: tensor, stability, power system, distributed generation, inertia moment, turbogenerator, mathematical model.

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ABNORMAL RESONANCE OVERVOLTAGES IN MAIN POWER ELECTRICAL NETWORKS WITH SOURCES OF DISTORTIONS

V.V. Kuchanskyi
Institute of Electrodynamics of the National Academy of Sciences of Ukraine,
Peremohy, 56, Kyiv-57, 03057, Ukraine.
e-mail: kuchanskiyvladislav@gmail.com

The paper deals with the analysis and classification of durable internal overvoltages in the main power electrical network. The work considers the possibility of developing overvoltages in abnormal modes with sources characterized by distortions: asymmetric, nonsinusoidal and combined. Investigated those abnormal resonance overvoltages which occur in the extra high voltage transmission lines 750 kV with nonsinusoidal and asymmetric sources of distortion depend of many interconnected processes and on the values of a large number of parameters. Such an overvoltage classification is not accidental, since the source of their occurrence and distortion characteristics determine an abnormal regime. Described an example of such distortion, is incomplete mode of operation of the extra-high voltage transmission line, which causes the appearance of resonance circuits with distributed capacities of the line and the inductances of the shunt reactors. Detected that the second type of abnormal resonance overvoltages occur when extra high voltage transmission line switching on to no-loaded autotransformer. The theoretical principles of the emergence of harmonic resonant overvoltages with the inclusion of the superconducting voltage on the unloaded autotransformer are given. The key factor which led to abnormal nonsinusoidal mode is saturation magnetical core of noloaded autotransformer is analyzed. The main approaches to the study of abnormal resonance overvoltages are described and directions of the subsequent researches are designated. The obtained results of the research indicate the expediency of studying the conditions of occurrence and existence of abnormal resonance overvoltages. Bibl. 15, fig. 5, table.

Key words: extra-high voltage power lines, abnormal resonant overvoltages, asymmetric mode, single-phase automatic re-closer, nonsinusoidal mode, no-loaded mode of autotransformer.

General description of the problem. The first extra high voltage (EHV) transmission 750 kV was put into service in Ukraine in 1980th. Nowadays the transmission lines 750 kV are the main system-forming lines in the United Electric Grid of Ukraine and provide electricity from powerful power units and also the necessary exchange between separate power systems. In addition, their development and efficient operation are an important prerequisite for the integration of the United Energy System of Ukraine into the European Network of Transmission System Operators for Electricity (ENTSO-E) in the future [11-13,15]. That is why damage such lines or equipment, which ensures their connection to the grid, is a severe system failure, can cause the collapse of the combined system into separate parts in which there will be a shortage or excess of generating capacities and, accordingly, cause disconnection of consumers in scarce regions and blocking of power stations in excess regions. Of course, such an abnormal mode of the bulk network will be significantly different from the optimal [3,4,7-15]. Thus, the prevention of the failure of the EHV transmission lines - an important scientific and practical task in terms of providing reliability of electricity supply and the provision of satisfactory indicators of quality and efficiency of operation of main electrical networks.

In the paper, one of the main sources of nonsinusoidal distortion EHV lines is considered the nonlinearity of the volt-ampere characteristic when the unloaded autotransformer is switched on. Such a regime causes the conditions for the appearance of overvoltages of even harmonic. It should be noted that the process of occurrence of overvoltages on the even harmonic is not generally known and the value of the characteristics of this kind of overvoltages depends on many factors and factors of the abnormal regime.

It should be noted that nowadays are used for ensuring the required reliability of the transmission line EHV is carried out today by building additional lines of the line [14,15]. It is clear that this requires additional capital expenditures. But it is possible to increase the reliability of electricity supply by carrying out repair work under voltage, as well as by using incomplete phase modes of the overhead line. At the same time, the losses from lack of electricity are reduced, the stability of the power systems and the optimal flow distribution regime are maintained, the possibility of timely elimination of defects during the preventive repair of the lines and switches.

The aim of article is creating a classification of a particular type of internal overvoltages, which occur in the abnormal nonsinusoidal and nonsymmetrical modes of extra-high voltage power lines.

Classification of abnormal resonance overvoltages (ARO) in main electrical networks. One of the main reasons for failure of equipment in the main electrical network are overvoltages, that is, an increase in the value of the operating voltage above the maximum permissible value, in accordance with the technical regulations [1,2]. This is due to the fact that a relatively small isolation reserve is provided for the constituent elements of main electrical networks due to the high cost for this voltage class.

Durable internal overvoltages arise due to resonance at coincidence of the values of the parameters of the circle elements [3-12,14]. This type of overvoltage occurs due to the properties of the network can be eliminated by changing the relationship between the parameters of the network and its mode [11-13]. Unlike switching overvoltages that last for hundreds of seconds, abnormal occur unpredictably, and can last for a long time above seconds, until the action of protection against voltage increase, voltage regulators or personnel interference does not affect the change of circuit or mode.

Abnormal resonance overvoltages are not taken into account when selecting isolation or parameters of traditional measures for suppression overvoltages, since these protective measures are designed to limit switching overvoltages, rather than to extinguish a long process. Therefore, the probability of the occurrence and development of systemic accidents at ARO is quite significant. For this reason, the work is devoted to the study of internal durable ARO. The abnormal overvoltages in main electrical networks can exist on the basic harmonic during incomplete modes of overhead lines and shunting reactors and overvoltage with automatic self-excitation of higher harmonic components [4,5,12,13]. But it should be noted that under the real conditions of existing power systems one or another type of abnormal overvoltage may not exist at all or the amplitudes of these overvoltages are so small that their research does not constitute a practical interest.

The use of the term of abnormal overvoltage is not accidental [11,14], because when working out literary sources [3-15] and studies of experimental results [11-13,15], it was concluded that this kind of overvoltage is fundamentally different from traditional ones. The difference and the special characteristics of overvoltages is that they are caused by an abnormal regime, primarily due to the effect of the source of distortion [3-6,11-13,15]. On (Fig. 1), the division of this type of internal overvoltage into two main categories, depending on the resonance at a certain frequency, is shown on the basic harmonic and higher harmonic components. Such a division is driven by the fact that the modes of bulk electric networks caused by the switching of unloaded power autotransformers in saturation mode and network modes in which the source of distortion does not contain nonlinear elements. That is, was done another division by the linearity sources of distortion - nonlinear or linear and the resonance in which circle - linear or nonlinear.

The following types of ARO are considered in the paper according to the developed classification given on (Fig. 1). The first type of ARO is caused by the source of higher harmonic components. The most typical case for main electrical networks is the connection of the transmission lines EHV to the unloaded group of autotransformers. An increase in voltage occurs on higher harmonic components: overvoltages arise at even harmonics in a linear circle to which the source of distortion is connected (a magnetic shunt of autotransformer operating in unloaded mode). The second type of abnormal overvoltages occurs in the asymmetric mode. A typical situation is the disconnection of the phase of the EHV transmission line with the possible disconnection of one of the groups of shunt reactors. Overvoltages can occur with a combination of asymmetric and nonsinusoidal modes. In the work of this type includes the switching of transmission lines EHV to an incomplete autotransformer group.

Durable ARO are one of the most difficult to analyze types of internal overvoltages [3-6,10-12,14]. The research problem is due to the fact that there are many elements in the main electrical network, the processes in which it is difficult to accurately and adequately simulate. These elements, in particular, include inductors with steel cores and conductors of EHV with corona discharge, as well as secondary arc of alternating current during single phase automatic re-closer, since these processes are non-linear [13-15]. That is, the volt-ampere elements are described by non-linear equations. It is precisely because of the presence of such elements that it is impossible to obtain accurate results about the existence of overvoltage in one mode or another.

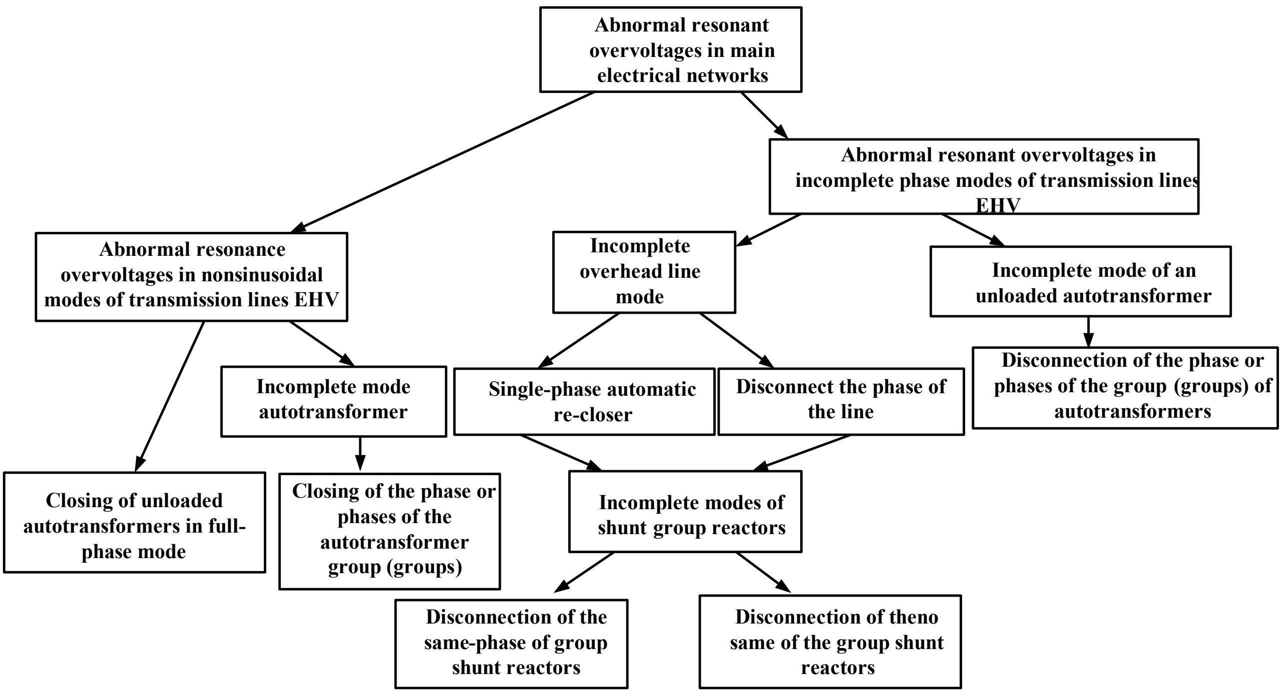

Fig. 1

It should be noted, that permissible short-term voltage rises in the frequency of 50 Hz in service conditions should not exceed the relative values relative to the highest operating voltage divided in [1] for electrical equipment of alternating current for voltage 750 kV are indicated in the table 1. The value of normal operation voltage for electrical equipment is 643 kilovolt.

Permissible in the operation of short-time voltage rises in frequency of 50 Hz

Type of electrical equipment	Permissible increase of voltage value with duration			
	20 minutes	20 seconds	1 seconds	0,1 seconds
Power transformers (autotransformers)	1,1	1,25	1,67	1,76
Shunt reactors, apparatuses, capacitive voltage transformers, current transformers, coupling capacitors, bus supports	1,1	1,3	1,88	1,98
Arresters	1,15	1,35	1,4	-

Abnormal resonance overvoltages at nonsinusoidal distortions. As is well known, the nonsinusoidal voltage and current causes the aging of electrical machines, transformers and cables due to heating, as well as the occurrence and last of ionization processes in isolation, especially at high frequencies of an alternating electric field. For electrical machines, transformers and cables, the most significant is the thermal aging of insulation, and the effect of higher harmonic components caused by significant distortions of the shape of the curves of voltage and current at the excitation of the autotransformer, on the ionization processes in the insulation, enhance the aging effect. Thus ARO due to saturation of the autotransformer magnetic shunt have a double negative effect on the isolation of the equipment, for example, from ARO in asymmetrical modes.

Abnormalities of nonsinusoidal modes are characterized by the appearance of higher harmonics of current and voltage [5-8,13-15]. The distortion of the shape of the curve of the voltage and currents in this case is due to the nonlinearity of the magnetization shunts. In recent years, great attention in the study of modes of electric networks has been given to fluctuations in circles with steel. The reason for this is the appearance of complex phenomena on the transmission lines of the EHV, such as resonances at frequencies different from the main [5,6,13-15].

The resonance of the phenomenon in circuit with steel, which are united under the general name of ferroresonance processes, have been known for almost a hundred years, but only with the development of modern theory of nonlinear oscillations using the latest methods implemented on modern computers, these phenomena have received a sufficiently complete theoretical justification The theory of nonlinear oscillations revealed a number of features that fundamentally distinguish nonlinear oscillatory systems from linear ones. Such features are a leap-like change in the nature of oscillations when changing system parameters (trigger effect), the appearance of oscillations and resonance at frequencies different from the frequency of the electromotive power of the circle - subharmonic, ultragarmonic, and fractional resonances [5,6]. Among the methods of research, the most widely used modernized methods of small parameter, complex amplitudes and methods of analysis of the theory of stability of periodic oscillations and other classical methods of analysis. And in order to investigate in detail the behavior of the autoparametric behavior of elements of a nonlinear circle, it is necessary to apply the theory of nonlinear dynamics and deterministic chaos. In general, these studies constitute a separate problem of modern electrical engineering. In this paper we consider resonance phenomena in a linear electric circuit, and nonlinear inductance is only a source of distortion, not an integral part of a circle.

In this paper, the attention is paid to the occurrence of overvoltages on even harmonic components caused by the connection of unloaded autotransformers in complete phase mode and incomplete mode of operation (Fig. 2). In literary sources [5,6,13-15], the causes of overvoltages are considered either briefly and confusingly, or engineering methods for calculating self-excitation regions of harmonics of even multiplicity are presented, from which the physics of the process of occurrence of overvoltages is unclear. This means that the mechanism and physical nature of the phenomenon of abnormal overvoltage is not clearly described, since there is no information about the full development of the process from the beginning to the end, and the source of the even harmonics is considered only to change the inductance of the magnet of the autotransformer. In general, the presence of a significant amount of contradictory information does not allow analyzing in detail the phenomena that occur when the low-loaded or unloaded autotransformer is turned on.

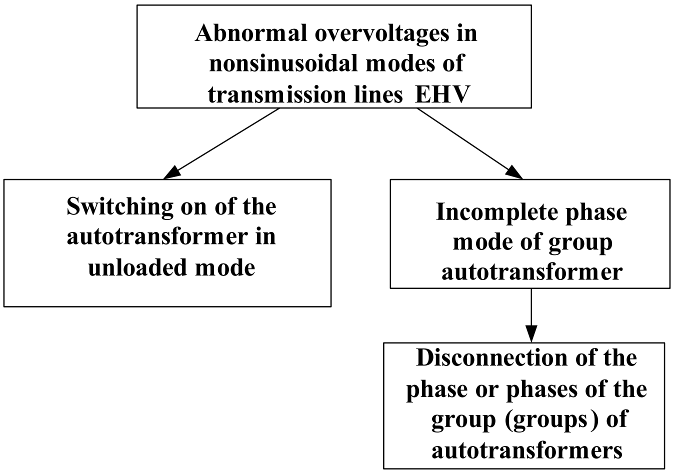

Fig. 2

As already noted above, in order to solve the problem of harmonic overvoltages, it is necessary first of all to adequately reproduce the nonlinear nature of the magnetization shunt. In practice, it is difficult to do so, when solving this problem, it is necessary to make certain compromises. Implementing the exact method is problematic, not only because of the great accounting difficulties. The accuracy of the source data and its completeness is no less important, since it is obvious that the accuracy of the analysis can not exceed the accuracy of the output data. In addition, for the research it is necessary to have data from the manufacturer of autotransformers on the curve of magnetization.

The physical nature of the emergence of pair harmonics on the transmission line of the EHV with an attached autotransformer is due to the periodic change in the inductance of the magnetic shunt when passing through it alternating current. This inductance varies with a double frequency in relation to the applied voltage. Provided that the proper frequency of the equivalent circuit is equal to 100 Hz, there may be an overvoltage on the second harmonic. For this it is necessary that the input impedance was capacitive and was approximately equal to the average value of the inductive resistance of the magnetic shunt of the autotransformer at this frequency.

The maximum overvoltage depends on many parameters, the most important of which are: the operating voltage of the transmission lines EHV; transmission line length; number of groups of shunt reactors and degree of compensation of charge capacity; the ratio of the reactive resistance of the straight line and the zero sequence of the line; the value of the preconnected active resistance to the switch and the duration of their connection; scatter at the moments of switching on individual poles.

It should be noted that although the occurrence of this type of overvoltage outlined quite long ago, but nowadays, the process of their origin and development is insufficient. It remained unclear even the reason for their appearance. Some authors believed that the source of distortion is a constant component of the flow coupling autotransformer, other scientists determined the reason for changing the parameters of the magnet shunt [10, 13-15].

Basically, harmonic overvoltages (Fig. 3) arise during the first stages of the restoration of electricity supply,

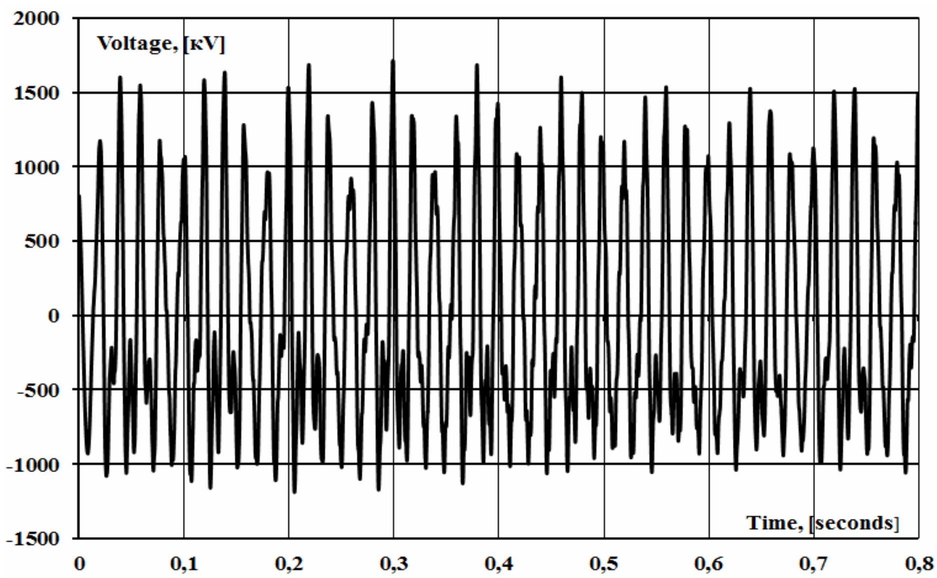

Fig. 3

when the whole system is weakly damaged. When switcing on the autotransformer, operating in idle mode, the magnetic shunt is saturated. This, in turn, results in the melting of magnetizing currents with a substantial content of the harmonics, including the second harmonic component, and thus the current source generating harmonic components appears to be connected to the transmission lines of the EHV. As a rule, the values of harmonic resonance overvoltages have a large multiplicity and are durable, so they can activate relay protection devices which led to disconnection of EHV line with all negative consequenses [3-15] or damage equipment isolation.

Thus, when the initial excitation of the autotransformer occurs, its magnetic core enters the state of saturation, in which magnetizing currents are generated causing an increase in the voltage of the harmonic components. To investigate the possibility of abnormal overvoltage it is expedient to use mathematical modeling [11-15]. However, studies conducted using the toolkit does not take into account the correlation between the factors affecting the characteristics of overvoltages. In addition, the use of simulation only makes it impossible to fully reproduce the probabilistic nature of overvoltage due to the lack of development of appropriate procedures in mathematical maintenance. In the work to solve these problems in order to study ARO, it is proposed to use an artificial neural network and software complexes, the creation of which is necessary for the preparation of the functioning of the artificial neural network. It is precisely this combination of modern analysis tools that has provided an opportunity to ensure that the results of research with the necessary accuracy in the current state of the complexity of the electric networks of the EHV are obtained.

Accordance with requirements which are shown on table 1 we can conclude that, ARO in nonsinusoidal source of distortion are very dangerous for insulation of power equipment. In such abnormal mode occur significant and slow decaying ARO on even harmonics. Analysis of Figure 3 shows that overvoltages under the influence of higher even harmonic attain large values, develop rapidly and durable exist. A distinctive feature of this type of overvoltage is the rapid self-excitation of pair harmonics and a significant distortion of the shape of the voltage sinusoid.

In this mode, it is clearly traced the influence of the fields of higher harmonics on the ionization processes in isolation only aggravate due to the fact that the forms of the curves of voltage and current are significantly spoiled when excited autotransformer. Thus, the overvoltages arising from the saturation of the magnetic shunt of the autotransformer have a double effect on the isolation of the equipment. On the one hand, there is abnormal increase of voltage and on the other hand, there is an action of the nonsinusoidality.

Abnormal resonance overvoltages in the presence of asymmetric distortions. Incomplete modes can occur spontaneously as emergency or planned modes especially as a measure that increases the reliability of the electrical system (Fig. 4). The latter category includes, for example, incomplete modes, which arise when applied on the lines of phase repair, as well as the disconnection of one or two phases of the line to melt the ice on overhead lines.

In main electrical networks, the flow of failures is almost entirely determined by accidents on the overhead line. In this case, as already noted, in lines with a voltage of 750 kV the overwhelming part of the trips is caused by single-phase short circuits. Unstable single-phase short circuits occurring on the line are accompanied by minimal disturbances on adjacent systems if they are eliminated in a cycle of single phase automatic re-closer [4,7,11,12,15]. In this case, the damaged phase of the line is disconnected from the two sides by the switches, and then, after a certain time, the so-called powerless pause, is automatically re-closed. During an uninterrupted pause, the open arc of the alternating current in the overlap should be extinguished, namely, the overlapping surface must be deionized and almost completely restore its electrical strength. When exploiting EHV lines to 60-70% of single-phase short circuits are unstable, that is, they can be eliminated in a short-term cycle without interruption, with the subsequent restoration of the normal circuit.

Relevance of the use of long incomplete phase modes can be explained by a number of reasons. First, today in main power electrical system of Ukraine there is a rapid growth of electricity consumption with the simultaneous lagging of the construction of new transmission lines EHV. Secondly, there is a disproportion in the distribution of generating capacities on the territory of the country, as a result of which large volumes of power are transmitted over long distances. Thirdly, there appeared a large number of relatively low-power consumers who receive electrical energy by one-circuit EHV in the hundreds of kilometers long. It should be noted that with a large length of the line, the probability of both scheduled and sudden disconnections increases [4,11,12,15].

In itself, the disconnection of phases or phases of groups of shunt reactors in the normal mode of operation will not lead to an abnormal increase in voltage [4,11,12]. The latter arise, as shown in the work, when the phase of the group of shunting reactors is switched off, which creates conditions for their resonance increase at the main frequency (Fig. 4).

It should be noted the possibility of occurrence of incomplete phase modes of overvoltage is not actually associated with the presence of asymmetry, but with nonsinusoidal distortions in the transmission lines EHV, which were considered in the preceding paragraph. Thus the inclusion of an unloaded autotransformer at a certain length of the line leads to the appearance of ARO on pair harmonics [5-7,13-15]. With incomplete phase activation of the autotransformer, the same processes take place as in the full-phase, but only at those phases that are activated. Specificity lies in the fact that the switching of the line occurs not on the three phases of the group of single-phase autotransformers, but on two. Such a mode in the bulk network is permissible from the point of view of asymmetry, because the value of the current in the reverse and zero sequence does not exceed the maximum permissible values. This is due to the fact that two or even three groups of single-phase autotransformers work on the terminal substation, so the disconnection of one phase does not lead to a significant deterioration of the regime.

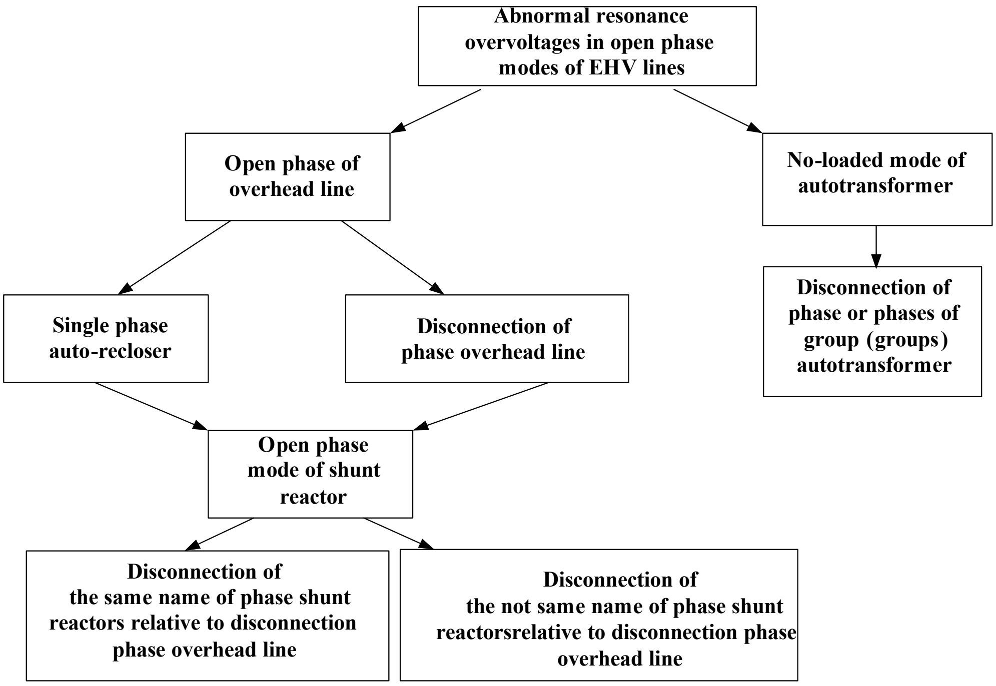

Fig. 4

When applying a single phase automatic re-closer, the switch-off phase of the transmission line leads to the of a transient process, after which the attenuation of a voltage in this phase is set at a level determined by the degree of compensation of distributed airline capacities by a group of shunt reactors [3,4,11,12,15]. This level may exceed the maximum permissible operating voltage. As the oscillograms of real processes in the operating networks have shown, often the transient process of changing the voltage in the phase after its disconnection has the form of bits with the filling of the sinusoid of the industrial frequency [11,12]. The values of the forced voltage depend on the parameters of a specific transmission line (length and design phase of the line, power supply system, availability, number and location of groups of shunting reactors). Single phase automatic re-closer may be accompanied by abnormal resonance overvoltages (Fig. 5). This type of

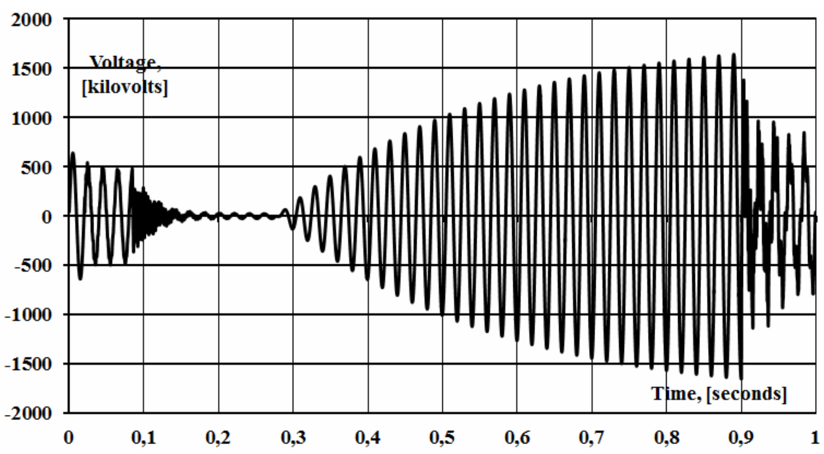

Fig. 5

overvoltage occurs due to the occurrence of resonant circuits with distributed line capacities and inductances of groups of shunt reactors. That is, at the actual lengths of the overhead line, the resonance properties of the line with the reactors appear not in the normal symmetric mode of operation, but in the asymmetric mode.

In this case, ARO are characteristic of a mode in which the deviation of the circuit and the parameters of the elements from the phase symmetry play an essential role. As an example of such distortion, the incomplete mode of operation of the extra-high voltage transmission line is considered, which causes the appearance of resonance circuits with distributed capacities of the line and the inductances of the shunt reactors. The statement of the problem differs from the traditional design, when the criterion for choosing the inductors of the shunt reactors is the overvoltages of the normal mode, but although the causes of overvoltages in the incomplete mode are well defined, their appearance and values depend on many factors of the abnormal regime. Therefore, when designing and operating the transmission lines EHV requires careful examination of the possibility of existence of necessary and sufficient conditions of the ARO in real electric networks.

Overvoltages arise due to the formation of a corresponding circle with distributed capacities of the line and inductance of the shunt reactors in the incomplete mode of operation of the transmission lines [4-6,8-12]. For a more complete and clear understanding of the cause of the ARO in incomplete mode. As is known from the literature [4-6,8-12], shunt reactors are used to increase the line throughput, reactive power regulation and voltage in the normal operating conditions of the EHV transmission lines. The compensating reactor is used specially to compensate for the currents of secondary arc recharge at single phase auto re-closer. With a four-circuit connection circuit, the inductance of the shunt reactors compensates not only the capacitance between the ground and the phase of the line, but also the mutual capacity of overhead line.

So, we can see on Fig.5 that on the switched off phase of the overhead line, the process of abnormal resonance overvoltages arises, the character of which is determined by the natural oscillation frequencies of the resonant circuit with linear elements. It should be noted that an abnormal resonance voltage rise can be considered as a single-frequency process with a natural frequency, which depends on the degree of compensation of the line's charging power [12]. In this process, the overvoltages significantly exceed the maximum permissible values from Table 1 by several times, both in terms of both values and duration. The overvoltages in the asymmetrical mode appear slowly without distorting the shape of the voltage curve, but with significant values in the case of the current resonance condition, in contrast to overvoltages on the higher harmonic components.

Conclusions. 1. The classification of abnormal overvoltages for nonsinusoidal and asymmetric sources of distortion of main electrical networks has been created. It is established that the particular type of overvoltage differs from the traditional internal ones: the duration and values that significantly exceed the maximum permissible values given in the international and domestic standards for the correlation of 750 kV power equipment. Each of the sources of distortion are considered a non-sinusoidal, asymmetric or combined phenomenon characterized by a resonant circuit in which at the fulfillment of the necessary and sufficient conditions there is a currents resonance, which will lead to abnormal resonant voltage increase.

2. It is established that one of the characteristic and widespread examples of an asymmetric source of distortion is the single-phase automatic re-closer, in which abnormal resonant

overvoltages occur in a linear resonant circle. In such an abnormal incomplete phase mode, abnormal resonance overvoltages are characterized by duration of approximately 0.4 seconds and values exceeding the maximum permissible 2-3 times, the shape of the voltage curve is sinusoidal. A typical example of a non-sinusoidal abnormal regime is the connection of a EHV line on an unloaded autotransformer, in which an abnormal resonant voltage rise occurs due to oscillatory processes in a nonlinear resonant circuit. With such a nonsinusoidal source of distortion, the curve of the sinusoid voltage is distorted by the pair harmonics. The duration of the existence of abnormal resonant overvoltages in this mode reaches a second or even a minute, and values exceed the maximum permissible by 1.5 times.

3. An abnormal resonant overvoltage in accordance with the developed classification due to sources of distortion and significant characteristics of existence constitute a real danger to the reliable functioning of the combined power system of Ukraine and is a significant obstacle to the implementation of the conditions for integration with the European energy association system operators of ENTSO-E.

4. Subsequent studies will be aimed at the development of mathematical models and methods for analyzing ARO in asymmetric and nonsinusoidal modes of extra high voltage transmission lines. With the help of the developed ensemble of the means, the analysis of the factors that most influence the conditions of the occurrence of this class of internal overvoltage will be performed. According to the analysis, effective measures will be developed to prevent ARO. It is also considered appropriate to carried out a study of the effects of ARO with values that exceeding the maximum permissible values several times for such traditional measures as arrests, varistors and nonlinear overvoltages limiters.

5. Thus, as the importance of the problem itself, as well as the peculiarities of its emergence, the course and the presence of a whole series of unspecified interrelated factors were among the main circumstances that determined the scientific and practical significance of research aimed at increasing the energy efficiency of the power system from under conditions of abnormal resonance overvoltage.

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В.В. Кучанський, канд. техн. наук
Інститут електродинаміки НАН України,
пр. Перемоги, 56, Київ-57, 03057, Україна

АНОРМАЛЬНІ РЕЗОНАНСНІ ПЕРЕНАПРУГИ В МАГІСТРАЛЬНИХ ЕЛЕКТРИЧНИХ МЕРЕЖАХ З ДЖЕРЕЛАМИ СПОТВОРЕНЬ

Наведено нові наукові результати досліджень, спрямованих на аналіз анормальних режимів у магістральних електричних мережах для обмеження анормальних резонансних перенапруг. Досліджено умови появи резонансних процесів у разі несиметричних та несинусоїдальних джерел спотворення. Наведено теоретичні засади виникнення анормальних резонансних перенапруг при ввімкненні лінії надвисокої напруги на ненавантажений автотрансформатор та під час здійснення паузи однофазного автоматичного повторного ввімкнення. Одним із засобів підвищення надійності й ефективності електроспоживання є застосування неповнофазних режимів ліній електропередачі надвисокої напруги 750 кВ. Реалізація однофазного автоматичного повторного ввімкнення в більшості випадків супроводжується проблемою резонансних перенапруг, які можуть стати причиною повного відмикання лінії. Ці перенапруги з'являються як наслідок резонансних явищ у колі з індуктивностями шунтуючих реакторів і розподілених ємностей ліній. Розглянуто анормальні резонансні перенапруги, що виникають внаслідок підмикання автотрансформатора до електричної мережі. Встановлено, що загальні причини появи анормальних резонансних перенапруг за наявності джерела несинусоїдних спотворень полягають у певному збігові значень параметрів елементів, які відповідають умовам резонансу струмів. Визначено, що внаслідок того, що резонанс відбувається у лінійному колі з нелінійним збудженням, яким є магнітний шунт автотрансформатора, підвищення напруги може виникнути неочікувано і значною мірою залежить від початкових умов. Описано основні підходи до вивчення анормальних перенапруг резонансу та намічено напрямки подальших досліджень. Бібл. 15, рис. 5, таблиця.

Ключові слова: лінії електропередачі надвисокої напруги, анормальні резонансні перенапруги,несиметричний режим, однофазне автоматичне повторне ввімкнення, несинусоїдальний режим, холостий хід автотрансформатора.

В.В. Кучанский, канд. техн. наук
Институт электродинамики НАН Украины,
пр. Победы, 56, Киев-57, 03057, Украина

АНОРМАЛЬНЫЕ РЕЗОНАНСНЫЕ ПЕРЕНАПРЯЖЕНИЯ В МАГИСТРАЛЬНЫХ ЭЛЕКТРИЧЕСКИХ СЕТЯХ С ИСТОЧНИКАМИ ИСКАЖЕНИЙ

Рассмотрены анормальные резонансные перенапряжения, возникающие вследствие подключения автотрансформатора к электрической сети. Приведены новые научные результаты исследований, направленных на разработку классификации отдельного типа внутренних перенапряжений в магистральных электрических сетях по источникам искажений. Исследованы условия появления резонансных процессов и рассмотрены методы по их исследованию в современных электрических сетях. При неполнофазном режиме работы в электрических сетях могут возникать при плановых и аварийных отключениях в случае применения средств противоаварийной автоматики, например, однофазное автоматическое повторное включение. Реализация цикла однофазного автоматического повторного включения в большинстве случаев сопровождается проблемой резонансных перенапряжений, которые могут стать причиной полного отключения линии. Рассмотрены анормальные резонансные перенапряжения, возникающие вследствие подключения автотрансформатора к электрической сети. Исследовано, что общие причины появления анормальных резонансных перенапряжений, при наличии источника несинусоидальных искажений, заключаются в определенном стечении значений параметров элементов, соответствующих условиям резонанса токов. Определено, что в силу того, что резонанс происходит в линейной цепи с нелинейным возбуждением, которым является магнитный шунт автотрансформатора, повышение напряжения может возникнуть неожиданно и в большой степени зависит от начальных условий. Показано, что перенапряжения данного типа являются следствием действия несинусоидальности на параметры режима и могут протекать сравнительно длительное время. Установлено, что этой характеристикой они отличаются от перенапряжений, которые возникают в результате коммутаций при нормальной схеме электрической сети без источников искажений. Описаны основные подходы к изучению ненормальных перенапряжений резонанса и намечены направления дальнейших исследований. Библ. 15, рис. 5, таблица.

Ключевые слова: линии электропередачи сверхвысокого напряжения, анормальные резонансные перенапряжения, несимметричный режим, однофазное автоматическое повторное включение, несинусоидальный режим, холостой ход автотрансформатора.

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