Susceptibility of electrical network to ferroresonance occurrence

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The calculations of electrical network susceptibility of chosen 110 kV, 220 kV and 400 kV networks to ferroresonance occurrence, its type and parameters were performed in the study. The influence of such parameters as voltage transformer (VT) magnetization characteristic, equivalent network capacitance, and the breaker grading capacitance on ferroresonance was investigated. The calculations were performed using the EMTP/ATP program. Some of the results were presented in this paper.

1. Introduction

The ferroresonance phenomenon in the power network has been known and described for many years. However, it is difficult to investigate this phenomenon because of its significant sensitivity to even small changes in network parameters [1, 2]. Also, the form and parameters of the network equivalent scheme of devices like VT, power lines and breakers exert an effect on the phenomenon character during computer simulations. Looking for the range of network parameters, in relation to ferroresonance appearance by means of the simulation method with gradually changing network parameters, is a long-term process and does not guarantee finding a proper solution.

The field measurement method aiming at finding resistance of network to ferroresonance is not effective because a slight change in investigation conditions can significantly affect obtained results. Ferroresonance in the investigated network can appear as a result of interaction between VT nonlinear inductance, network capacitance, and a breaker grading capacitance [1, 2].

The simulation investigation of susceptibility of 110 kV, 220 kV and 400 kV electrical networks to ferroresonance, its type, and parameters were carried out. The calculations were performed using the EMTP/ATP program.

The influence of such parameters as VT magnetization characteristic, its burden, equivalent network capacitance and the breaker grading capacitance on the ferroresonance phenomenon was investigated. The opening of high voltage breaker was the impulse which initiated the ferroresonance.

2. Results of ferroresonance calculations

The scheme of the 110 kV network, taken under consideration for ferroresonance calculation is shown in Fig. 1. After opening the breaker Q, the 110 kV network, i.e. busbars and lines replaced by capacitance C_E and inductive voltage transformer VT is supplied by the grading capacitance C_Q, which value depends on a breaker type within the range of few hundred to few thousand pF.

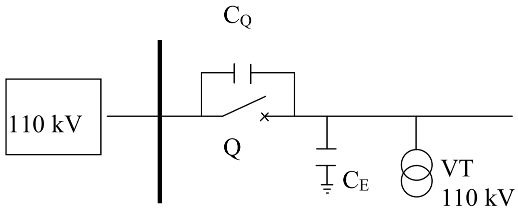

Fig. 1. Scheme of the 110 kV network with ferroresonance phenomenon

The magnetization characteristic of 110 kV VT used in substation is based on field measurements, Fig. 2.

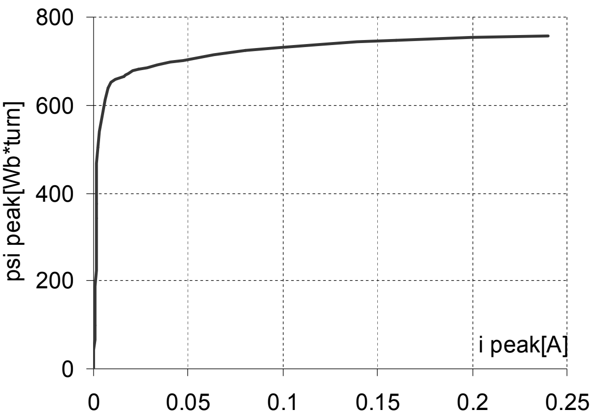

Fig. 2. The magnetization characteristic of 110 kV VT

The equivalent scheme of the investigated 110 kV network is presented in Fig. 3. The scheme can be described by the set of equations:

$$\begin{cases} \dfrac{d\Psi}{dt} = U_\mu; \quad \dfrac{dU_\mu}{dt} = 1/K_1 \cdot [-U_\mu \cdot [K_2 + K_3 \cdot (a_1 + n \cdot a_n \cdot \Psi^{n-1})] - \dfrac{i_2(\Psi)}{C_Q} + \omega \cdot U_m \cdot \cos(\omega \cdot t)]; \\ K_1 = (\dfrac{C_E}{C_Q} + 1) \cdot (\dfrac{R_s}{R_p} + 1); \quad K_2 = \dfrac{1}{C_Q \cdot R_p}; \quad K_3 = R_s \cdot (\dfrac{C_E}{C_Q} + 1) \end{cases} \tag{1}$$

where: Ψ -flux linkage, $u(t) = U_m \cdot \cos(\omega \cdot t)$ - source voltage, $U_m = 110\ \text{kV} * \sqrt{2}/\sqrt{3}$; $R_s = 30.3\ \text{k}\Omega$; $R_p = 10^9\ \Omega$.

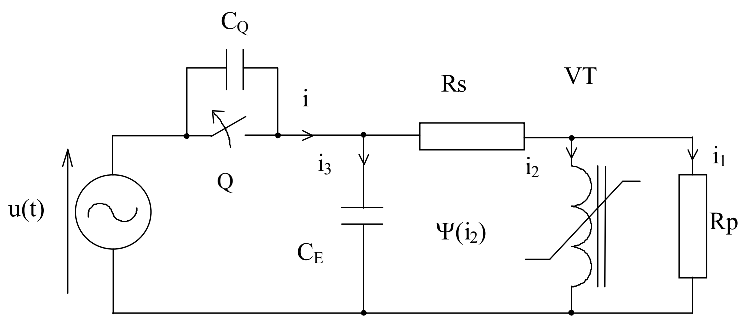

Fig. 3. Equivalent scheme of the investigated 110 kV network taken for ferroresonance calculation

Magnetization characteristic of VT can be described by the equation:

$$i_2(\Psi) = a_1 \cdot \Psi + a_n \cdot \Psi^n \tag{2}$$

where: $a_1 = 3.17 \cdot 10^{-6}$; $a_n = 1.025 \cdot 10^{-16}$; $n = 5$.

The graphical solution of the equations describing the network for steady state for chosen parameters is presented in Fig. 4. The intersection of the u vs. i network characteristic and the U_m line representing the source voltage determines the possible operation points 1, 2 and 3.

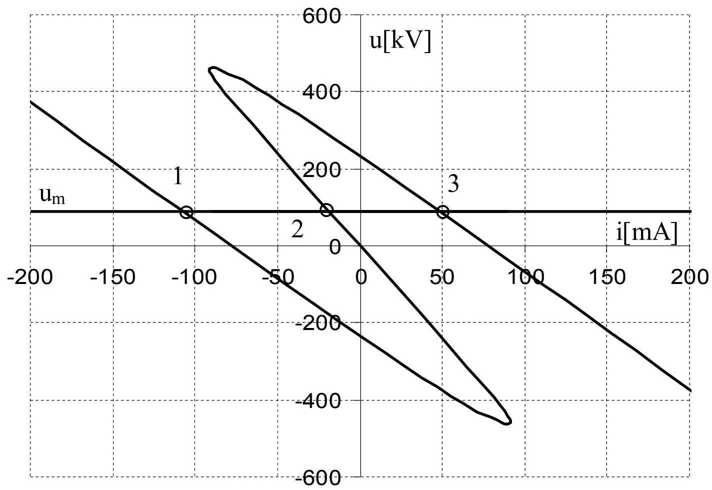

Fig. 4. Possible operation points. Solution for C_Q=1000pF, C_E=2000pF
(1 and 2 - stable operation points, 3 - unstable operation point)

The graphical method, though simple, has a numerous limitations [1, 2, 3]. More precise results, more similar to those observed in the network, provide the calculations by using the EMTP program. For different sets of parameters, the network behavior after the breaker opening was performed.

In the investigated range of C_Q and C_E capacitance variation, ferroresonance did not appear or it appeared as transient short-time or stable with network frequency of f_s = 50 Hz, $1/3 \cdot f_s$, $3 \cdot f_s$ or stable with chaotic shape.

For example, Fig. 5 shows the transients of phase voltages, VT currents, residual voltage and Fourier transform of phase voltages for ferroresonance with frequency of $1/3 \cdot f_s$ and Fig. 6 presents the ferroresonance with a chaotic shape.

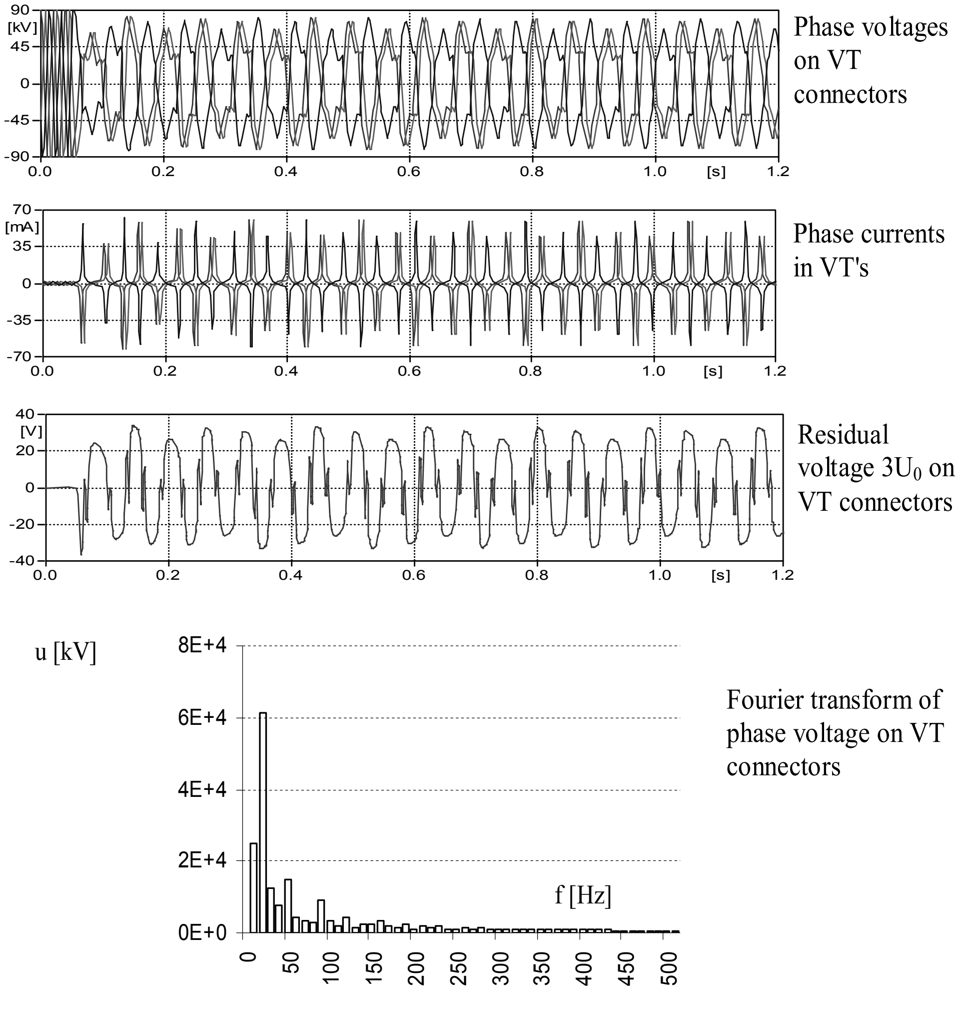

Fig. 5. Phase voltages, VT currents, residual voltage ($3U_0$) and Fourier transform of phase voltage on the secondary side of VT during the stable ferroresonance with frequency of 16.6 Hz (C_Q=300 pF, C_E= 250 pF)

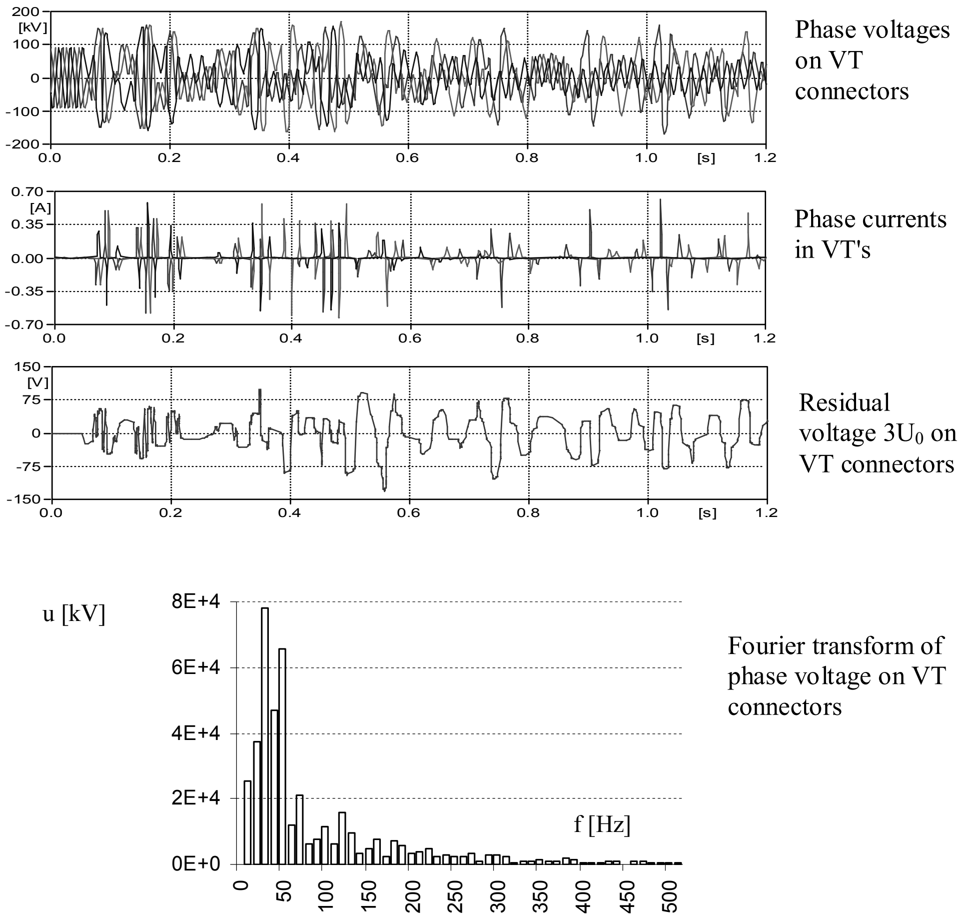

Fig. 6. Phase voltages, VT currents, residual voltage ($3U_0$) and Fourier transform of phase voltage on the secondary side of VT during the stable chaotic ferroresonance (C_Q=2000 pF, C_E= 1000 pF)

The results for the complete range of investigated parameters C_Q and C_E were placed on the ferroresonance map, whose fragment is presented in Fig. 7. It shows the areas free of ferroresonance (N), with stable chaotic ferroresonance (T/Ch), with stable harmonic ferroresonance (e.g. T/16 Hz), or ferroresonance disappearing after a short time (e.g. Z/0.9s). The maximal observed values of ferroresonance overvoltages are also visible. The map is calculated for unloaded voltage transformers.

The similar ferroresonance maps, but for voltage transformers loaded with resistance 10 Ω (in the open triangle of secondary coils) are presented in Fig. 8. The map of ferroresonance for the 400 kV network with unloaded voltage transformers is shown in Fig. 9.

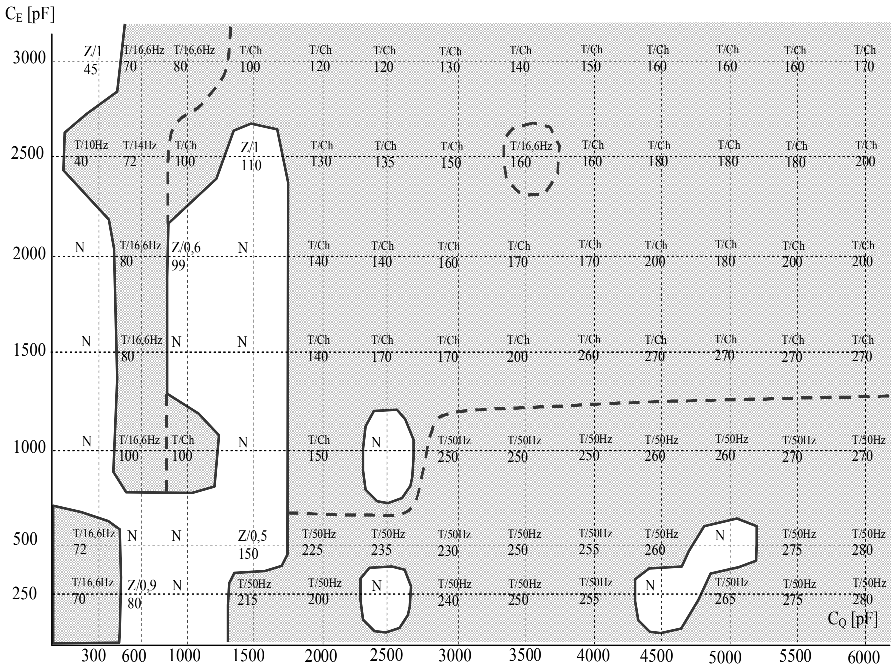

Fig. 7. The ferroresonance map for the investigated 110 kV network for unloaded VT (values of overvoltage in [kV])

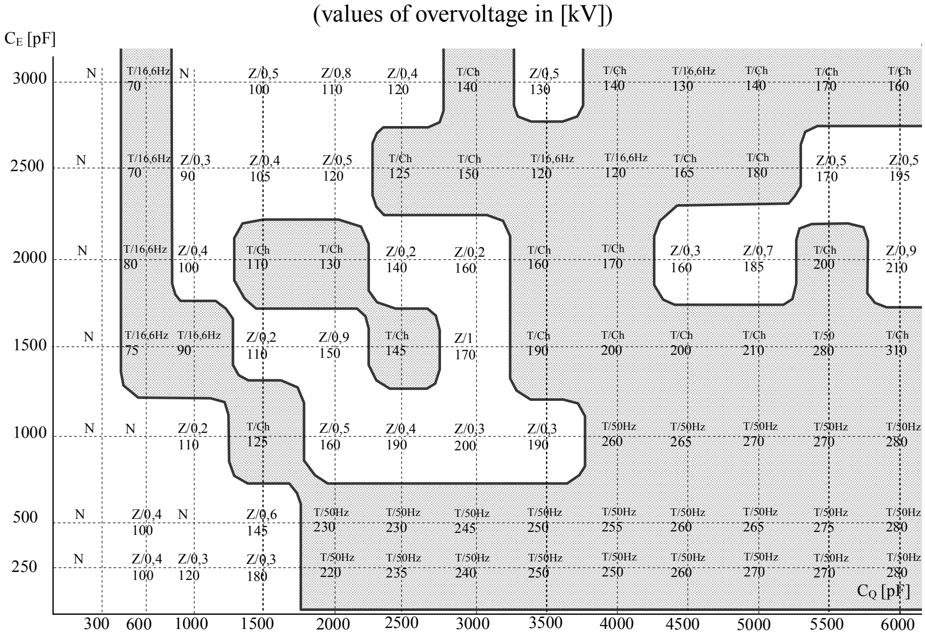

Fig. 8. The ferroresonance map for the investigated 110 kV network for voltage transformers loaded with resistance 10 Ω (in opened triangle of secondary coils)

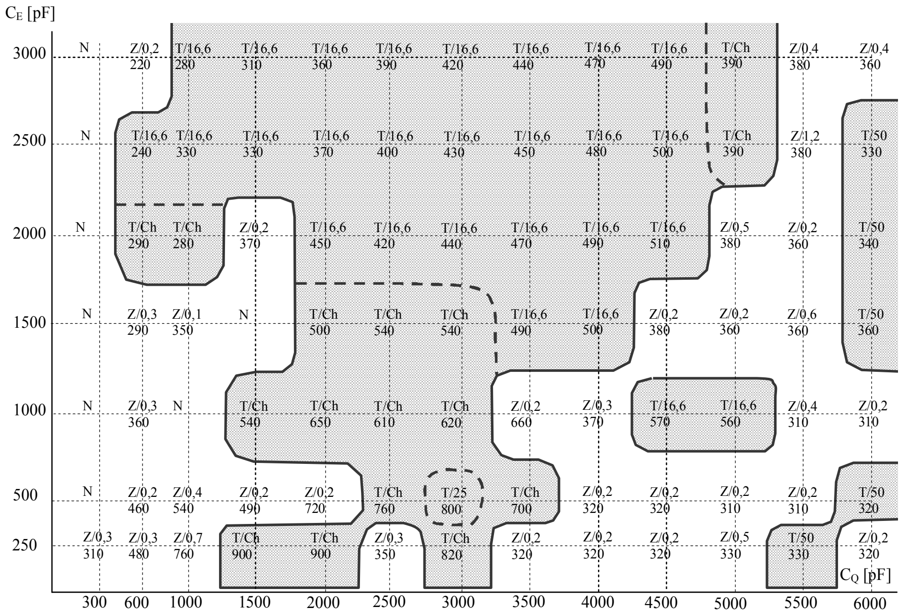

Fig. 9. The ferroresonance map for the investigated 400 kV network for unloaded VT (values of overvoltage in [kV])

3. Conclusions

The results of the simulation calculations of the investigated phenomenon, its properties and parameters for 110 kV substation with unloaded VT were presented as ferroresonance maps. Similar calculations for 220 kV and 400 kV networks with different VT types were performed. The VT parameters were measured in the testing station or were obtained from producers. The calculated results were partly verified by comparing them to those of network measurements. The study results can be useful for planning substation work and also for explaining VT or other network devices faults occurring in the past caused by ferroresonance overvoltages.

References

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