Transient Processes in Primary Winding of Voltage Transformers Under Single-Phase Short Circuits in 110 kV Power Grids with Cable Fixings

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ABSTRACT: Of late years, in densely housed megapolises 110-kV line circuits are used overhead and cable line sections. Most frequently occurring emergency states in such grids arise from line-to-ground faults with inflammation of electromagnetic voltage transformers. The causes of such accidents and developing efficient prevention measures are considered in this paper.

1. Introduction

The total length of cable fixings in high-voltage power distribution grids normally ranges from hundreds of meters to a few kilometers. In densely housed megapolises, 110-kV or higher-voltage line circuits are used involving extended, 5 to 15-km long overhead and cable line sections. Most frequently occurring emergency states in such grids arise from line-to-ground faults. With part of power-transformer neutral conductors at 110/10-kV single- and double-ended substations disconnected from the ground, and with electromagnetic voltage transformers (VTs) present in the circuit, commutations made to clear faulted lines with subsequent automatic reclosing may inflict severe damages to the VTs. Because of VT core saturation, there arise primary-current surges, leading to primary-winding failures. The amplitude value of the current surges may run far beyond the rated temperature-rise winding currents of 0.2 to 0.5 A.

Such accident scenarios took place in many power systems, for instance, at the Nagornaya Substation of the Yekaterinburg Power-Grid Company. Clearing of a faulted line in a 110-kV power grid with 1-km long cable fixing has lead to an explosion and inflammation of an NKF electromagnetic voltage transformer.

With the aim of identifying the causes of such accidents and developing efficient prevention measures, transient processes were examined occurring in the winding of NKF voltage transformers under single-phase short circuits in 110-kV grids with overhead transmission line and cross-linked polyethylene cable fixing. The study was performed using a mathematical model of three-phase network and the VMAES application suite.

2. Operational features of 110-kV power grids

Commercial 110-kV dead and effectively grounded power grids belong to the category of grids with high ground-fault currents. As a rule, earthing in such grids is applied to part of all transformer neutral conductors. Neutral conductors in power transformers are grounded considering relay sensitivity and selectivity requirements, and also possible application of short-circuit current limiters.

Very often, transformer winding faults in 110-kV and higher-voltage power grids result from ferroresonance phenomena developing in such grids. Ferroresonance phenomena emerging in 110-kV grids differ in origin from those in 6-35 kV grids. Possible causes of ferroresonances in 110-kV grids are:

- release of idler-circuit leads with multiple-break switchers in which equalizing capacitors are used;
- open-phase operating conditions in which, owing to interphase capacitive coupling, induction of voltages in the faulted phase occurs;
- enhanced ground capacitance in the power grid brought about, for instance, by cable fixings used in place of overhead-line sections [1].

3. Simulation of transient processes in a 110-kV network section comprising a cable fixing and voltage transformer

The purpose of the present study was to investigate into transient processes induced by short circuit clearings in 110-kV power grids and to analyze the influence the power-transformer neutral grounding pattern has on the level of primary currents in NKF voltage transformers with an example of circuits with overhead transmission lines analyzed in comparison with overhead transmission lines with cross-linked polyethylene cable fixing.

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Fig. 1 shows the single-line circuit diagram of a 110-kV power grid, in which one of the power transformers has insulated neutral. The simulated conditions involve clearing of a line-to-ground fault at the end of the line.

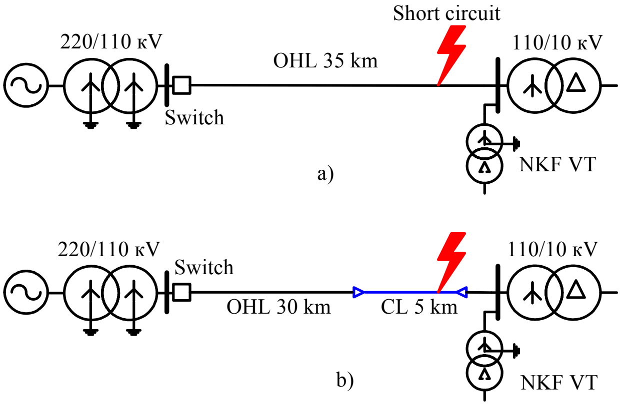

Fig.1. Single-line circuit diagram of a 110 kV power grid

An analysis of hot-side currents in VTs under single-phase short circuit in the 110-kV grid was performed using the VMAES application suite intended for simulating electromagnetic transient processes in power circuits. The calculation circuit was composed of VMAES library elements (Fig.2) [2].

From the standpoint of providing for dependable service of the equipment, the change of capacitive and inductive parameters of the grid upon replacement of an overhead-line section with a cable-line section may provoke, under certain circumstances (during rated duty, under overloads, under short circuits, etc.), emergence of a VT ferroresonance.

An analysis of possible causes of VT faults showed a continuous primary current far in excess of the rated temperature-rise winding current to present the most dangerous state of the power system.

4. Study of transient processes in variously grounded 110-kV power grids under single-phase short circuit

We consider transient processes taking place under a line-end ground fault for the equivalent circuit diagram shown in Fig. 2. It can be shown that, under normal conditions, in the VN primary coils almost sinusoidal currents flow, involving characteristic harmonics. On fault clearing, there arises a current surge, with a 14-Hz damping transient processes observed (Fig. 3).

In the oscillograms presented below the time is measured in seconds, and the current, in amperes.

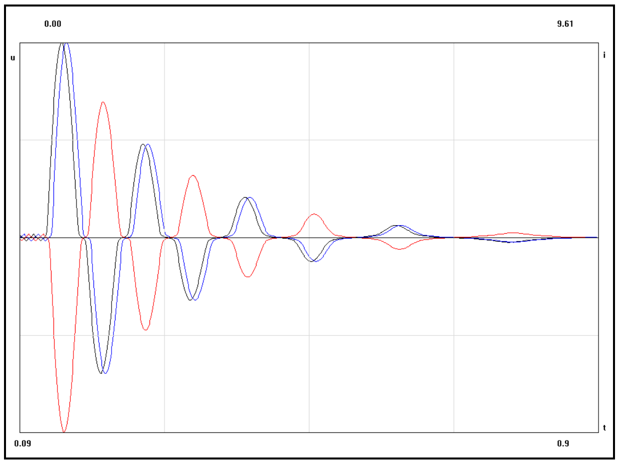

Fig. 3 VT primary currents induced by fault clearing (power transformer T2 unloaded).

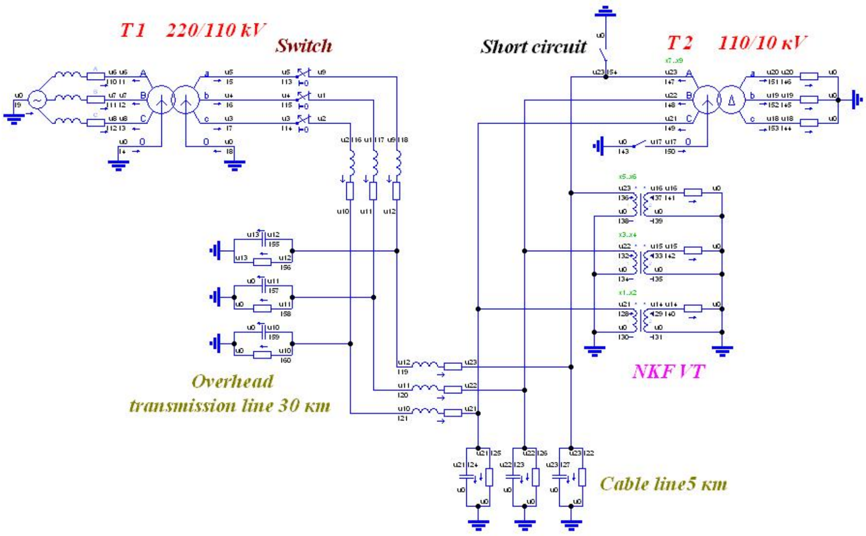

Fig. 2 Equivalent circuit representation of the 110-kV power grid with overhead and cable transmission lines

A comparison between the current amplitudes in the primary winding of NKF VTs in a 110-kV power grid with overhead transmission line and in a 110-kV power grid with overhead transmission line and cross-linked polyethylene cable fixing versus the transformer burden for a 100/10-kV power transformer is given in Fig.4.

The diagram in Fig.4 shows that in the 110-kV grid with insulated neutral operated with 5-km long cross-linked polyethylene cable currents arise constituting danger for the T2 VT primary winding both in rated on-load operation mode and in near-no-load operation.

Obviously, with some overhead transmission line sections replaced with cross-linked polyethylene cable fixings the short-circuit induced threat to the VT arises owing to increased grid capacitance since the cable-line capacitance is normally several times greater than the overhead-line capacitance.

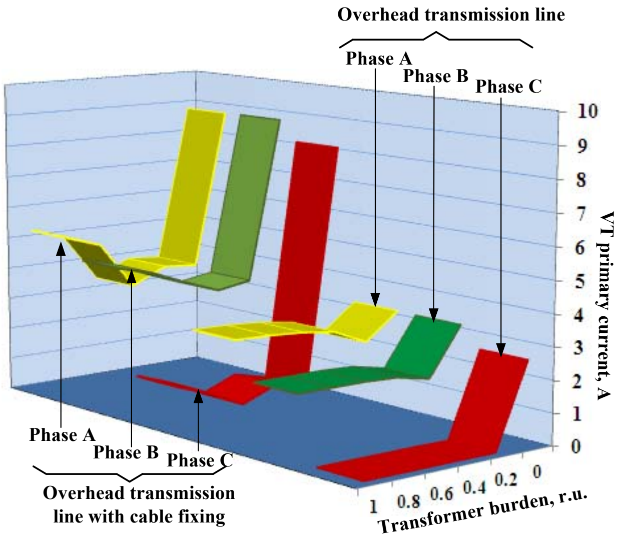

Fig. 4 VT primary-current level versus the transformer burden

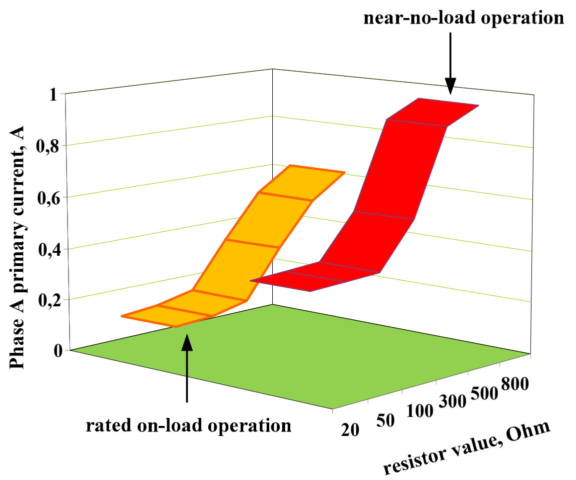

Fig. 5 VT primary-current level in 110-kV grid neutral grounded through variously valued resistors

Fig. 5 shows predicted transient processes in a partially grounded 110-kV grid neutral occurring under operating conditions most dangerous for VTs (rated on-load operation and no-load operation).

Hot-side winding failures in NKF VTs can be avoided by applying partial grounding of neutral conductors with high-voltage low-ohmic resistors.

Installation of a 20-Ohm high-voltage resistor into the neutral of the 110-kV grid power transformer (model in Fig.2) enables suppression of clearing-induced ferroresonance phenomena. Here, the NKF VT hot-side winding currents exhibit an aperiodic behavior. No dangerous VT primary-current surges were revealed (Fig.6). The amplitude value of the VT primary-current surge decreases to a value presenting no danger to VT thermal stability. This decrease occurs in a time of 0.08 s (four periods of the 50-Hz frequency).

On partial grounding of the 110-kV grid neutral conductor with a low-ohmic resistor, the level of VT hot-side currents decreases by a factor of 5-7. Such a current level under fault clearing conditions presents no danger to NKF VT winding as not exceeding the rated temperature-rise winding current of 0.2-0.5 A [3].

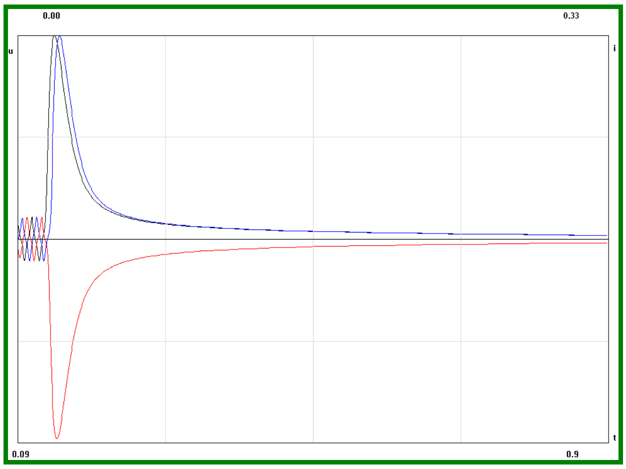

Fig.6 VT primary currents versus time.
The T2 neutral is grounded through a 20 Ohm resistor (transformer T2 unloaded).

An analysis of emergency states resulting from line-to-ground fault clearing in 110-kV grids shows that, in order to exclude damages inflicted to the equipment, one has to pass over from insulated 110/10-kV transformer neutral to neutral partially grounded through a high-voltage resistor with a value ranging from 20 to 100 Ohm depending on the particular grid configuration (presence of electromagnetic VTs, cable fixings, etc.).

5. Conclusions

With some sections of overhead transmission line replaced with cross-linked polyethylene cable fixing, on ground fault clearing the amplitude value of hot-side VT currents in 110-kV power grids increases by several times; this may inflict VT failures, thus violating the stable operation of the power supply system.

VT failures can be avoided by connecting high-voltage 20 to 100 Ohm resistors into the power-transformer neutral of 110-kV grid single- and double-ended substations.

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