EXPERIMENTAL INVESTIGATION OF FERRORESONANCE AND MITIGATION MEASURES IN 35 KV ISOLATED NETWORKS

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ABSTRACT

Ferroresonance is a nonlinear dynamic phenomenon that appears in the electric power system between a non-linear inductances and system capacities excited by a sinusoidal voltage source. The most common non-linear elements of the electric power system are the iron core inductances of power and measuring transformers, reactors, etc. in which saturation of non-linear elements can occur. As a consequence of ferroresonance there may be a significant increase in the voltage value and under the certain conditions an excessive increase of the current value across the transformer terminals. This phenomenon can lead to damage of the measuring transformers and other equipment used in the network. Ferroresonance is one of the most common low-frequency electromagnetic transient phenomena that appear in the isolated power networks. Therefore, special attention must be on analyzing the probability of ferroresonance occurrence in electric power systems. In this paper, ferroresonance measurement results will be given. The waveform of the phase to ground voltage and wave form of the open delta voltage is obtained. Also, the Fourier transformation is performed on these signals. Proposed measurements are conducted in the real 35 kV distribution network with isolated neutral point. Also, efficiency of some experimentally tested mitigation measure will be presented within this paper.

INTRODUCTION

Ferroresonance is a nonlinear phenomenon characterized by overvoltage and voltage and current oscillations waveforms [1,2]. In principle, the ferroresonance is a resonant phenomenon that occurs in isolated networks between the network capacitance and the nonlinear inductances of the voltage measurement transformers [3].

For the occurrence of ferroresonance, non-linear inductance (voltage measurement transformers, shunt reactors, power transformers), capacitances such as long line charging capacitor, series or parallel capacitor banks, grading capacitors, a voltage source and low losses have to be part of the power system [4,5]. The occurrence of ferroresonance issue from the change in network conditions such as overvoltages, lightning, electrical faults, insulation failures, switching operations in different elements of the power system, including transformers, capacitor banks and loads. The phenomenon of ferroresonance can, due to high values of voltage and current, result in the damage of equipment [6].

Ferroresonance is one of the most common low-frequency electromagnetic transients in the isolated networks [7]. To the phenomenon of the ferroresonance in isolated networks should be given special attention. In this paper, experimental investigation of ferroresonance and mitigation measures in 35 kV isolated networks are presented.

FERRORESONANCE PHENOMENON MEASUREMENTS

Principal measurement scheme

Ferroresonance is initiated by clearing operations of the earth faults. For the purposes of identifying the ferroresonant phenomena it was necessary to measure the waveforms of the line-to-ground voltages and feeders currents, as well as the voltage on an open delta on the secondary winding of an inductive voltage measurement transformer.

The line-to-ground voltages waveforms were measured at the busbar of the medium voltage network before the circuit breaker, and the feeder currents waveforms were measured at the feeders after the circuit breaker used for switching manipulations.

Waveforms of the line-to-ground voltages and the currents were registered using protection and control relays connected to secondary winding of the voltage and current measurement transformers. During the investigations, the protection relays was adjusted in order to extend the time of recording of the line-to-ground voltages waveforms and the current waveforms [6]. The voltage waveform on an open delta on the secondary winding of an inductive voltage measurement transformer was recorded using a digital oscilloscope, connected to the test circuit as shown on Figure 1. All mentioned measurements were done during switching operations on a specially prepared earth fault.

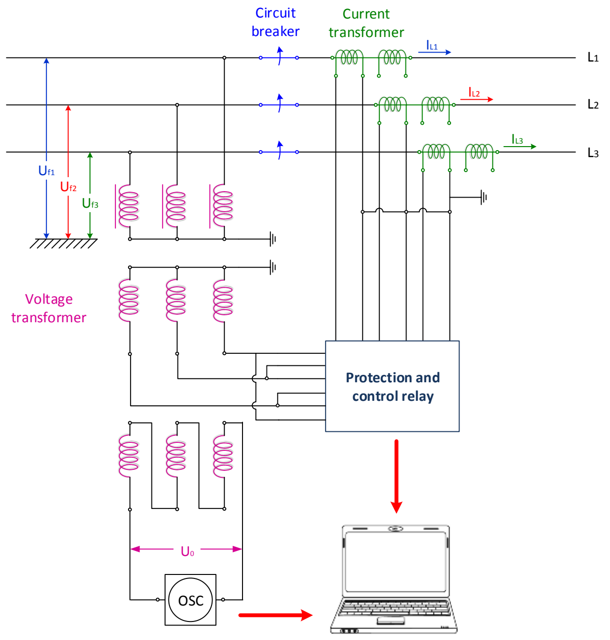

Figure 1. The principal scheme of the measurement

Testing procedure

Testing of ferroresonant phenomena occurrence, after clearing operation of the earth faults, are done according to prepared planning schemes with simulated earth fault in isolated networks.

The tests are carried out by disconnection of the ferroresonance damping devices. For schemes in which ferroesonance has occurred, additional tests were carried out installing the ferroresonance damping device in order to check the effectiveness of the applied measures (device) for preventing the ferroresonance occurrence for the given network configuration.

The identification of ferroresonant phenomena as well as the type of ferroresonant phenomena is determined by analysing the harmonic components of the measured line-to-ground voltages. Identification is carried out using Fourier analysis. A Discrete Fourier Transform (DFT) is used to analyse the discrete signal. One of the most effective DFT calculating algorithms is Fast Fourier Transformation (FFT), so the harmonic analyse of recorded signals (line-to-ground voltages) is performed using FFT algorithm. The results of the harmonic analysis are presented for each switching manipulation.

RESULTS AND DISCUSSION

In this section of the paper are presented the measurement results of the line-to-ground voltages waveforms, the feeders currents waveforms, the voltage on an open delta on the secondary winding of an inductive voltage measurement transformer according to case of ferroresonance occurrence after clearing of the simulated earth fault. Also, measurement results for the same test circuit with damping device used to mitigate ferroresonance are presented.

Test case 1

In the first test case (Figure 2.) the earth fault is simulated on 35 kV overhead line between substations TS 4 – TS 5.

Power supply is carried out through one 110/35 kV transformer from 110 kV substation, with the 35 kV circuit breaker switched on in 35 kV substation TS 1.

The switching operations are carried out in the 35 kV substation TS 4, with feeder circuit breaker to the 35 kV substation TS 5. The circuit breaker at the input of 35 kV substation TS 3 (from 35 kV substation TS 4), the circuit breaker at the input of 35 kV substation TS 1 (from 35 kV substation TS 2) and the circuit breaker at the input of 35 kV substation TS 5 (from 35 kV substation TS 2), were switched off.

Power supply of 35 kV substation TS 4 is carried over 35 kV overhead line between substations TS 4 - TS 1. The current and voltage measurement has been performed on the protection and control relay of the 35 kV feeder between substations TS 4 - TS 5. The voltage on an open delta is measured on the secondary winding of an inductive voltage measurement transformer in the measuring field of 35 kV substation TS 4.

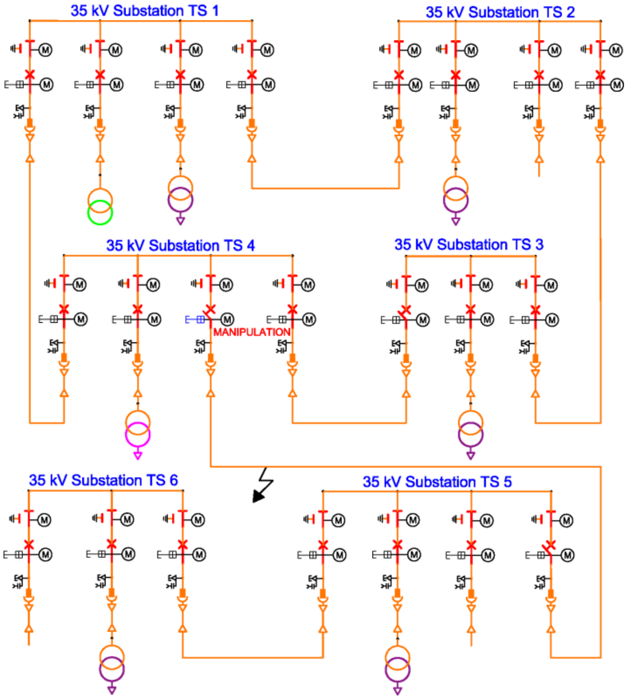

Figure 2. The scheme of the test circuit with marked manipulation circuit breaker and earth fault location [8]

Figures 3 to 9 show the results of the current waveforms measurements on the feeder, the line-to-ground voltages and the voltages on an open delta on the secondary winding of an inductive voltage measurement transformer. Also, the results of the FFT analysis performed on the line-to-ground voltages on the phase where the earth fault is introduced are shown [8].

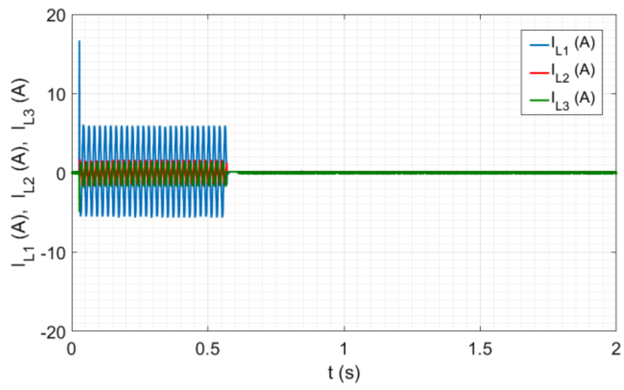

Figure 3. Waveform of the feeders currents

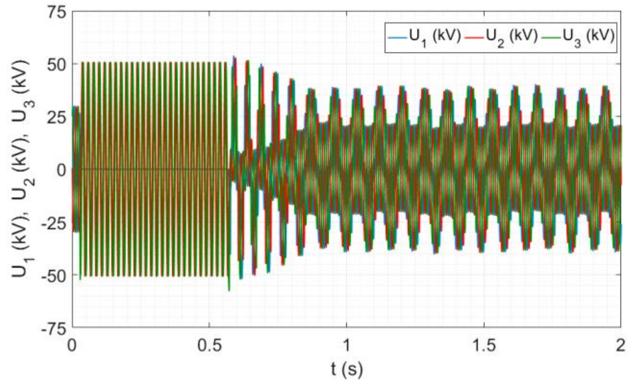

Figure 4. Waveform of the line-to-ground voltages

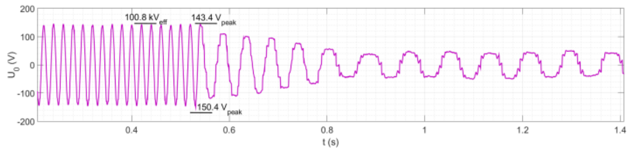

Figure 5. Waveform of an open delta voltage

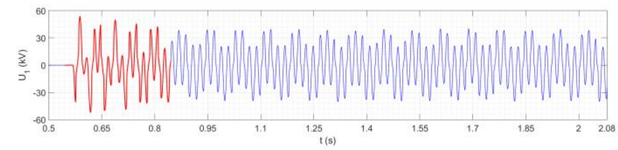

Figure 6. Selected first 10 periods of line-to-ground voltage U_{f1} analyzed by FFT

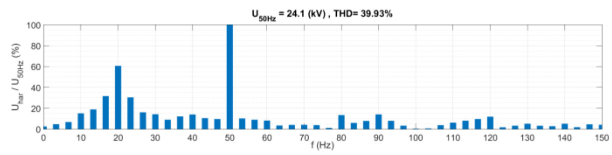

Figure 7. The FFT result for the first 10 periods of line-to-ground voltage U_{f1}

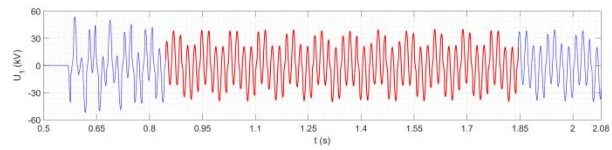

Figure 8. Selected 50 periods of line-to-ground voltage U_{f1} analyzed by FFT

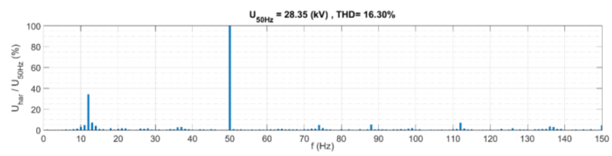

Figure 9. The FFT result for the selected 50 periods of line-to-ground voltage U_{f1}

The measurement results show that the analysed network has tendency of ferroresonant phenomena occurrence. The previous statement is confirmed by multiple tests, and during all the tests ferroresonant phenomena has occurred. The results indicate the presence of a non-stationary ferroresonant phenomena with very slow damping of the ferroresonance in the presence of the fourth subharmonic 12.5 Hz (in the amount up to 35%). The cause of damping can be the presence of consumption in the analysed distribution network. By analysing the first 10 periods of voltage signal from the measuring cell in the frequency domain, there is a significant presence of the frequency 20 Hz, even up to 60% of the value of the basic harmonic. Therefore, it can be concluded that this is a phenomenon of stationary subharmonic ferroesonance.

The maximum registered value of the overvoltage factor during the stationary ferroresonant occurrence is 2.07 p.u. The maximum registered value of the voltage on an open delta on primary side is 94.5 kV, which means that the system oscillates with the amplitude of 31 kV to the ground.

Test case 2

On the test circuit from the test case 1, the efficiency of the application of the VT GuardPro device is performed. The VT GuardPro is a advanced security device that protects medium voltage (MV) inductive voltage transformers against ferroresonant oscillations. The VT GuardPro device is a non-linear, time-dependent resistor that is installed on an open delta on the secondary winding of an inductive voltage measurement transformer. In contrast to classical active resistance, the VT GuardPro device has a lower resistance value (provides better damping properties), less dimension, and has advanced setting (time delay, threshold voltage) [8,11]. On the Figure 10 is given the simplified scheme of the VT Guard Pro device.

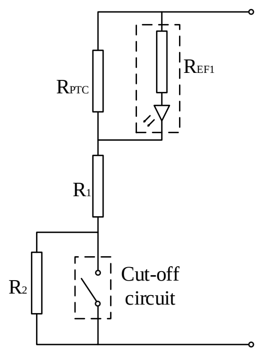

Figure 10. Simplified scheme of the VT Guard Pro device [8, 11]

Figures 11 to 17 show the results of the current waveforms measurements on the feeder, the line-to-ground voltages and the open delta voltage. Also, the results of the FFT analysis performed on the line-to-ground voltages on the phase where the earth fault is introduced are shown [10].

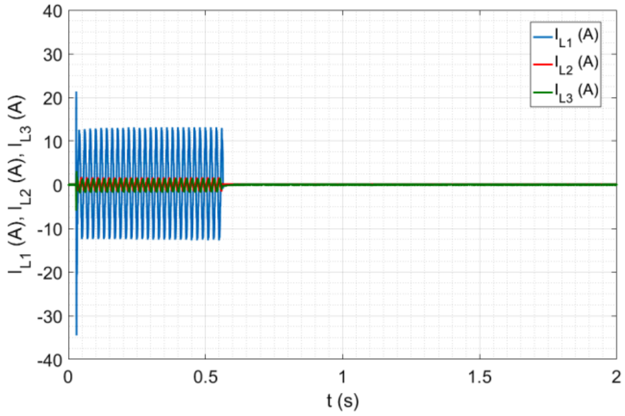

Figure 11. Waveform of the feeder currents

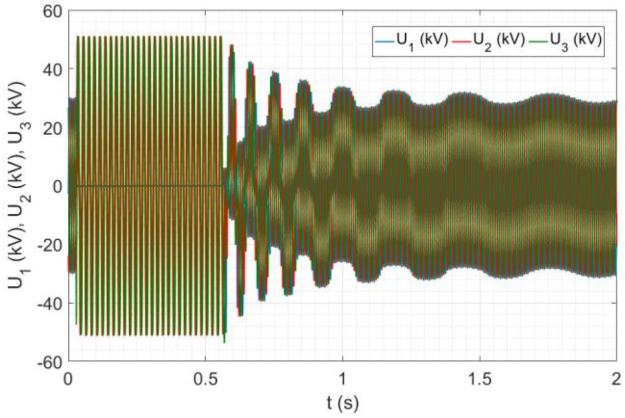

Figure 12. Waveform of the line-to-ground voltages

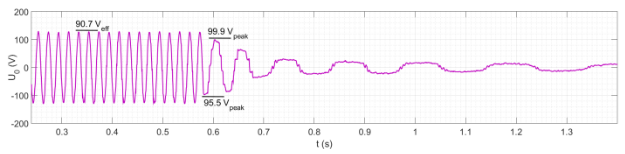

Figure 13. Waveform of open delta voltage

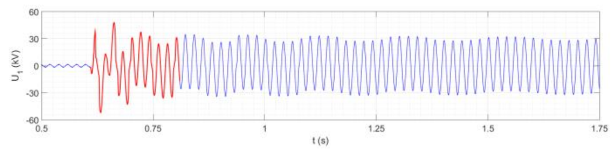

Figure 14. Selected first 10 periods of line-to-ground voltage U_{f1} analyzed by FFT

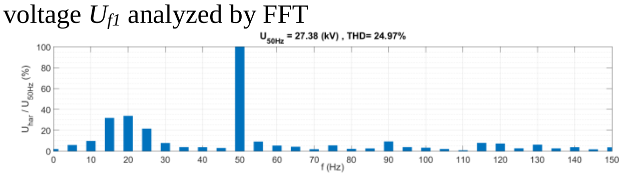

Figure 15. The FFT result for the first 10 periods of line-to-ground voltage U_{f1}

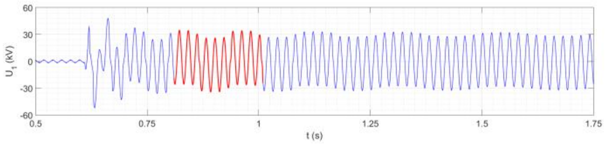

Figure 16. Selected 10 periods of line-to-ground voltage U_{f1} analyzed by FFT

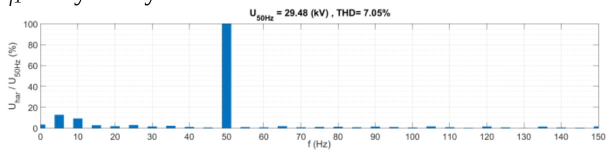

Figure 17. The FFT result for the selected 10 periods of line-to-ground voltage U_{f1}

The measurement results indicate that after the installation of the VT GuardPro device on an open delta on the secondary winding of an inductive voltage measurement transformer there is no appearance of ferroresonance. The previous statement is experimentally confirmed by multiple examinations on the same network configuration. The maximum registered value of the overvoltage factor during the transient process is approximately 2.0 p.u..

CONCLUSION

The measurement results carried out without the use of the damping device to mitigate ferroresonance indicate that the network in this configuration has tendency to ferroresonant occurrences. The maximum registered value of the overvoltage factor during the stationary ferroresonant occurrence is 2.07 p.u. In the stationary subharmonic ferroresonance, the line-to-ground voltages are equal to the sum of the corresponding symmetric line-to-ground voltages of the base frequency and usually a slightly higher voltage of the lower frequency, so that the maximum value of such ferroresonant voltages is usually slightly higher than the double amplitude of line-to-ground voltages, as confirmed by the measurement results.

Due to the tendency of the network in this configuration to ferroresonant phenomena, additional tests were carried out. Tests were carried out with the damping device the VT GuardPro used to mitigate ferroresonance in the TS 4 substation. In this case, a slower damping of the transient process occurred indicating that the VT GuardPro device prevented the appearance of a stationary ferroresonant occurrence.

REFERENCES

[1] A. Tokić, J. Smajić, 2015, "Modeling and Simulations of Ferroresonance by Using BDF/NDF Numerical Methods“, *IEEE Transactions on Power Delivery*, Vol. 30, No 1.

[2] A. Tokić, V. Milardić, 2015, *Power quality (in Bosnian)*, Printcom, Grafički inženjering, Tuzla, Bosna i Hercegovina.

[3] T. Kelemen, 1999, "Ferroresonance in the three-phase network with insulated neutral point (in Croatian)", *HRO Cigre, Cavtat.*

[4] A. Erbay, 2012, "Parameter Study of Ferro-Resonance with Harmonic Balance Method", *KTH Electrical Engineering*, Stockholm, Sweden.

[5] A. Tokić, M. Kasumović, N. Turković, S. Čaršimamović, M. Dževlan, 2017, " Ferroresonance of the voltage measuring transformers in isolated networks (in Bosnian)", *13. Savjetovanje BH K Cigre*, Neum.

[6] S. Čaršimamović, Z. Bajramović, A. Mujezinović, N. Turković, 2016, *Resonance and ferroresonance in electric power systems (in Bosnian), BH K Cigre*, Sarajevo.

[7] W. Simaa, M. Zoua, M. Yanga, D. Penga, Y. Liua, 2018, "Saturable reactor hysteresis model based on Jiles–Atherton formulation for ferroresonance studies", *International Journal of Electrical Power & Energy Systems*, Vol. 101.

[8] A. Tokić, S. Čaršimamović, A. Muharemović, S. Halilčević, I. Turković, M. Kasumović, 2016, "Identification and mitigation measures for ferroresonance phenomenon in 35 kV substation HPP Jablanica (in Bosnian)", Case study, Faculty of Electrical Engineering Tuzla/Faculty of Electrical Engineering Sarajevo.

[9] Resonance and Ferroresonance in Power Networks, CIGRE Brochure No. 569, WG C4.307, Feb. 2014.

[10] Preliminary Survey Report and the examination of the performed mitigation measurements, Identification and mitigation measures for ferroresonance phenomenon in 35 kV substation HPP Jablanica (in Bosnian", Case study, Faculty of Electrical Engineering Tuzla/Faculty of Electrical Engineering Sarajevo, Sarajevo 2016.

[11] VT Guard Pro/VT Guard Pro–D: Solution for Ferroresonance Elimination, Document No. 1VLC000651, ABB, Brno, Czech Republic, 2013.