NUMERICAL AND EXPERIMENTAL STUDIES OF FERRORESONANT OVERVOLTAGE IN HIGH-VOLTAGE NETWORKS

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ABSTRACT

The analysis of the ferroresonant overvoltage in major networks revealed that in spite of the significant numbers of researches carried out (in line with the above given principles), at present non of them does relate to synchronous restriction of the overvoltage but is defined by condition of characteristics selection of the ferroresonant overvoltage limitating devices.

Keywords: analysis, ferroresonant, overvoltage, limitating devices, synchronous.

I. INTRODUCTION

Development of computers and calculus mathematics methods broaden highly the potentials of ferroresonant process analysis. This enables to move from conventional models of ferroresonant process (destined only to study of the process with lumped elements) to the wide range models: with range from high-frequency to commercial frequency, including all main types of overvoltage which may occur on the switchgear from the initial to the terminal state of the circuit.

In the modern world the assessment of new protection methods against ferroresonant processes can not be based on overvoltage protection only. The overvoltage initiation in the switchgear is unsafe for equipment insulation and jeopardizes the equipment operation and reliability; it shall be defined at the earlier stage of the study [1].

There is every reason to believe that computer model utilization for numerical experiments on ferroresonant overvoltage to provide protection against any type of overvoltage including ferroresonant ones, will increase. The later is facilitated using the multiprocessor computers and parallel algorithm. The condition of initial computational grid breakdown is often collided during study of self regenerative voltage between switch contacts under short circuit and high-frequency overvoltage in switchgear idler bus isolator switch commutation.

II. MAIN PART

Numerical study of ferroresonant overvoltage in switchgears with voltage transformer which contain capacitive voltage divisors have been carried out at the Physics institute of the Academy of sciences of National Academy of Azerbaijan and at the number of institute in former USSR and at the scientific institutions in abroad [2,3,4].

In the Physics institute studies as a model of loading diagram and numerical experiment of ferroresonant processes the formula given at Fig.1.1 was selected. The study was done for three-phase network in the form of matrix equation. The voltage transformer magnetization characteristic was approximated by polynomial with exponential order of 11.

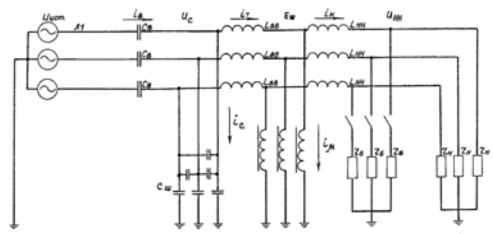

Fig.1.1. Loading diagram

In given model the electromagnetic process with voltage transformer idling ($i_{HN}^{-1} = 0$) is as follows

$$\frac{d\psi}{dt} = \left[1 + l_{BB}\varphi(\psi)\right]^{-1} u_c \qquad (1.1)$$

where

$$\varphi(\psi) = (a + bm\psi^{m-1} + Cn\psi^{n-1}),$$

$$i_{\mu} = a\psi + b\psi^{m} + C\psi^{n},$$

n=9, m=11,a=0,15, b=0,18, c=0,67 - factors and variables are quadratic and column 3rd order matrix. Null is taken as system (1.1) entry conditions.

Method of differential linear equations with distinctly different factors (developed by Djyvarli Ch.M and Dmitriyev E.V. [5] was used for (1.1). The advantage of this method in comparison with widely used Rhunge-Kutt 4^{th} order equation method used for transient process in electric model with distinctly different factors is that the system is solved with no additional calculation step diminution.

Combined equations are solved as per this method

$$y^{`} = f_i(x_1, y_1, y_2 ... y_n),\ i = 1,2,...n \qquad (1.2)$$

Using estimated factors

$$y_i(x + h) = y_i(x) + k_m \qquad (1.3)$$

Where h-calculation step, sec.

$$k_{1i} = hf_i(x_1, y_{1x}, y_{2x}, ... y_{nx});$$

$$k_{2i} = hf_i(x + \frac{h}{m-1}, y_{1x} + \frac{1}{m-1}k_{1m}, ... y_{nx} + \frac{1}{m-1}k_{1n});$$

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$$k_m = hf_i(x + \frac{h}{2}, y_1 + \frac{1}{2}k_{m-1}, ... y_{nx} + \frac{1}{2}k_{m-1})$$

Numerical algorithm for the above equations was constructed on the basic value $u_m=100\ \pi$. Irrespective of voltage transformer type and class, the range of reduction of lower voltage to basic is $100 \cdot \sqrt{2} / 100 \cdot \sqrt{3} \cdot \pi$. For all voltage transformer classes the inductance is $L_B+L_н = 0{,}33\cdot10^{-2\ h}$ henry or $L_{нн} = 0{,}22\cdot10^{-2}$ henry, $L_{Bн} = 0{,}11\cdot10^{-2}$ henry. Excitation current factors which are given in relative units, approximate voltage transformer transfer curves and are in basic units, where $u_m=100\pi$. In present study to consider the transfer curves, the curves based on experiments have been used; the curves approximation from is used and it was also applied in power transformer and autotransformer study. In calculation it is required that transfer curve serves the calculation of both transient and static condition, firstly allowing for all a primary factors affecting calculation accuracy and secondly, considering that computer model error not exceeds the error of node differential equation (differential equations of node points with difference method [6].

Numerical algorithm for the above equations with the basic value was constructed on the stable finite-difference scheme. Having analyzed the deviation of the field study of ferroresonant overvoltage from the corresponding ones on the above named model, the influence of the number of parameters on the reliability of the given model and algorithm of the ferroresonant processes was estimated. It should be noted that the mathematical model, not only describes the stable mode processes and therefore, the mathematical modeling results and the influence of the given parameters can be compared with the results received under stable mode and under parallel mode with the protection devices. This expands the method application range.

However, if present model is used for analysis of the process with different frequency than in ferroresonant processes, such as reset or disconnection of safety devices, the difference in experimental and calculation results increases. The above named model can be used in the limited range ferroresonant processes assessment and also it is very useful in assessment of high frequency cumulative overvoltage, which was discovered during ferroresonant overvoltage experimental work. Therefore, a number of previously obtained results is presented here.The numerical calculation results on four switches ВВБ-220 kV with 220 kV voltage transformer are given on fig. 1.2. The experimental results for bus de-energization with further developed ferroresonant processes from bus to НКФ-110 kV voltage transformer is given in. The established value of ferroresonant overvoltage is $1{,}5u_{фm}$, the maximum current in high voltage coil is 0,96 A. It was shown that with switch numbers increase, the intensity of ferroresonant process raises. The study has shown that overvoltage amplitude can reach 3,5 $u_{фm}$, and primary coil current reaches 6-8 A.

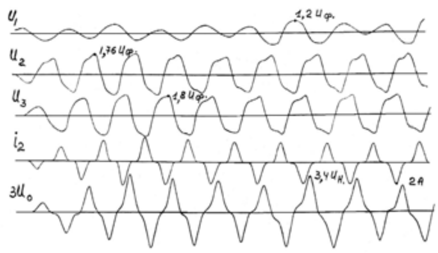

Fig.1.2. Results of the numerical calculations and experiment

To summarize the obtained numerical calculation results and experimental study result, the calculation is carried out for two, three and six switches ВВБ-330 kV with voltage transformer ТН-330 kV, with voltage transformer ТН-500 kV with two switches ВВБ-500 kV. It was established that ferroresonant processes develop unequally; they are very fast on one of the phase and delay on second phase and dramatically delay or in some cases even do not develop at all on the third phase. In the reason of such ferroresonant process development is explained.

The results give grounds for the comprehensive study of ferroresonant processes and for development and laboratory approbation of overvoltage protective devices and study of 3 phase circuit taking into account interference of circuit elements.

Few years later similar results have been received via numerical method in Novosibisk State Technical University. The calculations have been carried out for various bar capacity (from 3 to 50 nF) and potential divider capacity of 825 pF with the appropriate number of switches ВВБ-220 kV from 1 to 10. The maximum level of overvoltage during transition period reaches 2,2 $u_{фm}$, and in a steady mode it is 1,5 $u_{фm}$, and the maximum current is 1,5 A.

As it is well known, to conduct a field study of ferroresonant processes or high frequency overvoltage is complicated from one side by high power supply requirements and power shortage, i.e. separate network is unavailable; and from the other side, to carry out the study on site in operation is hardly possible from the safety point of view.

The existing experimental data relates mainly to switchgear with air break switch; using this data it is impossible or undesirable to develop the modern devices. Therefore, the highly important is to use the mathematical model which describes the process of ferroresonant overvoltage including initial stage of overvoltage evolution, and which helps to select the ferroresonant detection device and to study the process considering protection devices on switchgear; this model allows the emergency actions prediction.

Stability modes, their remoteness from transition process enhance to some extent the reliability of the safety devices which is important taking into account poor computerization of the switchgear overvoltage protection system. In addition to researches the computing experiment in which the analytical models have been taken from the above research, was carried out; the objective was to show the degree of correctness of the circuit selected and adequacy of the formulas. It worth to notice that in some way the analytical model simplification takes place as to solve the applied problems the overvoltage restrictive extended frequency range is required.

Computing experiment results which demonstrate the overvoltage pattern of change have been given. The calculations have been made using program for ferroresonant processes [19, ст.19]. As an example the following options have been taken: switch capacity vary from 1000pF to 9000pF while switchgear bus system capacity relatively earthing also vary from 1000pF to 9000pF, without nonlinear overvoltage limiting device. The results of calculation of ferroresonant overvoltage curves and percentage of harmonic component relating to nominal voltage in transient mode are shown on fig.1.3. As one can see from fig. 1.3, when capacity $C_ш$ changes from 1000 to 4000pF in transient mode, overvoltage is considerably high in the range of 1000pF to 6000pF, although some curve deviation for C_B=3000pF and lower take place.

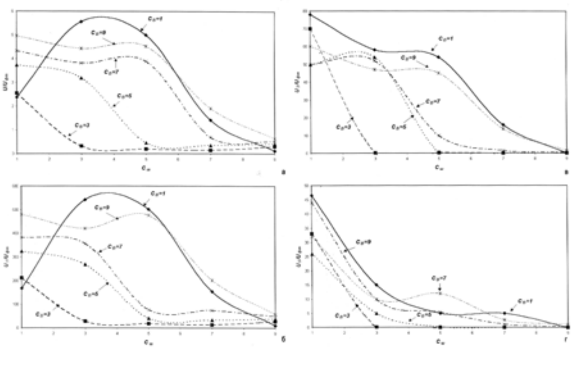

Fig.1.3. Calculated curves of the overvoltage in case of the transition processes and its harmonic components respect to nominal voltage: a – orders of the overvoltages, b – 3rd harmonics, c – 5th harmonics, d – 7th harmonics

The specified law remains also upon ferroresonant steady mode, ref to fig. 1.4.a. The zone of high percentage of single harmonic curves (first, third and fifth) is shown on fig. 1.3.b,c,d. In transition mode fifth harmonic curve is more stable up to C_B=3000pF. When C_B=1000pF zone of considerable overvoltage in transition mode is within voltage divisor capacity range of 2000 to 6000pF. It was noted that fifth harmonic in transition mode is the same almost in all cases, so it can be taken as a basic for modeling and ferroresonant detector can be set on this harmonic. Steady overvoltage values for similar voltage devisor capacities (between bus and earthing) are given at fig. 1.4. The assessment of the effect of capacities correlation on the overvoltage is required for optimal detector's harmonic selection and upon steady mode. The number of periods for steady mode is 15-20. In steady mode the third and fifth voltage harmonics, ref to 1.4c, can be used for ferroresonant process detection and safety device activation by means of impulse batch with width of 0,2-2ms and frequency of 1-5Hz.

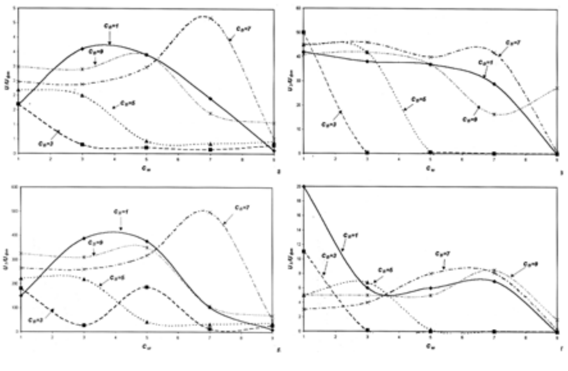

Fig.1.4. Calculated curves of the overvoltage in case of the steady regime and its harmonic components respect to nominal voltage: a – orders of the overvoltages, b – 3rd harmonics, c – 5th harmonics, d – 7th harmonics

The comprehensive researches of the ferroresonant processes with voltage transformer have led to the following results:

- To develop the protective instrument with new characteristics including switchgear assigned and sought quantity combination multivariable set; this would allow to apply this instrument to solve the ferroresonant overvoltage prevention problems;
- To develop the principles of the ferroresonant processes modelling and the models itself for mathematical description of the ferroresonant overvoltages with concentrated, variable and distributive parameters; this would allow developed algorithm application in complex circuits;
- To propose the number of approaches, methods and analysis algorithm for ferroresonant processes which allow assessment of adequacy of ferroresonant processes detection and suppression;
- To develop the principles and guides for switchgear reliability device selection and application.

The analysis of the ferroresonant overvoltage in major networks revealed that in spite of the significant numbers of researches carried out (in line with the above given principles), at present non of them does relate to synchronous restriction of the overvoltage but is defined by condition of characteristics selection of the ferroresonant overvoltage limitating devices.

III. CONCLUSION

The researches have shown that the results received affect significantly only on independent switchgear or its connection. The consideration of the others factors related to switchgear commutation device respond has not allowed getting the reliable results. Therefore, in major networks including switchgears equipped with sulfur hexafluoride [SF6] circuit breaker these results are not recommended for application. Further researches are required to define the efficiency of the overvoltage limitation in combination with complex approach applicable to real switchgear operation.

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