УДК 621.315.1

THE PREVENTION MEASURE OF RESONANCE OVERVOLTAGES IN OPEN-PHASE MODE IN EXTRA HIGH VOLTAGE TRANSMISSION LINES

V.V. Kuchanskyy
Institute of Electrodynamics of the National Academy of Sciences of Ukraine,
Peremohy, 56, Kyiv, 03057, Ukraine
e-mail: skilldur@ukr.net

The long time resonance overvoltages arising through resonance of current, due to coincidence of the range parameters in open-phase modes. This type of overvoltages caused by the network properties and can be removed by changing the ratio between its network parameters. Unlike switching overvoltages that last few hundredths of second, resonance overvoltages not only arise unexpectedly, but there may exist a long time until the effect of increasing voltage protection, voltage regulators or intervention personnel do not perform schema changes or regime. Resonance overvoltages not taken into account when selecting insulation or surge protection devices as these protective measures calculated to limit switching overvoltages, not to extinguish a long process. Therefore, the probability of accidents and development system failure in the resonance overvoltages is considerable. Thus the improvement of analytical methods and developing appropriate simulation and mathematical models to study the resonance overvoltages in their occurrence, development and existence, the solution of which is devoted this work, there is an actual scientific and practical problem. The paper also discussed the application of the developed methods and models to identify factors in electrical networks that have the greatest impact on the appearance and values of overvoltages, also selecting means of preventing and limiting this kind of overvoltages. References 7, figures 5, tables 2.
Key words: open phase mode, resonance overvoltages, shunt reactor, simulation model.

General description of the problem. Main power overhead lines of rated voltage 330-750 kV are bulk lines in supergrid electrical system and provide power delivery from powerful nuclear power unit and also provide necessary power exchange between power utility systems. In addition, their development and efficient operation is an important prerequisite for future integration of the United Energy System of Ukraine into the European grid. It is because damaged lines or equipment that ensures their interconnection to power system is a heavy accident, it can cause disintegration of the bulk supergrid system into separate parts, in which will be a deficit or oversupply of generating capacity, and therefore it will cause shutdown of consumers in scarce regions and stop blocks in power surplus regions. Of course, such an abnormal mode backbone of electric grid will be different from optimal [2-4, 5-7]. Thus preventing the failure of extra high voltage power lines is an important scientific and practical problem in terms of reliability of electricity supply and ensuring satisfactory quality and efficiency of the main power electrical systems.

One of the main causes of equipment failure in the main electrical network is overvoltages. Overvoltages are the values of voltage which according to the technical requirements exceed the maximum value of normal operating voltage. The reason is that the relatively small insulation reserve provides for the equipment of the electricity grid because of its high cost for a given voltage. Generally, cost of power systems insulation is a significant factor in capital investment.

In spite of overvoltages which appear in normal operation condition of extra high voltage lines, resonance overvoltages characterized by modes in which parameters deviation from the design parameters are essential. In paper under such source of distortion accept short time open phase mode of overhead line and group of shunt reactors. In such abnormal condition appears resonant circuit with distributed capacity of overhead line and lumped inductance of shunt reactors group. Although causes of occurrence these kinds of overvoltages are well-known, their appearance and characteristics depend on many factors. The shunt reactors group, which are installed on extra high transmission lines for compensation charge capacity are one the most fundamental factors. In other words in abnormal conditions it possible various combinations of open phase modes of shunt reactors group that is why in the design and exploitation extra high transmission lines is necessary scrupulous and inclusive checking necessary and sufficient conditions of abnormal overvoltages appearance in extra high voltage networks.

The approach of solving problem. The voltage arising from the formation of an appropriate range of line distributed capacitances with inductance group of shunt reactor at open-phase mode of power lines are shown [1, 2]. For a more complete and accurate understanding of the causes of resonance overvoltages at open-phase mode schematic diagram and equivalent circuit of shunt reactors set in neutral compensation reactor is depicted on Fig. 1. The neutral compensation reactor is used specifically for suppression of second arc current in pause of single phase auto-reclosure [4, 6, 7]. In four-rayed connection of group Fig. 1 inductance compensate not only the capacitance between the ground but also the interfacial capacitance between phases of the line

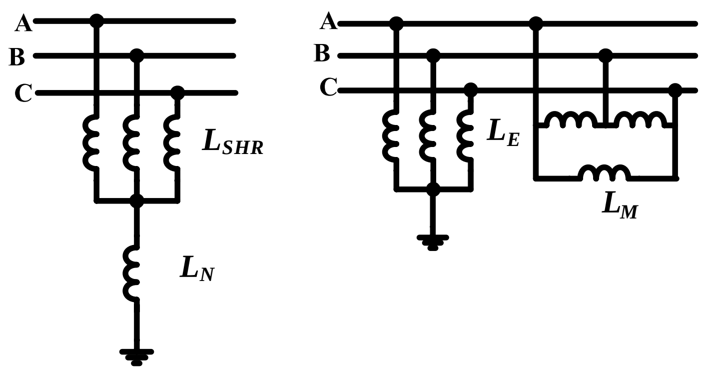

Fig. 1

For better understanding of the action of four-rayed connection of group shunt reactor expressions below are constituents L_M – interphase inductance between phases and L_E – inductance between phase and earth:

$$L_M = \frac{L_P}{L_N}\left(L_P + 3L_N\right), \qquad L_E = L_P + 3L_N, \tag{1}$$

L_N – inductance of neutral compensator reactor; L_P – inductance of shunt reactor.

On equivalent circuit of group shunt reactor Fig. 2 it is shown that installation in neutral compensation reactor is equivalent to appearance of two inductance circuit – L_E that is inductance resistance of shunt reactor for compensation of capacitance between phase and earth and L_M – inductance for compensation of mutual capacitance of the line. When value of equivalent inductance L_M is tuned to full compensation of mutual capacitance current resonance occurs Fig. 2:

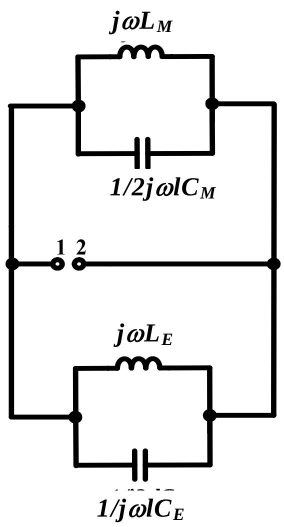

Fig. 2

In circuit Fig. 2 existence of resonance of currents is possible. The current resonance is characterized by higher values of overvoltages in the outer circle.

The model was developed to study the processes at single phase auto-reclose in the environment MATLAB/Simulink [1,3] which are illustrated on Fig. 3. This model includes additional models of group shunt reactors and arc of alternating current to investigate resonance overvoltages as against [3, 4]. There were made calculations to find the effective measure to prevent this kind of overvoltages. The three phase power system is simulated by voltage sources with fixed voltage and inductance. The overhead line is simulated by two parts, which are given complex matrices with distributed elements or values on the forward and reverse sequence.

The resonance overvoltages were obtained for real transmission line Khmelnytsky Nuclear Power Plant (Ukraine) – Rzeszow (Poland) with value of parameters which are shown in Tables 1 and 2. In Table 2 are shown parameters of equivalent systems.

In accordance with resonance circuit in Fig. 2, it is also possible to use a compensation reactor as an overvoltage prevention measure [6]. Compensating reactors as a measure for suppression resonance processes have found wide application in networks of extra high voltage [1–3, 6, 7]. Below the description of the resistance choice of the compensation reactor for detuning the resonance circuit with subsequent modeling of open-phase mode of the line is shown.

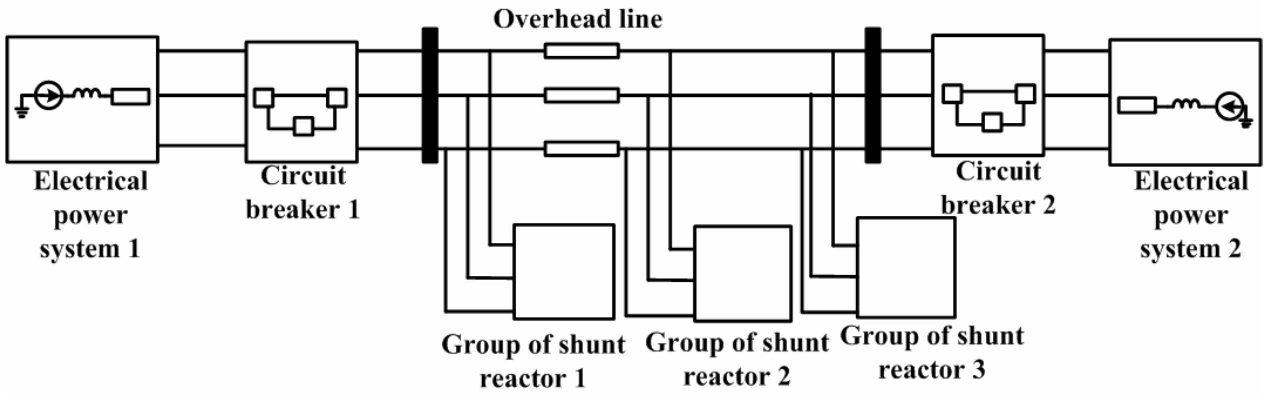

Fig. 3

Table 1

L_0, Henry^{-4}	C_0, Farad^{-9}	L_1, Henry^{-3}	C_1, Farad^{-8}	Numbers of groups shunt reactors, n	Length, (km)
2.44	9.89	8.9	1.305	3	396

Table 2

Parameters of systems				
Voltage U, kilovolts		Impedance of system Z, Ohms		Inductance of shunt reactor L_P, Henry
1	2	1	2	5.981
768	745	5.68+65.85i	8.78+70.85	

The degree of compensation of charging power of line:

$$k = Q_{SHR} / Q^{CP}, \tag{2}$$

Q_{SHR} – reactive power of groups shunt reactors; Q^{CP} – charging power of overhead line.

Ratio between capacitances:

$$m = (C_1 - C_0) / C_1, \tag{3}$$

C_1 – capacity of direct sequence transmission line; C_0 – capacity of zero sequence transmission line.

The equivalent resistance of parallel connected SHR:

$$x_1 = \frac{U_n^2}{Q_{SHR}}, \tag{4}$$

U_n – rated voltage of transmission line.

Then resistance of compensated reactor is defined by full compensation interfacial capacitance of transmission line Fig.1:

$$x_{cr} = \frac{x_1}{3} \cdot m / (k - m). \tag{5}$$

Modeling compensating reactor and SHR Fig. 4 were implanted be series inductively-active branches in which active resistance are set for a more detailed simulation as in reactors active power losses occur.

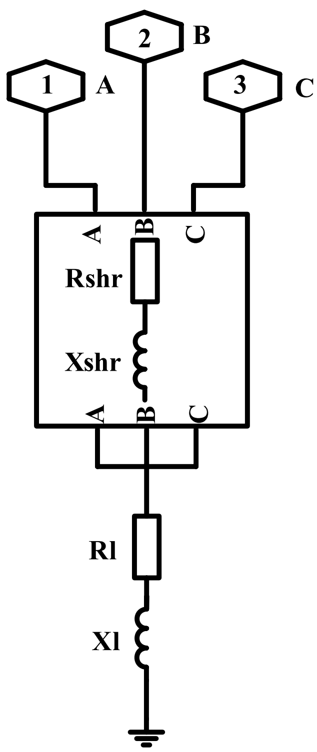

Fig. 4

Efficiency of compensatory reactor application are shown on

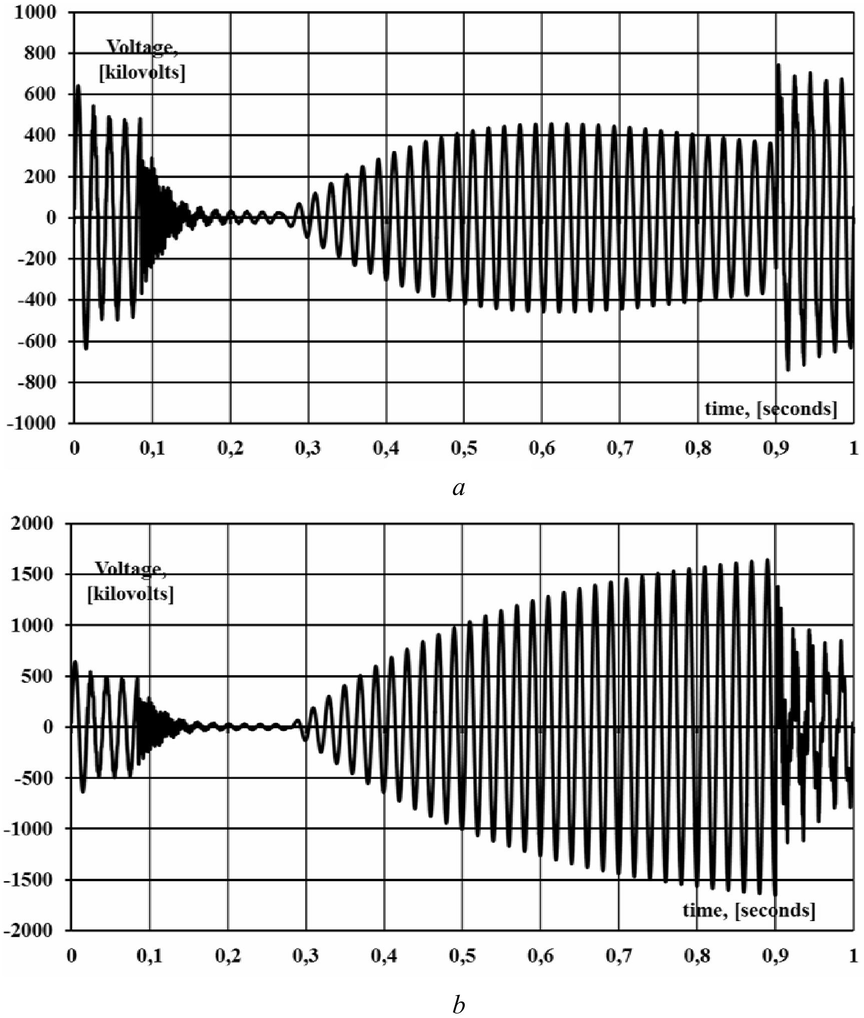

Fig. 5

Fig. 5. On Fig. 5 *a* are shown Mitigation of resonance overvoltages in case of application of compensating reactor with resistance obtained when installing three groups of shunt reactors and on Fig. 5 *b* are shown resonance overvoltages in case without instalation compensating reactors.

As can be seen from Fig. 5 *a* the compensation reactor with the calculated resistance according to the data in Tables 1 and 2 suppresses the resonance overvoltages. The problem of the operation of compensating reactors is that the resistance value is calculated (5) in the case of the maximum possible number of installed groups of shunt reactors.

Conclusions. On paper is shown what parameters of extra high voltage transmission line create resonance circuit and accordance with it a measure for prevention resonance overvoltage has been developed. This compensator reactor with correctly chosen inductance reactance can frustrate resonance circuit and suppress resonance overvoltages.

A simulation model of the power transmission line has been developed to simulate electromagnetic transient processes in the incomplete phase mode. In response to the developed model, a effectiveness of compensator reactor for prevention resonance overvoltages has been made. For calculation, the data of a real high-voltage power transmission line of a rated voltage of 750 kV was taken for testing how developed method for suppression resonance overvoltages real influence on this kind of overvoltages.

1. *Kuznetsov V.G., Tugay Yu.I., Kuchanskyy V.V.* Investigation of transposition EHV transmission lines on abnormal overvoltages // Tekhnichna elektrodynamika. – 2013. – № 6. – P. 53–56.
2. *Kuchanskyy V.* Criteria of resonance overvoltages occurrence in abnormal conditions of extra high voltage transmission lines // Naukovi pratsi Vinnyts'koho natsional'noho tekhnichnoho universytetu. – 2016. – № 6. – P. 51–54.
3. *Tugay Yu.* The resonance overvoltages in EHV network // Proceedings of IEEE Sponsored Conference EPQU'09 – International Conference on Electrical Power Quality and Utilisation, Poland, Lodz, September 15-17, 2009. – P. 14–18.
4. *Martinich T., Nagpal M., Manuel S.* Damaging Open-Phase Overvoltage Disturbance on a Shunt-Compensated 500-kV Line // IEEE Transactions on Power Delivery. – Volume: 30, Issue: 1, Feb. 2015. – P. 412–419.
5. *Atmuri S., Thallam R., Gerlach D., Lundquist T., Selin D.* Neutral reactors on shunt compensated EHV lines, Proceedings of IEEE Power Engineering Society // International Conference of Transmission and Distribution, USA, Chicago IL, 1994. – P. 15–21.

6. *Zevallos M. E., Tavares M. C.* Single-Phase Auto-Reclosure Studies: Influence of Transversal Parameters of a Transmission System on the Secondary Arc Current Reduction V. // Proceedings of International Conference on power systems Transients, Kyoto, Japan, June 14-17, 2011. – P. 1–6.
7. *Naumkin I., Balabin M., Lavrushenko N., Naumkin R.* Simulation of the 500 kV SF6 circuit breaker cutoff process during the unsuccessful three-phase autoreclosing // Proceedings of International Conference on power systems Transients, Kyoto, Japan, June 14-17, 2011. – P. 6–11.

УДК 621.315.1
В.В. Кучанський, канд. техн. наук
Інститут електродинаміки НАН України,
пр. Перемоги, 56, м. Київ, 03057, Україна

Заходи запобігання резонасним перенапругам у неповнофазних режимах ліній електропередач надвисокої напруги

Тривалі внутрішні резонасні перенапруги виникають через резонанс струму, внаслідок збігу значень параметрів елементів кола. Цей вид перенапруг, зумовлений властивостями мережі, може бути усунений шляхом зміни співвідношення між параметрами мережі та її режиму. На відміну від комутаційних перенапруг, які тривають соті долі секунди, резонансні не тільки виникають непередбачено, а й можуть існувати досить тривалий час, доки дія захисту від підвищення напруги, регуляторів напруги чи втручання персоналу не виконають зміни схеми або режиму. Резонансні перенапруги не беруться до уваги при виборі ізоляції чи параметрів нелінійних обмежувачів, оскільки ці захисні заходи розраховуються для обмеження комутаційних перенапруг, а не для гасіння тривалого процесу. Тому вірогідність виникнення та розвитку системних аварій при резонансних перенапругах досить значна. Таким чином, вдосконалення методів аналізу та розробки відповідних моделей для вивчення умов виникнення, розвитку й існування резонансних перенапруг є актуальною науково-практичною задачею. Розглянуто застосування розроблених методів і моделей для виявлення факторів в електричних мережах, які мають найбільший вплив на величини перенапруг, а також вибору засобів попередження і обмеження такого роду перенапруг. Бібл. 7, рис. 5, табл. 2.
Ключові слова: неповнофазний режим, резонансні перенапруги, шунтувальний реактор, імітаційна модель.

УДК 621.315.1
В.В. Кучанский, канд. техн. наук
Институт электродинамики НАН Украины,
пр. Победы, 56, Киев, 03057, Украина

Мероприятия по предотвращению резонансных перенапряжений в неполнофазных режимах линий электропередач сверхвысокого напряжения

Длительные внутренние резонансныя перенапряжения возникают из-за резонанса тока, вследствие совпадения велиин параметров элементов цепи. Этот вид перенапряжений, обусловленный свойствами режима работы электритческой сети, может быть устранен путем изменения соотношения между параметрами сети и ее режима. В отличие от коммутационных перенапряжений, которые длятся сотые доли секунды, резонансные не только возникают непредсказуемо, но и могут существовать достаточно длительное время, пока действие защиты от повышения напряжения или вмешательство персонала не выполнят изменения схемы или режима. Резонансные перенапряжения не принимаются во внимание при выборе изоляции или параметров нелинейных ограничителей перенапряжений, поскольку эти защитные меры рассчитываются для ограничения коммутационных перенапряжений, а не для подавления длительного процесса. Поэтому вероятность возникновения и развития системных аварий при резонансных перенапряжениях весьма велика. Таким образом, совершенствование методов анализа и разработки соответствующих моделей для изучения условий возникновения, развития и существования резонансных перенапряжений является актуальной научно-практической задачей. В работе также рассматривается применение разработанных методов и моделей для выявления факторов в электрических сетях, имеющих наибольшее влияние на величины перенапряжений, а также выбора средств предупреждения и ограничения такого рода перенапряжений. Библ. 7, рис. 5, табл. 2.
Ключевые слова: неполнофазный режим, резонансные перенапряжения, шунтирующий реактор, имитационная модель.

Надійшла 07.06.2017
Received 07.06.2017