Saulius GUDŽIUS[1], Alfonas MORKVĖNAS[1], Dovilė BRAZIONIENĖ[1], Vidmantas TIČKA[1], Ugne ILIOITIENE[1], Audrius JONAITIS[1], Virginijus VASYLIUS[1], Kęstutis JASIŪNAS[2]

Kaunas University of Technology (1), Litgrid, AB (2)

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Experimental Investigation of Switching Overvoltages of Shunt Reactor

Abstract. *This paper analyses different situations of transient processes determining the level of maximum overvoltage in case of a shunt reactor switching. The level of overvoltages is determined by a performed experiment, and a transient process of an overvoltage during switching and zero sequence current are recorded. The digital model of the diagram is made in order to simulate the transient processes of overvoltages in the connection diagram of the shunt reactor.*

Streszczenie. *Przeanalizowano różne sytuacje stanów nieustalonych, prowadzących do powstania najwyższych poziomów przepięć podczas przełączania dławika kompensacyjnego. Poziom przepięć określono eksperymentalnie, rejestrując procesy przejściowe napięcia podczas przełączania i prądu sekwencji zerowej. Utworzono cyfrowy model do celów symulacji przepięć powstających wskutek procesów przejściowych podczas przełączania dławika kompensacyjnego. (**Badanie eksperymentalne przepięć podczas przełączania dławika kompensacyjnego**)*

Keywords: overvoltages, arresters, substation, shunt reactor.
Słowa kluczowe: przepięcia, ograniczniki, podstacja, dławik kompensacyjny.

Introduction

Shunt reactors are used for the regulation of power flow and voltage in the electrical energy system. A reactor connected to a 10 kV winding of an autotransformer can be switched on and off several times during the day due to variable loads. Overvoltages during switchings are inevitable. The diagram of a reactor operates with an isolated neutral. In most cases there are no devices limiting the level of overvoltages in the connection diagram of the reactor. Faults have happened and the reasons of it were overvoltage. Reactor is connected to a star, and a 10 kV winding of an autotransformer has got a delta connection. The contacts of a circuit breaker during switchings may switch in a nonsynchronous manner and, during the switching off, the extinction of an electric arc takes place when the current changes its polarity in the phase. During switching on and off, asymmetrical operation takes place in the diagram. Due to the asymmetry during switching, the overvoltages of rather high amplitudes are recorded [1]. There were a few cases when the elements of the diagram had been damaged by overvoltages. In such a diagram of an isolated neutral at earthfault overvoltages during switchings may be of a rather high amplitude [2, 3, 4, 5]. Overvoltages of an exceptionally high level may arise in such situations when performing a reclosing of a disconnected part of diagram it has got a residual charge. Nonsynchronous closing of phases of circuit breaker and possible residual charge has to be taken into account when determining the maximum level of overvoltages, since, during the switching off of the inductive currents in the electrical network, the voltage is close to the maximum. Besides overvoltages of high amplitude may arise in the circuit due to a premature arc breaking in the circuit breaker when switching off the reactor by a vacuum circuit breaker [5]. These overvoltages may influence the insulation of equipment.

The electricity grid of the studied reactor (see Fig. 1) is in the territory of a transformer substation. Investigations to determine the maximum level of overvoltages and to evaluate the required characteristics of protection means from overvoltages are carried out in this paper.

Characteristics of Connection Diagram of Shunt Reactor

Switching overvoltages have been simulated in the diagram of connection of reactor under investigation (Fig. 2) determining the maximum level of overvoltages

Computational diagram (Fig. 3) has been composed in the connection circuit of the reactor for the simulation of the switching overvoltages. The reactor is connected by a cable.

Fig 1. Shunt reactor

The application of digital methods for simulation of overvoltages [1, 2, 6, 7, 8, 9] is the most convenient way for analysis of the transient processes in complicated lines.

The digital model of busbars and cables is composed of the lumped parameters in nodes and distributed parameters of lines [1, 2, 6, 8]. The element of the circuit of distributed parameters is composed of the prime elements of resistance, inductance, capacitance, and conductivity. A sudden voltage change from one point of line to adjacent is transmitted by the electromagnetic wave travelling in dielectric next to a line wire. The travelling speed of electromagnetic waves is equal to the speed of light. Electromagnetic wave in cables is travelling almost two times slower.

High frequency overvoltages are possible during the switching off of the inductive current of the reactor with a good circuit breaker due to the extinction of arc before the current changes its polarity. Residual magnetic energy and voltage in the capacitive element of reactor may cause

overvoltages of a high amplitude, which may be harmful to the equipment connected in the circuit of reactor.

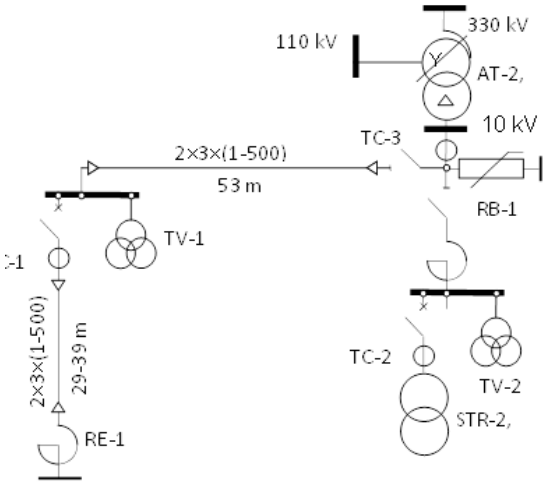

Fig. 2. Connection diagram of reactor

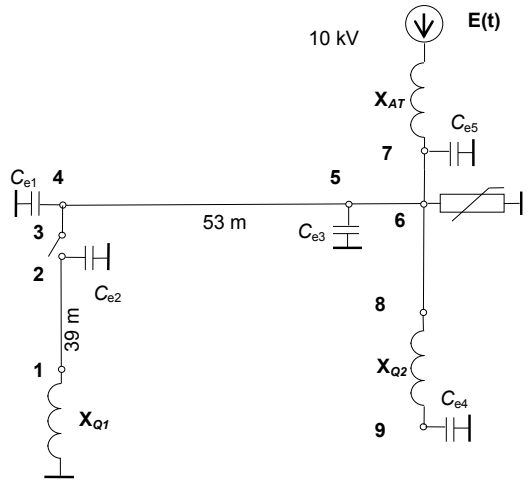

Fig. 3. Computational diagram of reactor connection

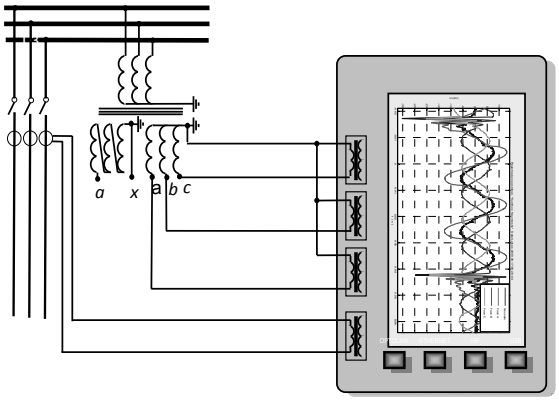

Fig 4. Scheme of connection of recorder

Investigation of Overvoltages Caused by Reactor Circuit Switching

Reactor is switched on and off several times a day when regulation of the reactive power flow of the system takes place. Inductive current of reactor is switched off by a vacuum circuit breaker.

The recorder of transient processes has been connected to the clamps (Fig. 4) of secondary circuits of phase voltages of voltage transformer TV-1 (Fig. 2) when analysing the level of overvoltages during the switching on and off of the reactor and current has been recorded during switchings by connecting one channel of the recorder to one phase current transformer TC-1.

The remaining three channels registered overvoltages by connecting sensors to a, b, and c phases (see Fig. 4)

A complete transient process of switching on of the reactor is provided in Fig. 5 and the beginning of it is illustrated in Fig. 6.

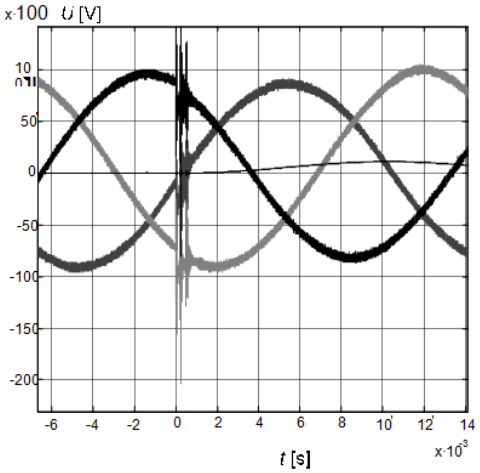

Fig. 5. Transient process of switching on of the reactor

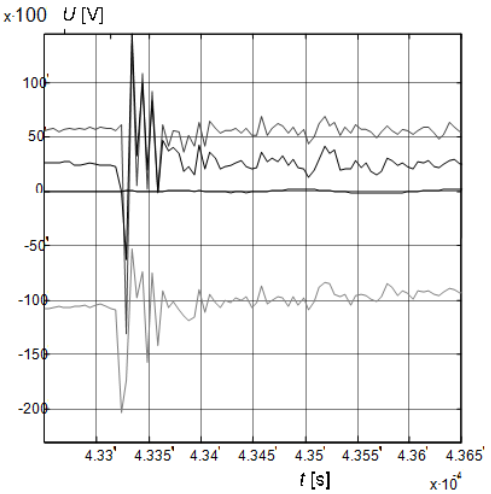

Fig. 6. Beginning of transient process of switching on of the reactor

After analyzing the oscillograms of recordings it was identified that the level of maximum overvoltages on the busbars where the reactor was connected can be up to 21.0 kV. The maximum amplitude of the phase voltage of a secondary voltage of transformer is 89.8 V. The level of overvoltages on 10 kV busbars can be 2.34 times higher than the maximum network voltage.

The transient process of switching off the reactor is shown in Fig. 7, Fig. 8 and Fig. 9.

Level of overvoltages after the arc is extinguished in the first phase to be switched off may reach a 2.3 times higher amplitude on connection busbars of voltage transformer during transient processes of switching off the reactor. After the last phase is disconnected when the reactor is switched off completely the voltage can still rise 1.44 times above the maximum network voltage.

After the analysis of switching characteristics of the circuit breaker, the difference of the connection of phases of

the circuit breaker between the first switched pole and the last pole is about 100 μs.

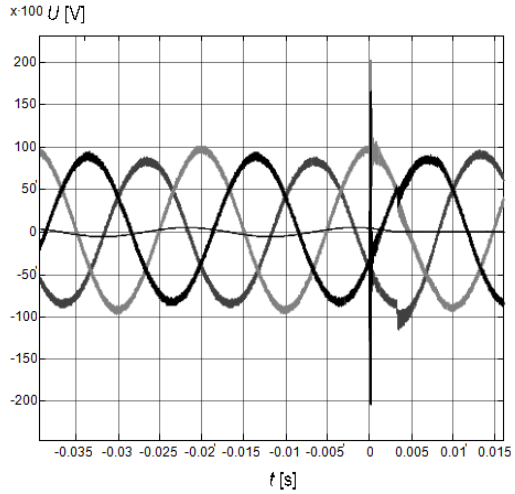

Fig. 7. Transient process of switching off of the reactor

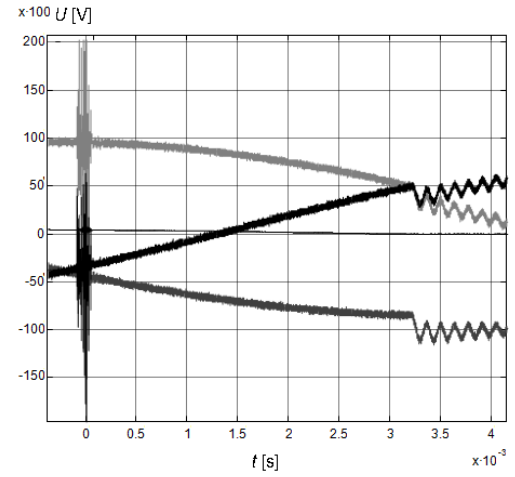

Fig. 8. Transient process of switching off of the reactor

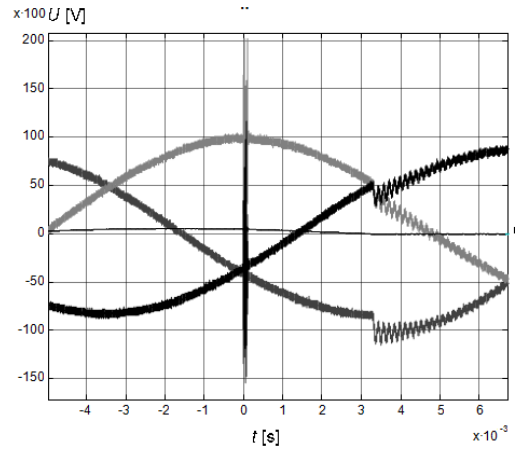

Fig. 9. Other process of switching off of the reactor

There are programs created for computer simulation of switching overvoltages, and equations of wave processes in lines are utilized in algorithms of these programs [1, 2, 6, 8, 9]. In order to more adequately reflect electromagnetic processes in electric supply diagrams composed of sections of various lengths lines and connection wires, shortest possible step of time discretisation has to be used. Compiled programs at acceptable durations of simulation allowed to reduce this step down to 1 ns. In order to get complete picture of overvoltages change up to 10^6 steps of complete calculation procedure has to be performed during one simulation with the step of such duration. Currents and voltages in sections of electric lines in calculation algorithm have been represented in modal coordinates.

The distribution of maximum overvoltages obtained by a simulating transient processes during switchings is shown in Fig. 10.

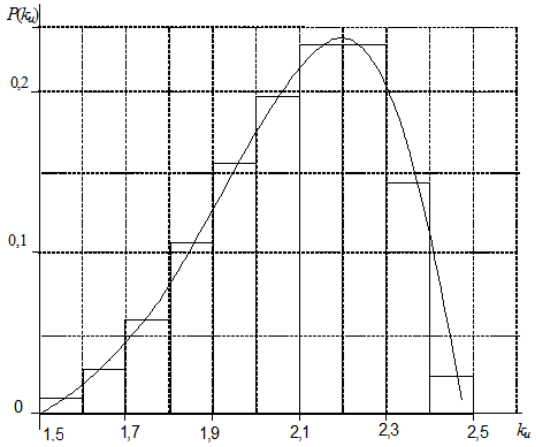

Fig 10. Histogram of the level of overvoltages

Level of overvoltages during the switching of the reactor is rather high, even though the connected line is rather short. The neutral of the electric network is isolated and a single-phase earthfault is possible in the network that is not disconnected by a relay protection. The switching reactor with earthfault in the electric network level of overvoltages can rise up to $4 \cdot U_{ph}$. Such level of overvoltages is dangerous to the insulation of equipment of the switched circuit of a reactor. Surge arresters should be installed in the circuit of a reactor to reduce overvoltages in order to protect the equipment insulation because frequent switching accelerates the aging processes of insulation, which, as a result, often cause failures in the connection circuit of the reactor.

Conclusions

1) Overvoltages can reach almost $2.4 \cdot U_{ph}$ due to the overvoltages that occur in the connection circuit of a reactor.
2) The most dangerous overvoltages occur in the circuit of a reactor when switching the cable of the reactor while there is earthfault in the system. The level of overvoltages can reach up to $4 \cdot U_{ph}$.
3) During the switching overvoltages that occur during the switching of the shunt reactor, it is necessary to use protection measures from overvoltages in order to protect the equipment insulation because constant commutation accelerates the insulation aging processes, which, as a result, often cause failures in the reactor connection circuit

***Authors**: prof. dr. Saulius Gudžius, Kaunas University of Technology, Studentu g. 48, Kaunas, Lithuania, E-mail: saulius.gudzius@ktu.lt; prof. dr. Alfonsas Morkvėnas, Kaunas University of Technology, Studentu g. 48, Kaunas, Lithuania, E-mail: alfonsas.morkvenas@ktu.lt, doc. dr. Audrius Jonaitis, Kaunas University of Technology, Studentu g. 48, Kaunas, Lithuania, E-mail: audrius.jonaitis@ktu.lt; lekt. Ugnė Ilioitienė, Kaunas University of Technology, Studentu g. 48, Kaunas, Lithuania, E-mail: ugne.ilioitiene @ktu.lt; assist. Dovilė Brazionienė, Kaunas University of Technology, Studentu g. 48, Kaunas, Lithuania, E-mail: dovile.brazioniene @ktu.lt; Vidmantas Tička, Kaunas University of Technology, Studentu g. 48, Kaunas, Lithuania, E-mail: vidmantas.ticka@ktu.edu; Virginijus Vasylius, Kaunas*

University of Technology, Studentu g. 48, Kaunas, Lithuania, E-mail: virginijus.vasylius@ktu.edu; dr. Kęstutis Jasiūnas, Litgrid, AB, Juozapaviciaus g. 13, Vilnius, Lithuania, E-mail: kestutis.jasiunas@litgrid.eu.

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