Switching Overvoltages on 400 and 750 kV Romanian Transmission Lines

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Abstract - **The paper presents the results of two studies concerning the 400 and 750 kV transmission lines in Romania. First the performance of three-phase and single-phase reclosing have been evaluated. The risks of flashover for different rated switching impulse withstand voltages have been computed. For reducing the line's insulation level, the possibilities of limiting the overvoltages at three-phase reclosing of the 750 kV shunt compensated transmission lines with trapped charge have been investigated,**

Keywords: Transmission line, switching overvoltages, risk of flashover, preinsertion resistors, controlled closing, ATP-EMTP.

I. INTRODUCTION

At operating voltages of 400 kV and above, the transmission line insulation level is largely determined by the magnitude of switching overvoltages. The need to withstand the switching surges can affect the cost of a system considerably, so that an accurate estimation of switching overvoltages under various conditions of operation is important.

The modernization process in the Romanian power systems, in order to make it compatible to the UCPTE system, raises also the problem of the transmission lines' reliability evaluation.

Switching transients on high voltage/extra high voltage transmission lines are stochastic phenomena. The severity of the switching overvoltages strongly depends on the closing phase instant.

Controlled closing of circuit breakers, that is closing or opening the contact by point-on-wave control has been a desirable method for switching stress reduction for many years. Also in Western Europe countries, a real break-through was achieved only in the last decade when more sophisticated electronic devices became available at reasonable cost [1].

The paper presents the results of two studies on autoreclosing performance of 400 kV and 750 kV shunt-reactor compensated transmission lines in Romania.

The reliability of the switching operation has been established for 400 kV and 750 kV lines, taking into account different rated switching impulse withstand voltages. The overvoltages caused by reclosing have been simulated under various switching conditions. The transient switching phenomena during autoreclosing cycle of shunt-reactor compensated lines are reviewed.

The beat aspect of the voltage across the circuit breaker is revealed and the correlation between the overvoltage level and the closing instant of the breaker poles is evaluated.

II. RECLOSING OF 400 kV and 750 kV LINE WITH SHUNT REACTOR COMPENSATION

A. 400 kV transmission line study

Two insulation levels have been used for the 400 kV system in Romania. The earlier lines used a rated switching surge withstand voltage of 1050 kV_{peak} and later lines used 950 kV_{peak}. The aim of the study was to establish the necessary conditions to limit the switching surge level at 2.47 pu on a 400 kV line and finally to use an insulation level of 850 kV_{peak}. Fig. 1 presents the model used for evaluating the switching transients at three-phase and single-phase autoreclosing of 400 kV line. The detailed studies have been performed with ATP-EMTP. The parameters for the 400 kV transmission line of length l=400 km are as follows: a tower configuration given by the tower PASS-400, with twin bundle phase conductors placed in the same plane, 450/75 mm^2 OL-Al and two earth wires, 150 mm^2 OL. The earth resistivity was assumed to be 100 Ωm. The frequency dependence of line parameters was taken into account.

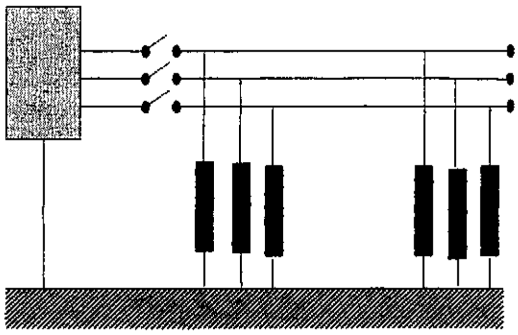

Fig. 1. Simulation model for high voltage transmission line with shunt reactor compensation

The shunt reactors have been modelled as parallel connection of inductance and resistance. An R, L equivalent circuit has been used for the complex feeding network.

Fig. 2 presents the overvoltage distribution for the three-phase (curve 1) and single-phase (curve 2) reclosing, without any methods of overvoltage limitation. The nonsimultaneous closure of the breaker poles and the presence of trapped charge for three-phase reclosing have been taken into account.

These studies showed that, without any method of overvoltage reduction, the 2.47 pu limit for the insulation level does not offer a satisfactory reliability of the switching operations.

The risk of flashover for the line insulation is given by:

$$R = \int_{0}^{\infty} p(U) P_T(U) dU \qquad (1)$$

where $p(U)$ represents the density probability function for the switching overvoltages and $P_T(U)$ represents the flashover probability for the insulation subject to the surge of magnitude U. If we assume that insulation breakdown characteristics have a normal probability distribution and the overvoltages distribution function is also normal, then (1) can be written as follows:

$$R = \Phi\left(\frac{\overline{U} - U_{50}}{\sqrt{\sigma^2 + \sigma_T^2}}\right) \qquad (2)$$

where Φ- the normal cumulative function, $\overline{U}$ - the mean and σ- the standard deviation for the overvoltages, U_{50} - the mean and σ_T - the standard deviation for the flashover voltage.

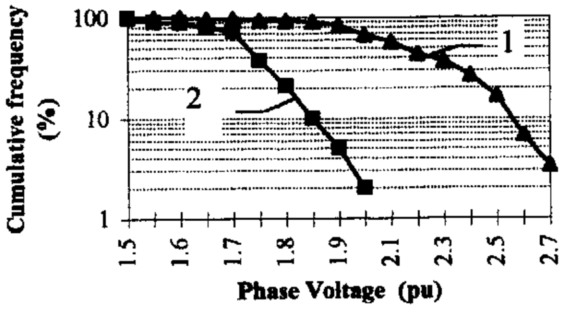

Fig. 2. Statistical distribution of switching overvoltage (receiving end) at single-phase and three-phase reclosing of 400 kV transmission line with shunt reactor compensation (no special overvoltage protection has been used)

The flashover voltage has been considered normal distributed with a standard deviation of 6% and a mean value given by:

$$U_{50} = \frac{u_p}{1 - 1{,}282\sigma_T} \qquad (3)$$

where u_p represent the rated switching withstand voltage [1].

Table 1 shows the characteristics of the overvoltage distribution presented in fig. 2. For comparison are presented the characteristics of the overvoltages' distribution determined from a field test [2]. The calculated risk of flashover values for three rated switching impulse withstand voltages are also given in table 1.

The flashover risk of rated switching impulse 850 kV_{peak} for the conditions of three-phase reclosing with trapped charge and with nonsimultaneous closure of the breaker poles has been considered high and not offering the necessary reliability of operation. Consequently methods of limiting switching overvoltages have been investigated.

Table 1: Characteristics of switching overvoltages on 400 kV line and risk of flashover

Operation	Overvoltage characteristics Receiving end		Insulation level u_p (kV_{peak})	Flashover risk R
Three phase reclosing	$\overline{U}$	2,17	850	0,0735
	σ	0,282	950	0,008
			1050	0,0005
Single phase reclosing	$\overline{U}$	1,654	850	0,0003
	σ	0,248	950	0,00004
			1050	$1{,}1 \cdot 10^{-6}$
Three phase closing	Field	test	850	0,0015
	$\overline{U}$	1,76	950	$4 \cdot 10^{-5}$
	σ	0,253	1050	$6{,}5 \cdot 10^{-6}$

The measured values presented in Table 1 refer to a closing operation, without considering trapped charge on the line. The calculated values for the reclosing operations, in Table 1, take into account the presence of trapped charge. This reason explains the differences between field test and simulation.

B. 750 kV transmission line study

The reliability study of switching operations on 750 kV transmission line has been performed using the simulation model in fig. 1.

Fig. 3 presents the statistical distribution of switching overvoltage at three-phase (curve 1) and single-phase (curve 2) reclosing of 750 kV transmission line with shunt reactor compensation. A 100 % compensation degree has been taken into account.

Parameters for the 750 kV transmission line of length l=400 km are as follows: a tower configuration given by the tower PASS-750, with five-bundle phase conductors placed in the same plane, 305/69 mm^2 OL-Al and two earth wires, 160/95 mm^2 OL-Al.

The characteristics of the overvoltage distribution from fig. 3 are presented in table 2. No kind of overvoltage protection has been taken into account.

The field test characteristics of the overvoltages distribution have been presented for comparison purpose [3]. The surge arresters have not been present at the field test.

The calculated risk of flashover values for three rated switching impulse withstand voltages 1300 kV_{peak}, 1425 kV_{peak} and 1550 kV_{peak} are also given in table 2.

The decision was made to limit the switching surge level at 1.7 pu (2 %-value) at the receiving end of the line. That means that there is a 2 % probability or less that the 1.7 pu limit will be exceeded.

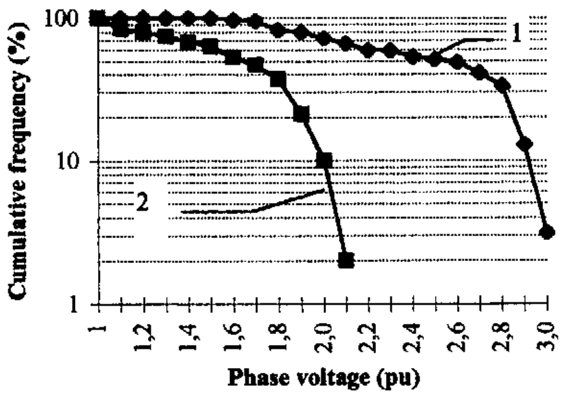

Fig. 3. Statistical distribution of switching overvoltage (receiving end of the line) at single-phase and three-phase reclosing of 750 kV transmission line with shunt reactor compensation

Table 2: Characteristics of switching overvoltages on 750 kV line and risk of flashover R

Operation	Overvoltage characteristics Receiving end		Insulation level u_p (kV_{peak})	Flashover risk R
Three phase reclosing	$\overline{U}$	2,39	1300	0,606
	σ	0,48	1425	0,432
			1550	0,281
Single phase reclosing	$\overline{U}$	1,73	1300	0,0244
	σ	0,228	1425	0,0033
			1550	$2,2\cdot10^{-4}$
Three phase closing	Field	test	1300	0,0221
	$\overline{U}$	1,75	1425	0,0026
	σ	0,21	1550	$2,1\cdot10^{-4}$

The values presented in table 2 show that the desired insulation level of 1300 kV_{peak} does not offer reliable switching operations. Further methods of overvoltages limitation have been investigated.

From table 2, the lines trapped charge influence is revealed also by the overvoltage level values at three-phase reclosing in comparison with the case of the line free of charge at three-phase closing operation.

III. COMPARISON OF OVERVOLTAGE LIMITATION METHODS

A. Preinsertion resistors

The first solution analyzed for overvoltages' limitation at lines receiving end is represented by the preinsertion resistors. The optimal value for the resistors has been determined using the model presented in fig. 4. For the 400 kV and 750 kV transmission lines with the parameters mentioned above the variation of the overvoltage value as function of preinsertion resistor's value is shown in fig. 5. The insertion time has been considered 8 ms.

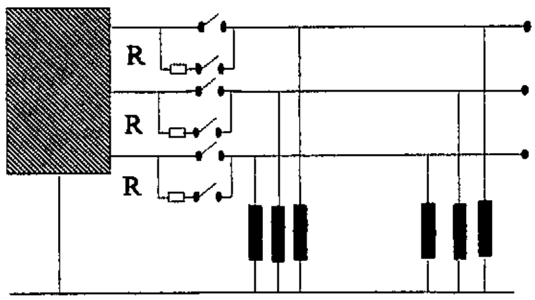

Fig.4. Schematic diagram of transmission line reclosing using preinsertion resistors

This study offered (fig. 5) the optimal values of preinsertion resistors of 400 Ω for 400 kV line and 500 Ω for 750 kV line [4].

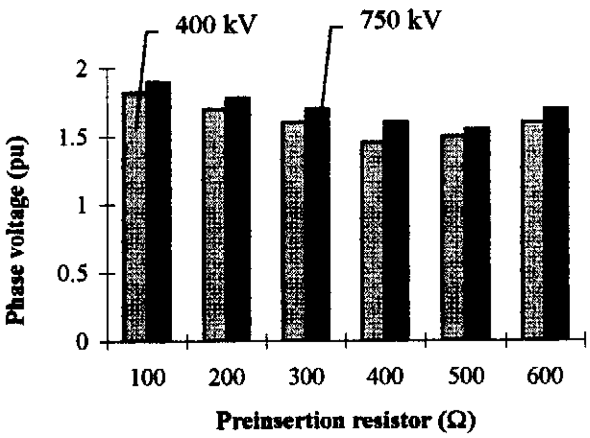

Fig. 5. Phase voltage at lines receiving end as function of preinsertion resistor value

Only the option of one step closing resistor was taken into account. Because of the mechanical complications and for economic reasons the multistep closing resistors have not been considered.

The second option taking into account for overvoltage limitation was the controlled closing of the circuit breaker, the line being equipped with surge arresters. The purpose of the surge arrester is to limit all the switching surges that will occur [5]. The control device will make possible that the circuit breaker poles will close on a minimum, voltage across the circuit breaker, as discussed next [5].

B. Controled closing

The line in combination with the shunt reactors represents an oscillating circuit. The trapped charge will discharge therefore through the reactor in an oscillatory manner. The frequency of the oscillation is determined by the reactor inductance and the line capacitance. The oscillation decays relatively slowly at a rate imposed by the losses of the line and reactor.

The frequency is slow, often of the same order as the supply frequency, and in general a difference in the frequency of the voltages on both sides of the breaker will exist. There is always a possibility of reclosing the supply on to the line in antiphase to the instantaneous value of the trapped charge voltage.

Fig. 6 presents the voltage differences across the open circuit breaker for a compensation degree of 50 % and -1 pu trapped charge.

The trapped charge decays in a damping oscillatory manner.

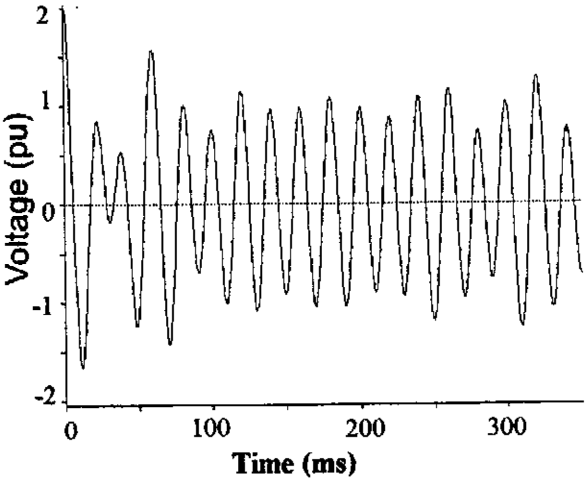

Fig. 6. Voltage across the open circuit breaker (50 % compensation degree)

In the representations in fig. 6 we can find a pronounced beat. The voltage shape is more complex for the lower compensation degree. In both cases the obviously closing target will be at the beat minimum or a voltage zero crossing.

Fig. 7 shows the overvoltage values at the receiving end of the line, for a 100 % compensation degree as function of the reclosing time instant. Initial trapped charge of -1 pu was considered. Curve 1 presents the values in case of reclosing at a maximum voltage difference on the circuit breaker and curve 2 at a minimum voltage difference.

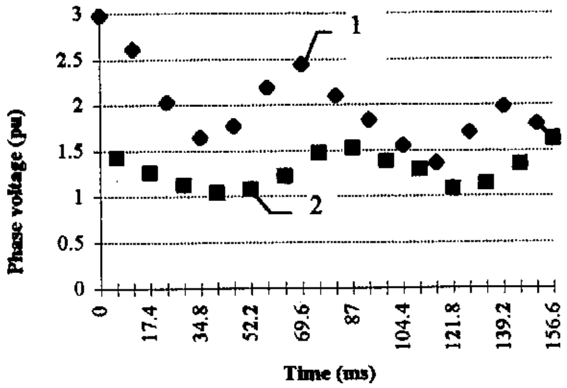

Fig. 7. Overvoltage level at the receiving end of the line as function of the reclosing time

Fig. 8 displays comparative how the overvoltage values at the 400 kV lines receiving end are distributed in case of the switching without any overvoltage control- curve 1, in the case of controlled switching- curve 2 and in case of using a 400 Ω preinsertion resistor- curve 3. With controlled switching, it was assumed that optimum closing instant is achieved, at voltage zero across the circuit breaker.

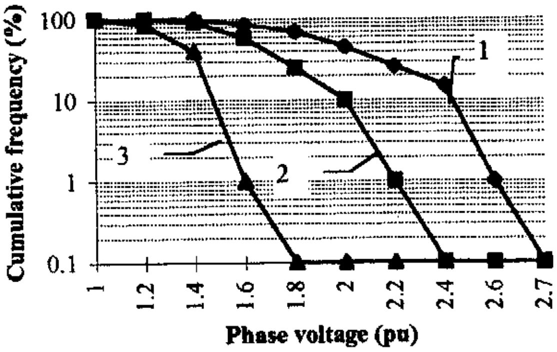

Fig. 8. Distribution of overvoltage for three-phase reclosing with trapped charge

IV. CONCLUSIONS

Reducing the insulation level of 400 kV and 750 kV transmission lines at 850 kV_{peak} and respectively 1300 kV_{peak} can not be achieved without additional surge limitation methods. This limitation can be ensured through the use of controlled circuit breaker closing when the lines are equipped with shunt reactors. Controlled switching of shunt reactor compensated lines can be feasible by means of an intelligent algorithm. Application of the controlled reclosing provides significant reduction of overvoltage in comparison with uncontrolled reclosing in case of trapped charge on the line and can be a solution for the future.

V. REFERENCES

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