ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING

YEAR : 2005 (1373-1377)
VOLUME : 5
NUMBER : 2

MATHEMATICAL MODELLING OF FERRORESONANCE FOR INVESTIGATION OF FERRORESONANCE CURRENTS

AHMET NAYIR [1] A.R.BABAYEVA [1] E.V. DMITRIYEV[2]
A.M.HASHIMOV[1] I.R. PIVCHIK[1]

[1]Institute of Physics, Azerbaijan National Academy, H. Javid ave. 33, 370143 Baku, Azerbaijan
e-mail: ahmetnayir@hotmail.com

[2] Novosibirsk Academy of Water Transport, Schetinkina str. 93, 630099 Novosibirsk, Russia

ABSTRACT

Ferroresonance currents are studied for determination technical requirements of device for detection and suppression of ferroresonance. Numerical calculations of over-voltages ferroresonance under the given method enable to investigate and develop various protection devices for investigation of ferroresonance currents.

Keywords: *Ferroresonance currents, over-voltages, investigate*

1. INTRODUCTION

Importance of investigations of working regimes of electric systems, leading to damage of electric equipment and insufficient distribution of electric energy, in order to develop their prevention and liquidation measures is determined by up-to-date requirements to reliability of electric supply of consumers. One of the most important reasons of occurrence of such regimes is ferroresonance conditions.

Ferroresonance conditions occur in electric circuits at operative switching, incomplete-phase switching-on, interlacing of arch earth-faults at interaction of non-linear magnetization inductances of magnetic wires of transformers with capacities of electric equipment of electric systems. Ferro-resonance conditions can cause sustained over-voltages on the buses of distribution devices, which are dangerous for over-voltage suppressors and other equipment of distribution devices.

Ferroresonance conditions are exposed in electric circuits with different nominal voltage and by means of grounding of power transformers' neutrals.

As ferroresonance conditions can cause big material losses, it becomes practically impossible to hold field tests. In this connection analysis of ferroresonance schemes, based on mathematical modeling and calculations seems to be the most effective and expedient.

Occurrence and course of ferroresonance conditions are determined by parameters of ferroresonance schemes: parameters of electric

Received Date : 16.12.2003
Accepted Date: 11.03.2005

transmission lines, set and characteristics of electric equipment of electric stations and substations. The task of analysis of influence of calculation ferroresonance schemes parameters to the nature of transition processes and values of over-voltages and current overloads are the topical issue for investigation of process course in ferroresonance schemes.

Exact analysis of ferroresonance conditions has significant difficulties due to non-sinusoidal form of current and voltage curves. Analysis of ferroresonance schemes using mathematical modeling methods requires presence of relevant way of using methods. In such case it is necessary to calculate transition and steady processes proceeding in the scheme and determine currents and voltages in circuit in time.

Since ferroresonance schemes relate to nonlinear electric circuits then as contrasted to linear ones where superposition principle is observed, there are no general ways of analytical solution of nonlinear differential equations in this case. Any change of form and amplitude of acting signal in nonlinear circuits lead to new task with new solution.

We have created a new device to switch electric transmission line off, which is based on current protection, switched on for zero sequence currents, which contains zero sequence filter, reacting to geometrical sum of currents of three phases.

This device does not have weak sensitivity on reacting to incomplete-phase work of electric transmission line and non-switching line off by switches in this working regime of electric transmission.

The purpose of this device is to switch electric transmission line off at incomplete-phase regime by way of extending of functional possibilities of existing device and therefore at indicated regime provide protection of reducing transformer on substation without switches on the highest voltage side with reduced capital and operating expenses.

Use of proposed device exclude the necessity of use of device for protection of reducing transformer from over-voltages on substation without switches on the highest voltage side, reduces costs of substation, decrease area of substation as well as reduce scope of construction-assembling works.

The purpose of this paper is to study ferroresonance currents to determine technical requirements of device for detection and suppression of ferroresonance. Currents at investigation of ferroresonance have not been considered up to now and device was created neither for determination of voltage, nor for determination of current.

Investigated ferroresonance currents, which are removed by zero sequence filter, give the characteristics of ferroresonance.

2. USED METHOD FOR CALCULATION

Equations of multi-wire electric transmission line in view of surface effect in ground and in wires and crown are written in matrix form as following:

$$\left.\begin{aligned} -\frac{\partial u}{\partial x} &= L_0\frac{\partial i}{\partial t} + f\left(\frac{\partial i}{\partial t}, t\right) \\ -\frac{\partial i}{\partial x} &= C_0\frac{\partial u}{\partial t} + \varphi\left(\frac{\partial u}{\partial t}, u\right) \end{aligned}\right\}$$

here L_0, C_0 are matrices of eigen and mutual geometrical inductances and capacities of ETL; u,i are column matrices of voltages and currents; $f\left(\frac{\partial i}{\partial t}, t\right)$- function, taking into account influence of surface effect in ground and wires; $\varphi\left(\frac{\partial u}{\partial t}, u\right)$- function, taking into account effect of crown.

Equations are solved in domain, limited by straight lines x=0, x=l, t=0 and open in direction t. The following formulas have been obtained [1]:

$$u_d - u_p + Z(i_d - i_p) + h\cdot \left[Z\varphi_e\left(\frac{\partial U_e}{\partial t}, U_e\right) + f_e\left(\frac{\partial i_e}{\partial t}, i_e\right)\right] + 0(h^2) = 0$$

$$u_d + u_q + Z(i_d - i_q) + h\cdot \cdot\left[-Z\varphi_e\left(\frac{\partial U_e}{\partial t}, U_e\right) + f_e\left(\frac{\partial i_e}{\partial t}, i_e\right)\right] + 0(h^2) = 0$$

here $Z=\left(L_0C_0^{-1}\right)^{0,5}$ is wave resistance of line without losses; $u_d,u_p,u_q,u_e,i_d,i_p,i_q,i_e$ are voltages and currents in points of considered domain of solution of equations system (1) with coordinates (x,t), (x-h, t-τ), (x+h, t-τ), (x, t-τ) respectively.
Calculation formulas for computation of column matrices of voltages and currents u_d and i_d multi-wire electric transmission line with coordinates (x,t) are following:

$$u_d=0,5(1+\sigma)^{-1}\cdot\left[u_p+u_q+Z(i_p-i_q)-2\sigma(\mp U_3)+2\theta_2\right]$$

$$i_d=0,5(Z+Z_n)^{-1}\cdot\left[u_p-u_q+Z(i_p-i_q)+2\theta_1\right]$$

Here u_d, u_q, i_p, i_q are column k-dimensional matrices of known voltages and currents in points p and q of ETL with coordinates p(x-h,t-τ), q(x+h, t-τ).
Column k-dimensional matrix is:

$$\theta_1=Z_n\sum_{k=1}^{3}\chi_k i_k^{/},$$

here Z_n, χ_k, $i_k^{/}$ are matrix coefficients and current, which definitions are given in.
Column k-dimensional matrix is:

$$\theta_2=hZ\sum_{k=1}^{3}G_kU_{f_{c_k}},$$

$U_{f_{c_k}}$ - known voltage in point f; h – calculation step on distance; Z – square matrix of wave resistances of line without losses; G_k – coefficients, given in [1]; σ - kxk– dimensional matrix coefficient, equal to σ=hGZ; G – determinable diagonal matrix.
Calculation scheme is given on fig. 1.

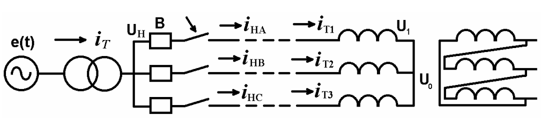

Figure 1. Calculation scheme of substitution

1. In case of switching phase "A" on:
When $i_{H_0}=0,\ \ i_{H_C}=0$

$$\frac{di_T}{dt}=L_T^{-1}\left[e(t)-r_Ti_T-u_H\right]$$

$$u_H=(Z+Z_H)i_{H_A}+\upsilon_q$$

$$u_H=\begin{vmatrix}u_{H_A}\\u_{H_B}\\u_{H_C}\end{vmatrix}=\begin{vmatrix}Z_{11}&Z_{12}&Z_{13}\\Z_{21}&Z_{22}&Z_{23}\\Z_{31}&Z_{32}&Z_{33}\end{vmatrix}\begin{vmatrix}i_{H_A}\\0\\0\end{vmatrix}+\begin{vmatrix}\upsilon_{q_A}\\\upsilon_{q_B}\\\upsilon_{q_C}\end{vmatrix}$$

$$u_{H_A}=Z_{11}i_{H_A}+\upsilon_{q_A}$$
$$u_{H_B}=Z_{12}i_{H_A}+\upsilon_{q_B}$$
$$u_{HC}=Z_{13}i_{H_A}+\upsilon_{q_C}$$

2. In case of switching phases "A" and "B" on, $i_{H_C}=0.$

$$u_H=\begin{vmatrix}u_{H_A}\\u_{H_B}\\u_{H_C}\end{vmatrix}=\begin{vmatrix}Z_{11}&Z_{12}&Z_{13}\\Z_{21}&Z_{22}&Z_{23}\\Z_{31}&Z_{32}&Z_{33}\end{vmatrix}\begin{vmatrix}i_{H_A}\\i_{H_B}\\0\end{vmatrix}+\begin{vmatrix}\upsilon_{q_A}\\\upsilon_{q_B}\\\upsilon_{q_C}\end{vmatrix}$$

$$u_{H_A}=Z_{11}\cdot i_{H_A}+Z_{12}i_{H_B}+\upsilon_{q_A}$$
$$u_{H_B}=Z_{21}\cdot i_{H_A}+Z_{22}i_{H_B}+\upsilon_{B}$$
$$u_{HC}=Z_{31}\cdot i_{H_A}+Z_{32}i_{H_B}+\upsilon_{qC}$$

In compliance with the following formulas can be written for line [2]:

$$u_d+(Z+Z_H)i_d=u_p+Z\cdot i_p+ +h\left[Z\varphi_e\left(\frac{\partial U_e}{\partial t},U_e\right)+f_e\left(\frac{\partial i_e}{\partial t},i_e\right)\right]+ +0(h^2)=0$$

$$-u_d+(Z+Z_H)i_d=-u_q+Z\cdot i_q+ +h\left[-Z\varphi_e\left(\frac{\partial U_e}{\partial t},U_e\right)+f_e\left(\frac{\partial i_e}{\partial t},i_e\right)\right]+ +0(h^2)=0$$

$$A_p=u_p+Z\cdot i_p+ +h\left[Z\varphi_e\left(\frac{\partial U_e}{\partial t},U_e\right)+f_e\left(\frac{\partial i_e}{\partial t},i_e\right)\right]+ +0(h^2)=0$$

$$A_q = -u_q + Z \cdot i_q + \\ + h\left[-Z\varphi_e\left(\frac{\partial U_e}{\partial t}, U_e\right) + f_e\left(\frac{\partial i_e}{\partial t}, i_e\right)\right] + \\ + 0(h^2) = 0$$

$$u_1 = \begin{vmatrix} u_{1_A} \\ u_{2_B} \\ u_{3_C} \end{vmatrix} = \begin{vmatrix} Z_{11} & Z_{12} & Z_{13} \\ Z_{21} & Z_{22} & Z_{23} \\ Z_{31} & Z_{32} & Z_{33} \end{vmatrix} \begin{vmatrix} i_{T_A} \\ i_{T_B} \\ 0 \end{vmatrix} + \begin{vmatrix} \upsilon_{pA} \\ \upsilon_{pB} \\ \upsilon_{pC} \end{vmatrix}$$

$$u_{1_A} = Z_{11} \cdot i_{T_A} + Z_{12} i_{T_B} + \upsilon_{pA}$$
$$u_{1_B} = Z_{21} \cdot i_{T_A} + Z_{22} i_{T_B} + \upsilon_{pB}$$
$$u_{1C} = Z_{31} \cdot i_{T_A} + Z_{32} i_{T_B} + \upsilon_{pC}$$
$$\frac{d\varphi_1}{dt} = u_{1A} - u_0; \quad u_0 = \frac{1}{3}(u_{1_{\setminus A|}} + u_{1_B} + u_{1_C})$$

Analytical description of transition process in linear scheme can be obtained on the basis of solutions of the system of linear differential equations. In this case solution is single and there are no difficulties to obtain it. However in multi-wire lines with non-linear components analytical analysis of transition processes is as a rule impossible [2].

Processes taking place in one phase at ferroresonance conditions significantly depends on effect of others. Based on this it should be admitted that practically sole authentic way to investigate ferroresonance conditions in multi-wire line is a modeling of transition processes by means of computer programs, which shall have a possibility of modeling of multi-wire line and joint solution of equations of transition processes. The program developed by the Institute of Physics of the National Academy of Sciences of Azerbaijan is one of such programs and is designed to calculate transition processes in arbitrary schemes of electric circuits. Ferroresonance processes in the circuit of 110 kV at incomplete-phase switching-on of line have been investigated using this program.

The reasons of incomplete-phase regimes of supply of power transformers and occurrence of ferroresonance can be: burnout of fusing element of high-voltage safety devices (fuses) in one or two phases, incomplete-phase commutations by disconnectors or switches, breaks of air lines wires.

Non-linear over-voltages limiters (OVL) relate to protective devices of equipment from thunderstorm and internal over-voltages. Parameter, which characterizes healthy condition of OVL, is full current of conductivity through it at nominal voltage. OVL is considered healthy if current does not exceed extremely admissible value established for each class of OVL. Dynamics of "aging" of OVL can be judged upon change of current of conductivity in process of operation. As a rule, value of current of conductivity practically does not change for a long time. However if processes of changing of parameters started in OVL as a result of natural aging or frequent overloads on current due to commutation or ferroresonance over-voltages, exceeding average values of currents of conductivity, increase of current may take avalanche nature. Raising of current over extreme value leads to growth of active losses in OVL, its overheating and explosive destruction [3,4]. At ferroresonance, which lasts several seconds, OVL may not stand for.

In connection with above the question of control over dynamics of change of current of conductivity of OVL at nominal voltages and earlier diagnostics of its condition is raised.

3. RESULTS

For protection from ferroresonance it is necessary to investigate ferroresonance currents, i.e. to get its form, harmonics and established regime. Incomplete-phase regime, accompanying with long ferroresonance over-voltages is shown on figs 2 and 3.

It is possible to indicate simple criteria of absence of ferroresonance at incomplete-phase regimes in such schemes: ferroresonance does not take place if capacity current of supplying transformer is less than current of open-circuit transformer.

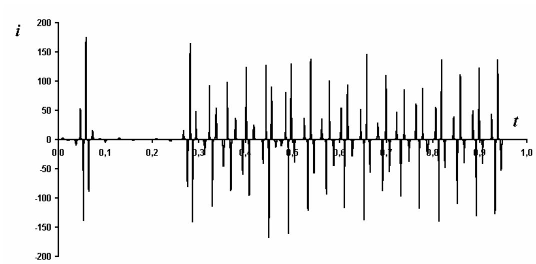

Figure 2a. The calculated oscillogram of the ferroresonance current for $S = 10\, kVA$ and $l = 18\, km$

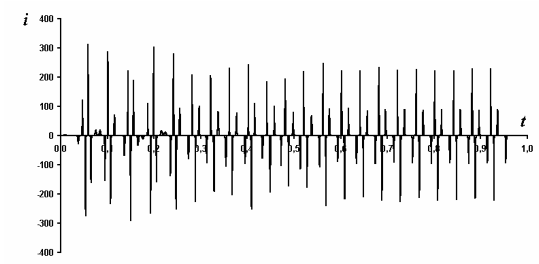

Figure 2b. The calculated oscillogram of the ferroresonance current for $S = 10\ kVA$ and $l = 36\ km$

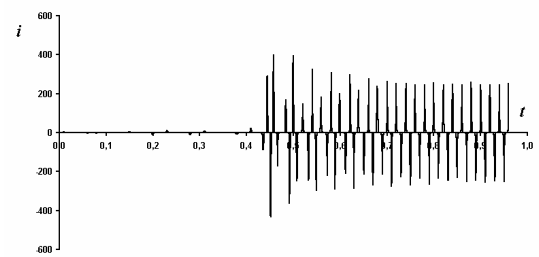

Figure 2c. The calculated oscillogram of the ferroresonance current for $S = 10\ kVA$ and $l = 72\ km$

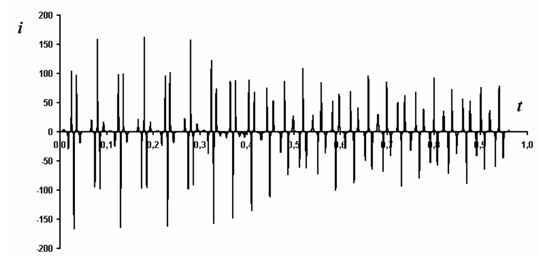

Figure 3a. The calculated oscillogram of the ferroresonance current for $S = 20\ kVA$ and $l = 18\ km$

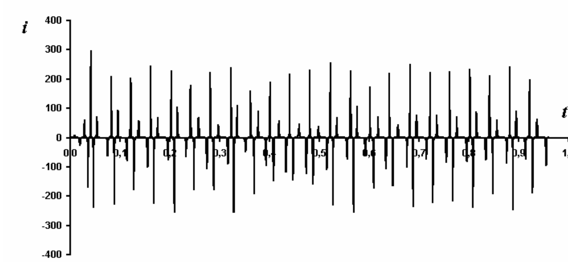

Figure 3b. The calculated oscillogram of the ferroresonance current for $S = 20\ kVA$ and $l = 36\ km$

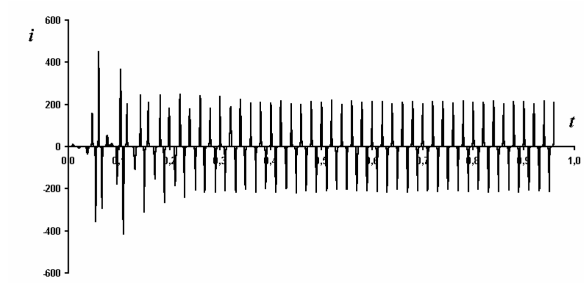

Figure 3c. The calculated oscillogram of the ferroresonance current for $S = 20\ kVA$ and $l = 72\ km$

As is shown from figures, at investigation of ferroresonance currents established amplitude in the period t=(0,1÷0,95) s is observed.

Illustrations of processes below accompanying with ferroresonance over-voltages, are made for transformer with power of S_T=20kVA.

4. CONCLUSION

Numerical calculations of over-voltages ferroresonance under the given method enable to investigate and develop various protection devices for investigation of ferroresonance currents.

5.REFERENCES

[1]. Y.V.Dimitriyev, Arif Hashimov, Ahmet Nayır. Elektrik iletim hatlarında oluşan gerilimlerin modelleri. Bakü, Elm,197pp,2002. (in Turkısh)

[2]. G.A. Yevdakunin, S.S. Titenkov. Ferrorsonance over-voltages for non-symmetrical switching-on for 6-10 kV power transformers // Russian AS Trans.: Power Engineering, №6, 2001 (in Russian)

[3]. A.N. Danilin. On the diagnostics of the protection mechanisms for electric equipment against thundery and internal over-voltages // Russian AS Trans.: Power Engineering, №1, 2001 (in Russian)

[4]. Crane D. Ray, Walsh Georgew. Large mill power outages caused by potential transformer ferroresonance. IEEE Trans. Ind. Appl, 24, No:4, p.634-640, 1988 .