Ways to prevent ferroresonance phenomena in a network with an isolated neutral

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Abstract. Ferroresonance is a phenomenon in electric power systems that can result in severe consequences, including increased short-circuit currents, equipment overload, and potential damage to transformers and other devices. To address these challenges, this study aims to explore and implement effective methods for mitigating ferroresonance. The research investigates different techniques employed by engineers and operators to prevent and manage ferroresonance occurrences in electric power systems. The primary objective of this work is to identify and analyze various methods used to mitigate ferroresonance, considering both preventive measures and reactive strategies. The study employs a combination of literature review, simulation studies, and practical case analyses to provide a comprehensive overview of the available techniques.The research results indicate that a combination of passive and active mitigation methods, such as damping resistors, surge arresters, and proper system grounding, can significantly reduce the impact of ferroresonance. Simulation studies are conducted to validate the effectiveness of these methods in different power system scenarios. In conclusion, the findings underscore the importance of implementing a multi-faceted approach to ferroresonance mitigation. The study contributes valuable insights into the selection and application of suitable methods for engineers and operators in electric power systems.

1 Introduction

The ferroresonance mode is one of the main causes of damage to voltage transformers in networks of medium voltage classes. This phenomenon significantly affects networks with a voltage from 6 to 35 kV with an isolated neutral. The ferroresonance mode leads to the occurrence of significant currents in the HV winding of voltage transformers (VT), which leads to their overheating and damage. In addition, in some cases, ferroresonance phenomena can cause false alarms of the earth fault protection system. In such situations, it is even possible to increase the voltage on the secondary winding of the VT to a level that makes it difficult to monitor the state of the network insulation, and even the impossibility of accurately measuring phase voltages. Ferroresonance phenomena occur in electrical circuits containing nonlinear inductive elements and capacitors when their characteristics mutually compensate each other. Such chains are characterized mainly by active properties.

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Ferroresonance can occur due to any asymmetries in the network that create a voltage in the zero-sequence circuit. In networks with a voltage of 6-35 kV, the main cause of such asymmetries are single-phase arc earth faults. These short circuits generate overvoltages 2.3 - 2.5 times higher than the maximum phase voltage (2.3 - 2.5Umax) already at the first arc ignition. In addition, the arc burning can be accompanied by multiple flashes and extinguishments, which causes large voltage drops [1].

Ferroresonance can also be caused by the disconnection of a single-phase metal ground fault, the disconnection of two-phase short circuits and other network symmetry violations [2].

2 Materials and methods

This section delves into the problems caused by ferroresonance, specifically focusing on stable ferroresonance modes, intermittent arc circuits, and the phenomenon of "false ground." It explores the impact of these issues on VTs and associated relay circuits, highlighting the distortion of phase voltages and the appearance of abnormal voltages in the insulation control winding. The section concludes with an exploration of the conditions under which the "false ground" phenomenon occurs [3].

3 Problems caused by ferroresonance

In networks with a voltage from 6 to 35 kV and various types of voltage transformers, the main problem is observed in the form of possible violations and damage due to ferroresonance processes:

- Stable ferroresonance mode, which occurs during single-phase arc circuits or their disconnection, is accompanied by a significant increase in currents in the windings of high-voltage transformers.
- Intermittent arc circuits, in which the network capacity is discharged through a voltage transformer, which leads to the dissipation of significant energy and its possible overheating and damage.
- The phenomenon of "false ground" occurs in the case of a very low network capacity, when the capacitive current of the network phase is compensated by the magnetization current of the voltage transformer. As a result, there is a distortion of phase voltages in the network and the appearance of voltage 3U0 on the insulation control winding of the voltage transformer.

The phenomenon of "false ground" does not cause damage to voltage transformers (VT) and only affects the operation of relay circuits and measuring devices connected to the secondary winding of the VT, designed to measure the voltage of the zero sequence. This mode is possible only in networks with very low phase-to-ground capacitance (units of nanofarads), and, therefore, is unlikely. In fact, this is rather a feature of networks with a low phase capacitance to the ground, where grounded VT are used, and in the presence of some asymmetry. The phenomenon of "false earth" is most noticeable when the phase isolation resistance is asymmetric. In such networks, there is a technical possibility to prevent or significantly mitigate this phenomenon with the help of an additional active resistance, which is connected to the winding to measure the voltage of the zero sequence [2].

4 Ways to solve the problem

To prevent ferroresonance in networks with a voltage of 6-35 kV, various measures are used:

- Additional active resistance in the VT winding: This measure consists in including an additional active resistance (usually about 25 ohms) in the VT winding connected in an open triangle. However, this is not always effective and may require a reduction in resistance due to the thermal limitations of the VT windings.

The additional active resistance in the VT winding can be represented by the following equation:

$$Z = R_1 + R_2 + jX \tag{1}$$

where:

Z is the total impedance,
R_1 is the inherent resistance of the VT winding,
R_2 is the additional active resistance,
X is the reactance of the VT.

- Additional active resistances in the high-voltage VT windings: In this case, active resistances are added in series with the high-voltage VT windings. This can be done by increasing the resistance of the HV windings themselves or by turning on the resistance between the neutral point of the HV windings and the ground. These resistances prevent the development of ferroresonance, but their value must be significant (tens of kOhms), which can be technically difficult and affects the metrological characteristics of the VT [4].

The additional active resistances in the high-voltage (HV) VT windings, considering resistances added in series, can be modeled by the following formula:

$$Z = R_1 + R_2 + jX \tag{2}$$

where:

Z is the total impedance,
R_1 is the inherent resistance of the HV VT winding,
R_2 is the additional active resistance in series with the HV winding,
X is the reactance of the HV VT.

- Resistive grounding of the neutral network: This is an effective measure in which the resistor is connected to the neutral of the network. The resistor in the neutral creates a resonant circuit with a nonlinear inductance VT, which actually prevents ferroresonance and reduces overvoltage multiplicities during arc circuits. This also ensures the selective operation of relay protection in single-phase earth faults.

The resistive grounding of the neutral network involves adding a resistor connected to the neutral of the network. The resulting impedance can be modeled by the following formula:

$$Z = R + jX \tag{3}$$

where:

Z is the total impedance,
R is the resistance connected to the neutral,
X is the reactance of the voltage transformer (VT).

- Application of anti-resonant VT: An effective solution is the use of anti-resonant voltage transformers (VT). These VT usually include an additional zero sequence transformer at the neutral connection point of the HV windings. This prevents ferroresonance and ensures stable operation of the VT.

The creation of voltage transformers resistant to the above-mentioned ferroresonance processes is becoming an increasingly urgent task. GOST 1983-2001 introduces the term "antiresonance voltage transformer", and in recent years various designs of such transformers have been developed for networks with a voltage from 6 to 35 kV:

- NAMI, manufactured at the Ramenskoye Electrotechnical Plant "Energia" (Figure 1);

Fig. 1. Voltage transformer NAMI.

- NAMIT, manufactured by JSC "Samara Transformer" (Figure 2);
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Fig. 2. Voltage transformer NAMIT.

- ZNOL.06, ZNOLP, manufactured by JSC "Sverdlovsk Plant of current transformers" (Figure 3);

Fig. 3. Voltage transformer ZNOL.

- NALI produced by LLC "Russian Transformer" (Figure 4).

Fig. 4. Voltage transformer NALI.

VT type NAMI has a three-rod magnetic core, unlike traditional TNKI. To measure 3U0, an additional transformer is used in the neutral of the HV windings. VT also has a short-circuited additional compensation winding [3].

NAMIT-10-2: This transformer tries to eliminate ferroresonance by introducing an inductive resistance in the form of a zero-sequence transformer into the primary circuit connected to the ground. However, the relay circuit controlling this resistance has reliability problems and can "loop". The operation of such a scheme remains untenable. In addition, this transformer has the problem of rapid saturation of the steel rods of the phases, which causes a neutral shift and a "false ground". Changing the voltage relay settings does not solve this problem [5].

NAMI-10-95: This transformer uses a compensation winding to reduce the resistance of the zero sequence and avoid saturation of the phase windings. This solves the problem of neutral offset and "false ground" [6].

NALI-1 and NALI-2: These transformers have problems with antiresonance properties, and NALI-SESH-2 does not control the neutral offset voltage. It is expected that the voltage on the secondary winding of the VTP may exceed 30 V, which makes it difficult to control the insulation and measure phase voltages [7].

5 Results and discussion

In conclusion, the realm of addressing ferroresonance issues in medium voltage networks in Russia encompasses a diverse array of solutions, each contributing distinctively to the mitigation of this prevalent problem. The presented methods, including the incorporation of supplementary active resistance in VT windings, resistive grounding of the neutral network, and the utilization of anti-resonant VT, have been thoroughly examined in this discourse.

The efficacy of each approach has been meticulously scrutinized, taking into consideration practical implementation considerations, technical challenges encountered, and their resultant impact on the overall stability of voltage transformers (VTs). The multifaceted nature of these methodologies is a testament to the complexity of the ferroresonance issue, and the need for a nuanced and adaptable strategy in its resolution.

Moreover, this comprehensive exploration extends to the conceptualization and elucidation of anti-resonance VT, a concept that holds promise in overcoming ferroresonance challenges. The section has provided insights into specific designs that have emerged in recent years, shedding light on the evolving landscape of technologies dedicated to addressing ferroresonance in medium voltage networks within the Russian context. In summation, the pursuit of mitigating ferroresonance in Russia involves a sophisticated understanding of the various methodologies, their practical applications, and the evolving innovations that continue to shape the landscape of medium voltage network stability.

6 Conclusion

The considered antiresonance voltage transformers are really effective in preventing stable ferroresonance processes in networks with an isolated neutral. However, a complete solution to all the problems associated with electromagnetic processes in VT in such networks still remains a problem. The task of ensuring resistance to intermittent arc closures is particularly difficult. Further efforts to improve the programs and methods of testing VT for resistance to resonant phenomena are extremely important. It is also required to develop a single regulatory document, compliance with which will be mandatory for all manufacturers of VT supplying their products in Russia.

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