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Numerical Modeling of Transient Overvoltage Shunt Reactor Current Switching in 400 kV Network

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Abstract—**In this paper is presented the simulation of transient overvoltages on the 100 MVAr / 400 kV / 144 A shunt reactor switching and experiments in network.**

The numerical simulation programme has been realized on a specialized software SIMULINK basis for electrical power systems.

Beside the network circuit elements (voltage supply, resistors, reactors and capacitors) the simulation scheme also contains the following three main blocks: a circuit breaker model, a calculation of the chopping current module and a calculation of the transient overvoltage module.

Index Terms—**Modeling, Network Tests.**

I. Introduction

THE shunt reactors are important elements of electric systems, which have to be protected against abnormal regime.

Because of their attachment manner in circuit, they are protected against overload and short circuit current effects.

Due to D.C. component, it is only possible a temporary increasing of the current on connection up to a maximum value, lower than the double of current peak value in normal regime.

For shunt reactor, this does not represent a dangerous stress neither thermic nor electrodynamics.

Analyzing some faults, it has been noticed that they have occurred due to the local deterioration of insulation, pursuant to transient overvoltages on current switching with high voltages circuit breakers.

Regarding stress, shunt reactors switching is included in switching of small inductive current category.

The particularities of this regime are:

- switching current is equal with rated current of shunt reactor, therefore lower than breaking current of circuit breaker;
- in many cases, current breaking occurs a little bit before natural passing through zero, a phenomena named current chopping;
- due to the big value of shunt reactor inductance, the stored energy (magnetic energy) determines an increasing of terminal voltage therefore a tough shunt reactor insulation stress.
- according to circuit breaker performances and certain aleatory parameters (moment of contact opening when voltage passes through zero, distance between contact in the moment of current breaking), an arc reignition can occur, a fact that can generate supplementary stresses (voltage with high speed variation).

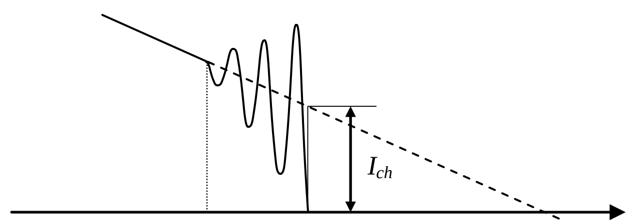

Fig. 1. Current chopping

The current chopping is caused by arc instability (a current oscillation with a high frequency and with amplitude that rapidly increases, superimposed on the current at rated frequency). So, the current will pass through zero before the moment it would normally do.

The oscillation frequency is much higher than the rated frequency, so that the current passing from I_{ch} to zero can be assumed to be instantaneous. At passing through zero, the current is interrupted. The chopping current is the value which the rated frequency current would have in the moment of breaking.

The chopping current value depends on a lot of parameters such as:

- quenching medium;
- number of quenching chamber connected in series per pole (the chopped current increases with the growing of chamber number per pole);
- equivalent capacitance value on circuit breaker terminals (a bigger capacitance causes a bigger

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chopping current).

The shunt reactor on which the experimental determinations have been made is DFAL 8056 400 kV / 100 MVAr type.

The main characteristics are:

- rated current: 144.3 A at 400 kV;
- inductance: 5.017 H (average value);
- capacitance between a phase winding and earth: 3,531 pF (average value);
- longitudinal capacitance of a phase winding: 345 pF (average value);
- power factor cosφ: 0.0078295.

II. Simulation Of Maximum Stresses

The modeling of phenomena occurring at inductive loads disconnecting is based on using some equivalent circuits, single-phased in most of cases. Three-phased circuits are used when is desired to mark out the phase coupling.

Depending on system particularities and on phenomena to be analyzed, the number of elements taken into account is different. The most complete circuit is shown in fig. 2.

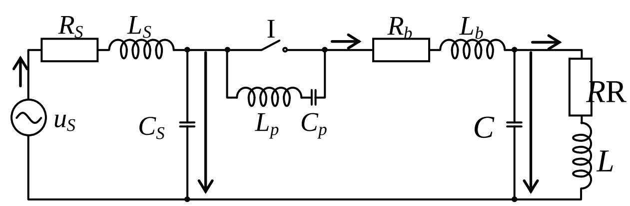


Fig. 2. Equivalent single-phase circuit

The power electric system is modeled by a circuit consisting of voltage supply u_s, resistor R_s, inductance L_s, and capacitor C_s.

Serial circuit L_p, C_p parallel connected with circuit-breaker *I*, is modeling current high frequency oscillations occurring at small current values which lead to current chopping.

The up circuit is represented by R_b, L_b elements (modeling linkage between circuit-breaker and coil) and *R*, *L*, *C* (modeling compensating coil). Capacitor *C* includes, besides proper capacity of another equipment (voltage transformer, surge arrester) between up circuit and earth.

III. Presentation Of Used Model

Taking into account constructive and rated characteristics nominal of coil (neutral directly earthed, 5 columns core, so it doesn't exist magnetic coupling between phases and core) and those of network (neutral earthed), one can use a single-phase circuit.

In order to determine maximum values of recovery voltages, which can stresses compensating coil in exploitation, was realized within SIMULINK a model of circuit, presented in fig. 3.

Beside elements presented in fig. 2, this diagram contains some blocks simulating circuit-breaker operating.

So, the module circuit-breaker model represents the model of a single-phase circuit-breaker, its closing is instantaneous at the moment is closing input commutation from "0" to "1". The opening is given by commutation of opening input from "0" to "1" and can be achieved in different ways, depending on input value of chopping current.

If the input chopping current has zero value, the circuit opening is achieved at first zero-passing of the current through circuit-breaker.

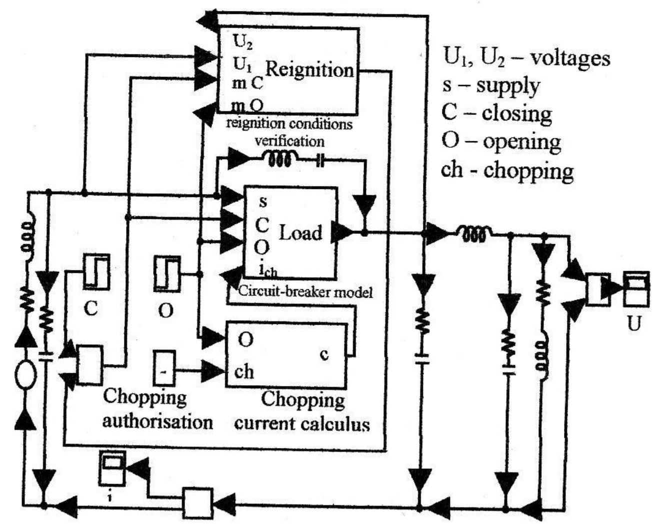


Fig. 3. SIMULINK Model

If the input chopping current has non-zero value, the circuit opening is achieved at the moment of opening input commutation from "0" to "1", so it can be simulated a current chopping.

The module verification reignition conditions compare the momentary value of recovery voltage with keeping voltage circuit-breaker. When recovery voltage overpass keeping voltage then the output reignition commutes from "0" to "1" and directs the circuit-breaker closing. Keeping voltage of circuit-breaker is modeled by a linear variation:

$u_t = u_o + k \cdot t$

where u_o is initial value, *k* growing coefficient and *t* represents time, measured from the moment of effective interrupt of current through circuit-breaker.

The module chopping current calculus has as inputs the opening command and chopping authorization (which id "0" if we wish current interrupt at zero passing and it is "1" when we wish current chopping).

IV. Results On Model

Through modeling of some experimental above cases was put in evidence a very good concordance between the results obtained with this model and the stresses directly obtained by measurements, both regarding the value of maximum voltage and regarding oscillating frequency. The model was used to determine the probable value of recovery voltage at which the compensating coil can be stressed in exploitation when for commutation it is used a minimum-oil circuit-breaker (fig.4). The value of 15 A for chopping current was obtained through statistic analysis of experimental obtained values for chopping current within network tests. This way one obtained a medium value of 11.26 A, and a standard deviation of 3.85 A. In such conditions the value of chopping current with the appearance probability greater of 1 % will be 15.1 A, (if we suppose a normal repartition of chopping currents).

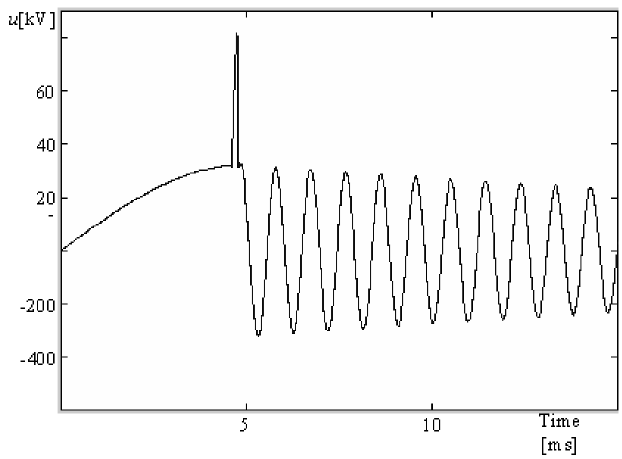


Fig. 4. Recovery voltage at coil terminal at current breaking with 250 μs before natural zero passing (I_{ch} = 15 A)

The value of maximum voltage correspond to an overvoltage coefficient k_m = 2.58 which is superior to norms admitted value (k_m is transient overvoltage/phase to earth voltage).

This model can be used also for modeling arc reignitions in circuit-breaker. A reignition example is presented in fug. 5 (osc.1), where the overvoltage coefficient is k_m = 2.38

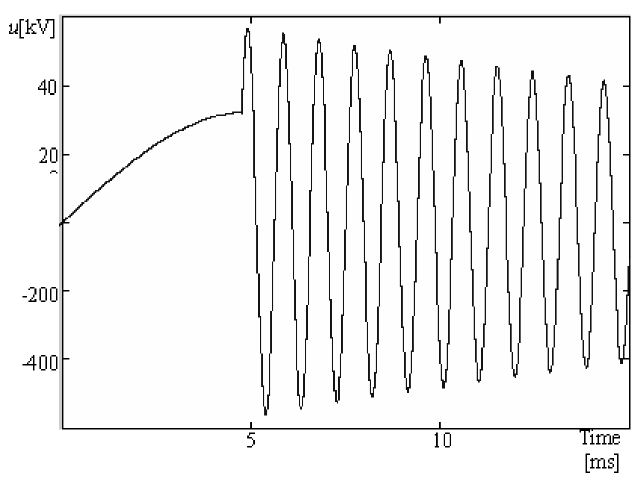


Fig. 5. Example of arc reignition in circuit-breaker

V. Experiments For Overvoltages Determination In Networks

The tests made on real network circuit in a 420 kV substation (fig. 6) pursued the measurement determination of overvoltages in order to validate the numerical model.

The shunt reactor switching has been made with 420 kV oil circuit-breaker with six break points. It has been marked with six break points. It has been marked out simple and multiple reignitions and transient overvoltages (k_e = 2.32; see fig. 7, osc.2).

The results obtained by modeling and experimental are shown in table no.1. The results also show that the model can be validated.

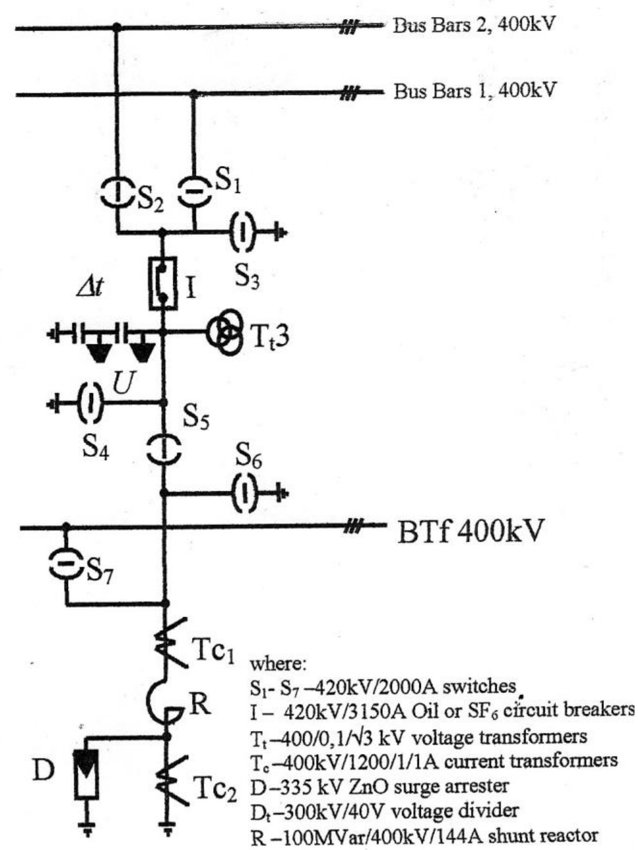


Fig. 6. Diagram of 400 kV substation

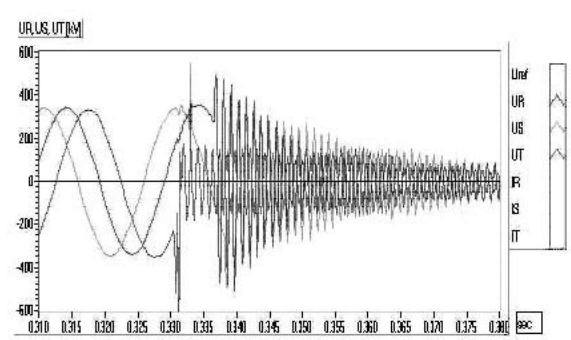


Fig. 7. Computer recorded oscillogram on network test

TABLE I

Osc.	Transient Overvoltage		Overvoltage Coefficient		Remarks
	U_M	U_S	K_M	K_E	
	kV	kV	u.r.	u.r.	
Osc. 1	637	-	2.58	-	Chopping Current
Osc. 1, 2	589	574	2.38	2.32	Reignition

VI. Conclusions

At shunt reactor current switching, the stresses have been determined by numeric calculation with modeling programs and by the experimental measurement on real circuits in HV network.

Current chopping, simple and multiple reignition and transient overvoltages have been modeled with SIMULINK program.

In case of oil circuit breaker modeling, a chopping current high dispersion occurs which determines high overvoltages (e.g. for I_{ch} = 15 A, k = 2.58, over allowed limit).

Simple and multiple reignitions generate high overvoltages (k_m *= 2.38 by modeling,* k_e = 2.32 by experiment).

The obtained results show a correspondence between the overvoltages and transient frequencies values between model and experiment.

VII. References

[1] ***, "IEC 61233/1999 Disjoncteurs haute tension a courant alternative – Establissement et coupure de charge inductive".

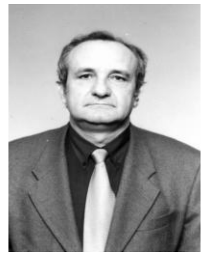
[2] G. Curcanu, I. Mircea, H. Ionescu, P. C. Stroica, M. Ciontu "Studii si experimentari pentru determinarea supratensiunilor tranzitorii la comutatia curentilor sunt cu intreruptoare de 420 kV cu ulei si SF6 in statia Urechesti - Gorj", in *Proc. of CNE 02, Neptun, Romania, 2002.*

[3] ***, "Manoeuvres controlee des disjoncteurs HT a courant alternative – Guide pour une application aux lignes, reactances, condensateurs, transfomateurs 1 partie," in *Electra, No. 183, avril 1999.*

[4] ***, "Manoeuvres controlee des disjoncteurs HT a courant alternative – Guide pour une application aux lignes, reactances, condensateurs, transfomateurs 2 partie," in *Electra, No. 185, august 1999.*

VIII. Biographies

Paul Stroica was born in Rosiorii de Vede, Romania, on February 18, 1964. He graduated in 1988 from the Electrotechnical Faculty, Craiova, and studied at the University of Craiova. He graduated in 2004 from the Electromechanical Faculty, Craiova his PhD. His employment experience included the Romanian Electromontaj Company Craiova, RENEL - Romanian Electricity Authority, Craiova Transmission and Distribution Subsidiary, CONEL - Romania Electricity Company, Craiova Transmission and Dispatching Branch, TRANSELECTRICA - National Power Grid, Craiova Transmission Subsidiary, Company for Maintenance of the Romanian Power Grid SMART S.A. - Craiova Subsidiary. He was for 6 years senior engineer in high voltage maintenance activities, 6 years head of high voltage department, 1 year technical manager maintenance-development. Since 2001 he is manager of SMART Craiova Subsidiary. He is for 10 years Member of IEEE, Power Engineering Society, and for 8 years Member of CIGRE. His field of interest included high voltage.



Ion Merfu was born in Bratuia, Romania, on September 28, 1949. He graduated from the Energetic Faculty, Bucharest, and studied at the Polytechnic Institute of Bucharest. His employment experience included the RENEL - Romanian Electricity Authority, Craiova Transmission and Distribution Subsidiary, CONEL - Romania Electricity Company, TRANSELECTRICA - National Power Grid, Craiova Transmission Branch. He was for 9 years senior engineer in high voltage maintenance activities, 14 years head of high voltage department, 6 years manager of Craiova Branch, 1 year deputy general manager of CONEL and 1 year general manager of TRANSELECTRICA. Now he is manager of TRANSELECTRICA Craiova Branch. His field of interest included high voltage.