OVERVOLTAGES LIMITATION IN THE 400 kV NORD TRANSILVANIA NETWORK

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Abstract: **The paper presents a computer model, which simulates the over-voltages in a 400 kV substation of Nord Transilvania power network. The analysis suggests ways of minimising these over-voltages to limit the potential detrimental effects on equipment. The over-voltages caused by "switching on" and "switching off" a large reactor are presented. For several switching times the distribution of over-voltages and DC offset are presented and how these parameters are influenced by the switching angle. These results are used by an expert system to model the synchronising of the reactor breaker. The system describes the program of the shunt reactor breaker command by anticipation. The method propose to reduce the amplitude of the over-voltages to an acceptable level is control switching of each phase combined with the use of surge arrester. The PSCAD simulations are compared with the field measurements "in situ" of the switching shunt reactor.**

Keywords: Transient Over-voltages, High Voltage Network, High Voltage Breaker, Synchronised Switching, Shunt Reactor, Surge Arrester, PSACD Simulation

I. INTRODUCTION

Energy demand in the Romanian Power System has declined since 1989 by 42% and this tendency changes the charge of substations and the power flux of transport and distribution networks. The Romanian Power System has today an excess of nominal capacity installed in its power plants as well as an extensive transmission system (220-400-750) kV. The High Voltage networks are discharged significantly as a consequence of the diminish of large consumers and an increase of medium ones, therefore the HV network is now lightly loaded. So during the low demand periods (i.e. nights, weekends, holidays) the power control involves using shunt reactors, synchronous compensators and even HV long line disconnection.

The connection with UCPTE Power System has a major importance and involves great investments in developing and improving the HV networks, especially in the interconnected area with the neighbors.

Through modification of the functioning conditions, determined by the necessity of using shunt reactors to control the voltage, result an increase number of reactor switchings. Between 1988-1994 were recorded about 1200 switchings of shunt reactor at the substation under study, with an average of 190 operations per year. The operations are generated by few-loaded network during the weekend or night. In the Romanian Power System some hundred operations per year are not uncommon, so it is necessary to analyse the over-voltages generated by shunt reactor switching on the 400 kV network and also determine the optimum protection measures. [15]

The system under study, the Gadalin substation, Romania includes: the 400 kV network, the circuit breaker, the shunt reactor bank (3x60 MVAr) and the surge protective device (zinc oxide arrester). Fig.1

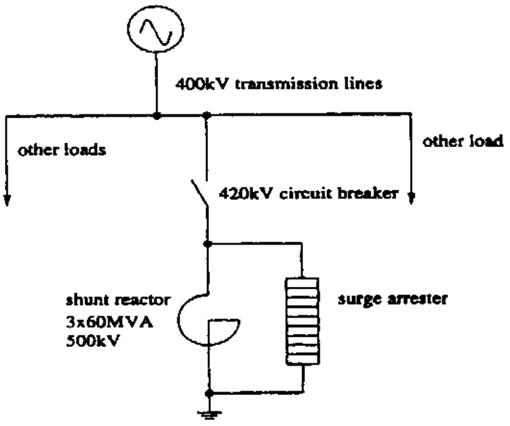

Fig.1 The Gadalin substation

PSCAD simulation has been used to find the best point of wave for contact touch and contact separation, to investigate the expectable effect of exchanging the time of switching on each phase and to predict the transient over-voltages. The model is based on the electrotechnical characteristics of the power station, the equipment and the network to be switched.

In November 1996 the shunt reactor commutation over-voltages in Gadalin substation were measured "in situ" with a 400 kV classical circuit breaker and a SF6 testimony breaker. The simulation results obtained are in good agreement with field tests.

II. SYNCHRONISE SWITCHING OF LARGE SHUNT REACTOR

When interrupting a large reactor, the breaker voltage oscillates to the peak value of the recovery voltage. The breaker must be able to cope with the recovery voltage's rate of rise at its peak value. The dielectric strength between the arcing contacts must build up faster than the rate of the recovery voltage if re-striking is to be prevented. So the probability if re-ignition and the maximum voltage at which re-ignition can occur, is determined by whether the contact distance has become large enough to withstand the transient recovery voltage when it approaches its peak value. [8]

Depending on the type of circuit breaker, this results in a chopping over-voltage that is typically 1.1-1.2 p.u. for SF6 breakers. The chopping over-voltage adds to amplitude of the transient recovery voltage thus increasing the re-ignition probability.

When the arc between the circuit breaker contacts breaks, the full system voltage (recovery voltage) suddenly appears across the open gap and hence across the circuit. The a.c. arc is extinguished at each current zero. In HV circuits and without extra measures the arc re-ignites after passing current zero and continues to burn. [3]

The magnitude of switching over-voltages depends mainly on the phase position at which the switching takes place, the network configuration and the type of load that will be connected or disconnected. One of the most significant methods of reducing the commutation over-voltages amplitude to acceptable levels, is the point-of-wave switching. Synchronised switching is intended to eliminate re-ignitions, which may (especially in large numbers) jeopardise the insulation of the reactor, the breaker itself and other nearby equipment. [4]

For the majority of circuit breakers in service, the contact closing or opening is a duty performed without any consideration of the phase instant. This means that the severity of the switching, in terms of stress on the system, the breaker itself and other nearby equipment, is determined by a probability distribution. [6]

Synchronised switching is designed to withhold a closing or opening operation up to the best possible point on wave moment for the switching. It is therefore assumed that the three phases can be controlled and switched individually. To achieve this, each pole must be switched at the optimum point on wave for the contact touch or contact separation and the relay must be informed about what operating times are to be expected. [1]

The synchronising system utilises a microprocessor that derives command outputs and individual settings for all three poles. The relay makes it possible to connect the load to the network at a predetermined instant which gives the best transient suppression. [3]

A software ensemble, composed by a data base, network simulations (PSCAD, EMTP or Saber simulations) an expert system and a planning program for the instant of operating command gives the solution in such a way that switching – circuit closing or opening – will take place at a best point on wave. [13] The expert system is able to model the functioning of the system by using the passive data previously acquired. The basic function of the system is previewing having as start point a current situation generally by using a model constructed on a historical base. [14]

The system can deal with the situation that changes through the time by storing the data in the historical field of data base (i.e. the operating times for the mechanical device of the breaker), that can be used for a long term analysis and replay the data for the ponderate media of the last ten operations for example.

The frequency of memorisation may according to the current context and the relative importance of the changes. The situation is available for each phase of the breaker.

The time for switching command include: the time needed to find a reference voltage zero, the breaker's operating time for each pole and a waiting time from the reference instant to output command, taking into account by the expert system's rules. The latter is different for the poles because the pole's operating times are not necessarily equal.

This basic information are given to the knowledge base and the expert system analysis the inference rules and provide a real solution for switching.

III. PSCAD SIMULATION

The results of the field tests carried out in November 1996 for 12 off switchings of a classical circuit breaker and 13 off switchings of a SF6 circuit breaker are shown in Appendix1. For IO 420 kV circuit breaker there are no off switchings without re-ignition of the electric arc. For the H 420 kV circuit breaker was recorded only one re-ignition of the electric arc every two switchings off. So it is a great probability for re-ignition to occur with a random opening of the shunt reactor. [10] Therefore it is very important to analyse the over-voltages generated by shunt reactor switchings and determine the optimum protection measures.

PSCAD/EMTDC (Power System CAD/ Electromagnetic Transient and DC) consists of a set of programs which enable the efficient simulation of power-system networks. PSCAD allows the user to enter a circuit graphically, solve transmission-line and cable parameters, interact with EMTDC simulation while in progress and assess the results of a simulation. [5]

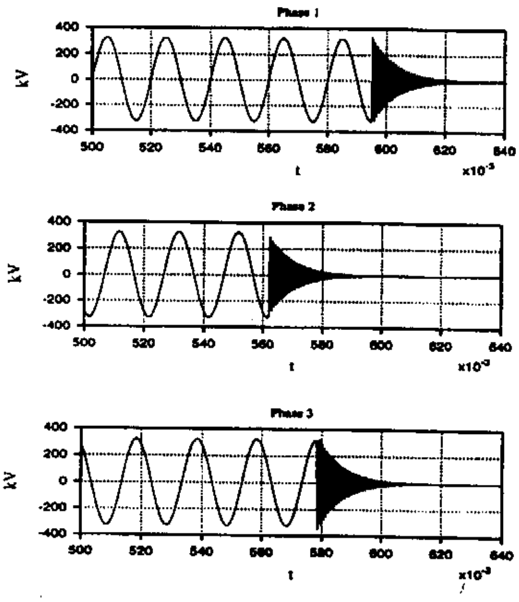

Fig.2 PSCAD simulation results without surge arrester at the best point on wave

Fig.2 shows the PSCAD simulation results without surge arrester at the best point on wave when opening the HV breaker of a large shunt reactor. Determining, for each pole, the optimum point on wave for contact touch or contact separation results in substantially reduced switching transients.

It can be seen from Fig.3 that a large over-voltage is generated when the HV breaker is opened not at the best point on wave. The magnitude depending on each pole's operating time. If the moment is very far for the best moment, large over-voltages are developed in the system. The optimum point on wave for switching out is at the current zero.

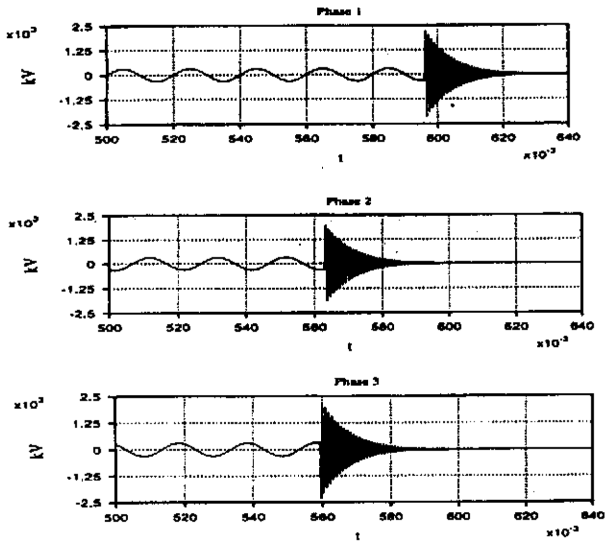

Fig.3 The PSCAD simulation results without surge arrester not at the best point on the wave

Fig.4 shows the variation of the over-voltage as the switching angle changes. A very large increase in over-voltage occurs when the switching angle is far from the optimum position.

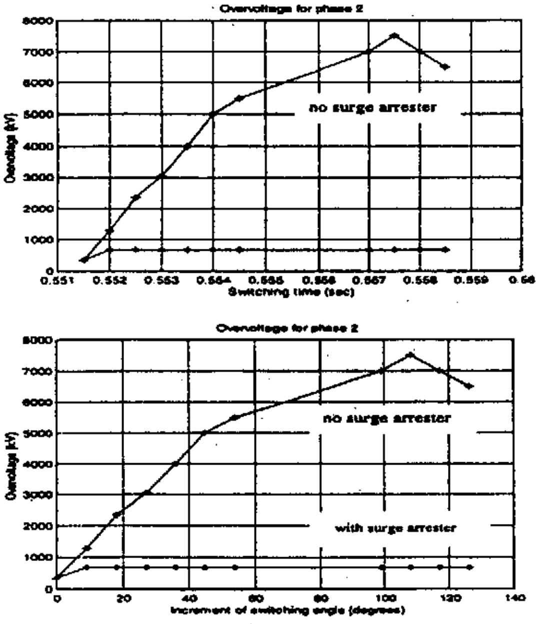

Fig.4 The distribution of over-voltages

Fig.5 shows the simulation results of opening a controlled circuit breaker when the line is protected with a surge arrester. The over-voltages are clearly limited in amplitude by the surge arrester.

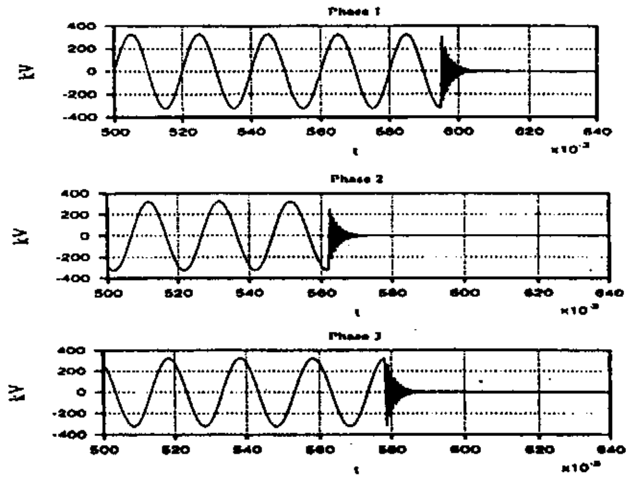

Fig.5 The PSCAD simulation results with surge arrester at the best point on the wave

Fig.6 shows the simulation results for uncontrolled opening of the HV breaker with surge arrester. The surge arrester again limits the over-voltages, but at the instant of switching, large over-voltage are still generates.

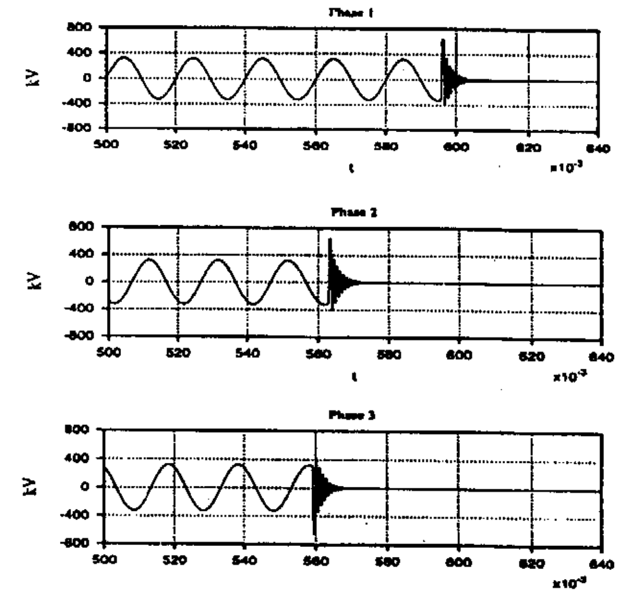

Fig.6 The simulation results with surge arrester not at the best point on wave.

When all three phases are closed at the same time, there is a large DC offset in at least two phases. The optimum point on wave for the switching on of each phase is at the peak of the voltage. Fig.7 displays the DC offset current upon energising the large reactor and how this changes with switching angle.

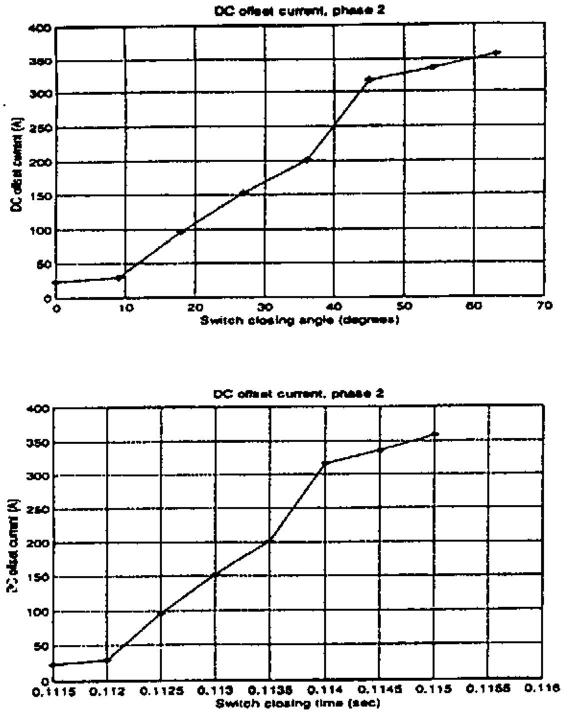

Fig.7 The DC offset current

IV. CONCLUSIONS

This paper presents a series of domain simulation results for the energisation and de-energisation of a large shunt reactor. PSCAD simulations have been used to analyse the system and good agreement between simulations and site-measured results has been obtained. (Table 1)

The aim of the simulations for the commutation over-voltages on a shunt reactor, was to establish the correspondence between simulations on PSCAD program and the field measurement results. The intention of the authors is to establish a valuable data base for the expert system used in point on wave switching. [14] The main objective of the paper is to propose a set of electrotechnical rules and simulations that will enable the user to choose an apropiate program for the commutation which are more suitable to the field measurements. For this purpose the measurements was done "in the field" on the same shunt reactor and the phases were equiped with different types of circuit breaker: the R and S phase with an IO-400kV-1600A-6000MVA and the phase T with a H-400kV-SF6-1600 A.

With random opening of shunt reactor circuit breaker over-voltages are produced according to figure 3. These over-voltages can be reduced with switching at the peak of the supply voltage to each phase (figure 2), which corresponds to the current zero in the reactor when the stored energy within the reactor is at a minimum. The general variation of the peak over-voltage amplitude with switching angle is shown in Figure 4. A further reduction in the amplitude of the over-voltage can be obtained using a surge arrester. The optimum method of reducing such switching over-voltage is to combine both point on wave-switching and the use of surge arrester.

When energising a shunt reactor a large DC current component appears in the phase current, depending on the switching angle. To suppress this, the optimum switching point is the peak of the a.c. phase voltage. Without optimum switching the DC component will take many cycled to decay due to the low system resistance and the high Q factor of the reactor.

The simulation results presented in this paper show that a combination of point on wave switching and the use of surge arrester allows the switching of shunt reactors with a minimum impact on the a.c. power system. Whatever switching strategy is used, the simulation described in this paper can be used to predict the transient performance of the system during switching operations and to assist protection engineers in determining the optimum settings for the power system protection relays.

Table 1
Comparison of calculated and measured over-voltages

	Phase-to-ground overvoltage p.u. (with surge arrester)
	Without synchronisation
Computer simulation	1.65
Field tests IO 420	1.59 – 1.79
Field tests H420	1.18 – 1.54

V. REFERENCES

1. CIGRE Study Committee 13, Task Force 13.00.1: *Report on Controlled Switching*, CIGRE 13-93 (TF 13.00.1) IWD4, 1993
2. CIGRE Study Committee B, Task Force 13.00.1: *Report on Controlled Switching "A state-of-the -art-survey"*, Electra 163/164 January/February, 1996
3. Dalzied, I., Foreman P., Irwin T., Jones C.J.: *Application of controlled switching in High Voltage system*, Proceedings of 1996, CIGRE, Section 13, paper 315
4. Alvison, R.: *Controlled switching of circuit-breaker for capacitor banks, lines, shunt reactor, power-transformer*, A technology status review, in ABB review BC-96-027
5. Arrillaga J., Arnold C.P., *Computer analysis of power systems*, John Wiley & Sons, 1990
6. Peelo D.F., Ruoss E,M., *A new IEEE application guide for shunt reactor switching*, IEEE Transactions on Power Delivery, vol.11, no.2, April 1996, pp.881-887
7. Alvinsson R., Solver C.E., *Switching to lower transients*, Modern Power Systems, March 1991, pp.41-45

8. Flurscheim C.H., *Power circuit breaker theory and design*, IEE Power Engineering Series 1, Short Run press Ltd, 1982
9. William D.Stevenson Jr., *Elements of power systems analysis*, McGraw-Hill International Book Company, 1982
10. Prikler L., Ban G., Banfai G., EMTP Models for simulation of shunt reactor switching transients, Electrical Power & Energy Systems, Vol.19, No.4, 1997, pp.235-240
11. Fanica, V., Ungureanu, M., *The analysis of over-voltages generated by off switchings of shunt reactors in 110 kV and 400 kV networks*, Power Study Institute, Bucharest, 1996
12. Smith K.S., Ran L., Leyman B., *Analysis of transformer innrush transients in offshore electrical systems*, IEE Proceedings Generation Transmission and Distribution (in print)
13. Smith K.S., Ran L., *Time domain modelling of electrical machines and drives using modern CAE software*, IEE 6th International Conference on Electrical Machine and Drives, Oxford, UK, September, 1993, pp.323-327
14. Ungureanu, P., Cipcigan L.:*Point on wave switching: optimum circuit closing timing established by an expert system based on EMTP rules*, EEUG European EMTP-ATP Meeting, Hungary, 1996, Session F
15. Ungureanu, P., Cipcigan L.: *Expert System for the Synchronized Switching of the High Voltage Breaker*, IASTED, MIC '97, Innsbruck, Austria,1997, Sesion 01 Power and Energy Systems, pp.24-27
16. Ungureanu, P.: *Transient over-voltages in the Romanian Power System; the power exchange between Interconnected Power System and Romanian Power System*, SNRE, Cluj, Romania, 1992, pp30-38
17. Wilson, D.H., Whittington, H.W., *Electricity supply in the transition economies of Bulgaria and Romania*, IEE Power Engineering Journal, June 1996, pp.100-106
18. *** *Measurements "in situ" on off switchings of the shunt reactor in Gadalin substation*, HV Research Laboratory, Craiova, Romania, 1996-1997

APPENDIX 1

CIRCUIT BREAKER 400 kV	SWITCHINGS OFF	Re-ignition of the electric arc		OVERVOLTAGE FACTOR (p.u.)		ELECTRIC ARC DURATION (ms)
		First re-ignition	*Second re-ignition*	*Breakdown*	*Re-ignition*	
IO 420 (oil) Phase R, S	12	10	2	1.59…1.79	2.29…2.39	15…21
H420 (SF6) Phase T	13	5	-	1.18…1.54	2.15	4…15