

# Comparative Analysis of Control Switching Transient Techniques in Transmission Lines Energization Maneuver

P. Mestas, M.C. Tavares

**Abstract**—The long transmission line energization can cause high overvoltage stresses mainly along the transmission line, but also in the supply network. A traditional method of limiting switching overvoltages to acceptable levels is to use circuit breakers equipped with pre-insertion resistors.

This paper describes a study made in an actual 500 kV AC transmission system considering two alternatives in order to limit switching surge overvoltages during line energization: the use of metal oxide surge arresters at both line ends and along the line and the use of synchronized closing of circuit breakers.

Digital simulations have been made with PSCAD/EMTDC. The degree of shunt compensation is considered as independent parameter.

**Keywords:** Synchronized switching, metal oxide surge arrester, pre-insertion resistor, PSCAD.

## I. INTRODUCTION

THE switching transient in a transmission system cannot be prevented as well as its total suppression is extremely difficult. However, its magnitudes have to be limited to become compatible with insulation level of the system equipment. The transmission line energization is a typical maneuver, whose transient magnitude is influenced by the system configuration as well as by the equipment characteristics. Consequently, overvoltage control measures have to be adopted providing suitable protection for the network.

For long transmission lines, traditionally the switching transient overvoltages are limited through the adoption of pre-insertion resistors in the line circuit breakers. Although this is an effective mitigation method it presents a decreasing acceptance due to the high cost of implementation and maintenance. [1,2,3]

The first alternative analyzed to replace closing resistors is

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the installation of metal oxide surge arresters (MOSA) at both line terminals. The effective protection characteristics, the high reliability and the high dissipation capabilities of modern gapless MO surge arresters can meet, in many cases, the overvoltage limitation requirements of extra high voltage (EHV) transmission lines switching. Further reduction of the switching overvoltage can be achieved by the use of an additional arrester in the middle of the line or by the application of special arresters with lower protection level and higher discharge energy capability. [1,2,6]

Another method to reduce the switching transient is synchronous switching. It is a method for eliminating transient overvoltages through time controlled switching operations. Closing commands to circuit breaker are delayed in such a way that contact separation will occur at the optimum time instant related to the phase angle. Successful field experiences have been presented during the last years using synchronized control maneuvers of capacitors banks and shunt reactors in high-voltage systems. [4,5,7,9]

The objective of this paper is to analyze the overvoltages levels generated in a transmission line during the energization maneuver for distinct mitigation devices. Such survey is basic to infer the performance of the "conventional methods" as it is the case of the pre-insertion resistors and/or surge arresters versus the controlled switching breakers. Finally a comparative analysis of these three trends of overvoltages mitigation is made and it is determined the best technical conditions for the optimization of the energization process.

## II. SYSTEM MODELED

The study was performed in an actual 500 kV power system with the configuration shown in Fig. 1. The PSCAD/EMTDC (Power System Computer Aided Design / Electro Magnetic Transient DC) has been used for the simulations [10].

The line parameters calculated for fundamental frequency (60 Hz) using the routine LINE CONSTANT do PSCAD and are presented in the Table I. The line was supposed ideally transposed and the frequency dependence of the longitudinal parameters was modeled with frequency dependent (phase) model.

TABLE I  
BASIC LINE UNITARY PARAMETERS – 60 HZ

components	longitudinal (Ω/km)	transversal (μS/km)
non homopolar	0.0161 + j 0.2734	j 6.0458
homopolar	0.4352 + j 1.4423	j 3.5237

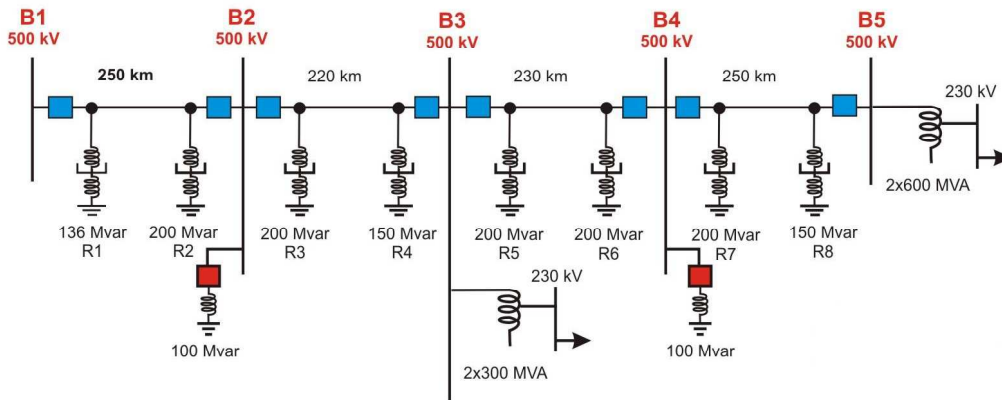


Fig. 1. 500 kV Transmission line details

The procedure to energize the line is to energize each section from one extremity (B1 or B5), assuming that the previous busbar was already stabilized in adequate voltage level, before the following section is energized.

The monitored maneuver presented in this paper corresponds to the last line section energization in the direction B4 → B5. The pre-switching voltage at the sending end was 1.00 p.u. and 0.95 p.u. for 70 % and 95 % shunt compensation, respectively. The transient overvoltages had been registered in 7 points of the line section B4-B5, being the two terminals and 5 intermediate points.

### III. SURGE ARRESTER

The surge arrester is used basically to protect the transmission line and connected equipments against switching and lightning overvoltages. In this paper only switching overvoltage protection is considered.

Considering that up-to-date ZnO arresters may have low protective levels and high dissipation capabilities, they can be applied as economical devices to mitigate transmission line switching surges. Further reduction of switching overvoltage can be achieved by the use of additional arresters in the middle of the line or along the line or by the application of special arresters with lower protection level and higher discharge energy capability. [4,6]

All surge arresters are modeled appropriately according to their V-I characteristics curve. The following metal oxide surge arresters were assumed:

- Metal oxide arrester rated 420 kV with a protection level of 830 kV at 2 kA, normally specified for 500 kV Brazilian transmission lines. [7]
- Metal oxide arrester rated 396 kV rated arrester with a protection level of 783 kV at 2 kA.
- Metal oxide arrester rated 360 kV rated arrester with a protection level of 742 kV at 2kA.

The circuit breaker poles were closed when the voltage at each phase was at its maximum, simulating the worst overvoltage condition.

The overvoltage profiles along the lines are given for 70 %

and 95 % shunt compensation and for the four surge arresters cases considered as follows:

- Without any surge arrester;
- Surge arrester at line ends only;
- Surge arresters at line ends and midpoint;
- Surge arresters at line ends and two additional arresters.

#### Metal oxide arrester rated 420 kV.

As seen from the figure 2, using 420 kV rated arrester for the 95 % shunt compensation line, the line overvoltage along the line is not reduced. At the remote terminal the overvoltage value is reduced only in 1,1%.

The 70 % shunt compensation line energization (Fig. 3) resulted in higher overvoltages as expected and therefore the surge arresters played some role in reducing the overvoltages. At the remote terminal the overvoltage value is reduced in 5%.

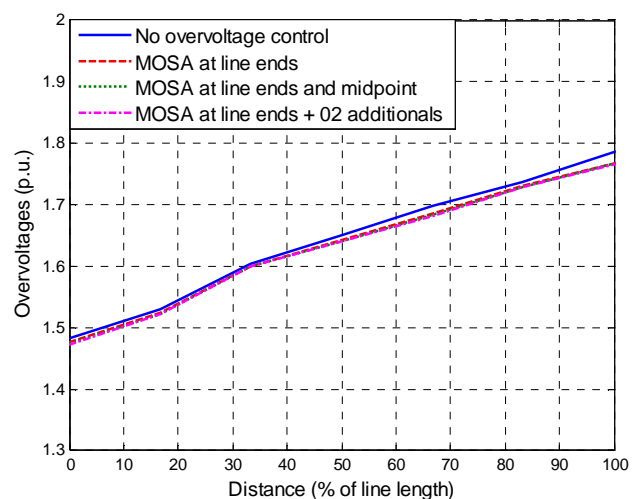


Fig. 2. Overvoltage profile along the line with 95 % shunt compensation using arrester  $U_r = 420$  kV Class 5.

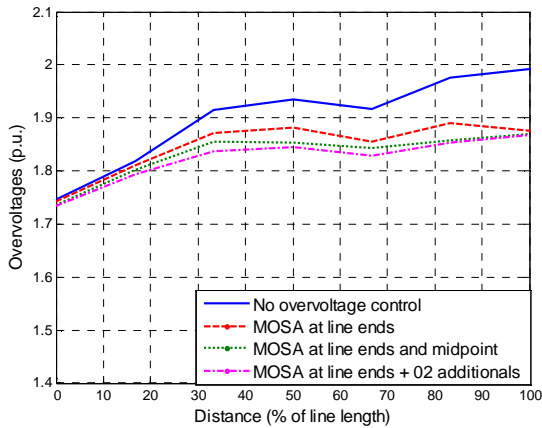


Fig. 3. Overvoltage profile along the line with 70 % shunt compensation using arrester  $U_r = 420$  kV Class 5.

### Metal oxide arrester rated 396 kV.

According to Fig. 4 and Fig. 5 using 396 kV rated arresters, the overvoltage in the remote terminal is reduced in 6.15 % and 13.56 %, reaching values of 1.68 and 1.72 p.u for the transmission line with shunt compensation of 95 % and 70 %, respectively. With this rated arrester a better performance in reducing the overvoltage is observed for both cases.

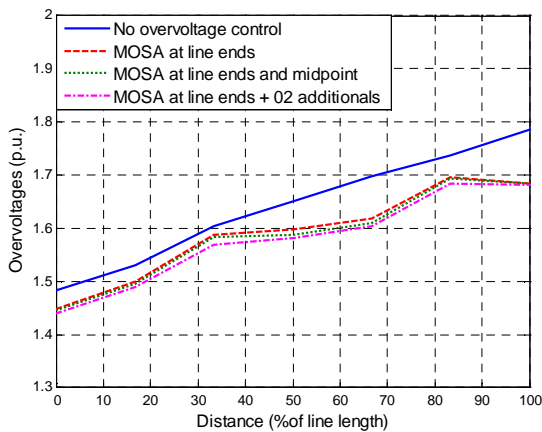


Fig. 4. Overvoltage profile along the line with 95 % shunt compensation using arrester  $U_r = 396$  kV Class 5.

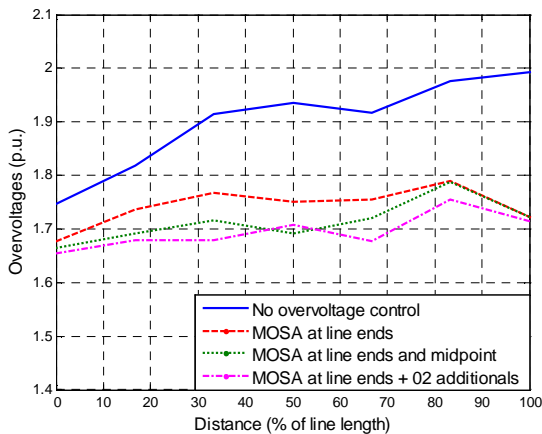


Fig. 5. Overvoltage profile along the line with 70% shunt compensation using arrester  $U_r=396$  kV Class 5.

### Metal oxide arrester rated 360 kV.

The Fig. 6 and Fig. 7 shows the overvoltage profiles using 360 kV rated arrester Class 3. As expected, the line overvoltages along the line are reduced, particularly at the terminals. With this arrester type it was possible to obtain overvoltages of approximately 1.5 pu. This case appears with an illustrative and comparative purpose since an important parameter to define the surge arrester is the protection level, but as the active elements of the surge-arresters are stressed continuously by the nominal voltage, the proper selection for a specific application is not only determined by the protective level but also by the system operation characteristics, as the temporary overvoltage and the maximum operation voltage.

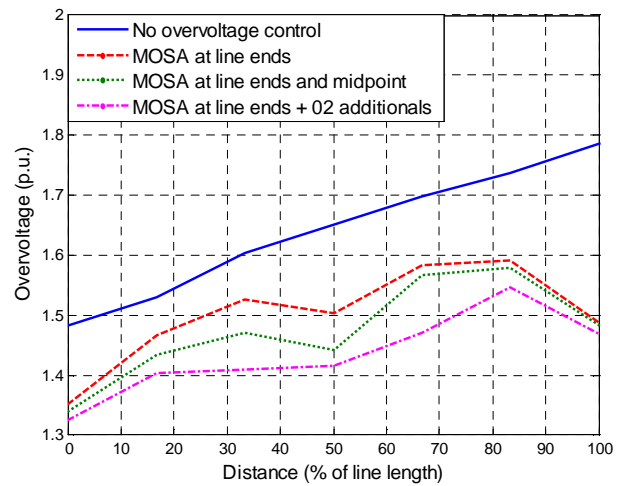


Fig. 6. Overvoltage profile along the line with 95% shunt compensation using arrester  $U_r=360$  kV Class 3.

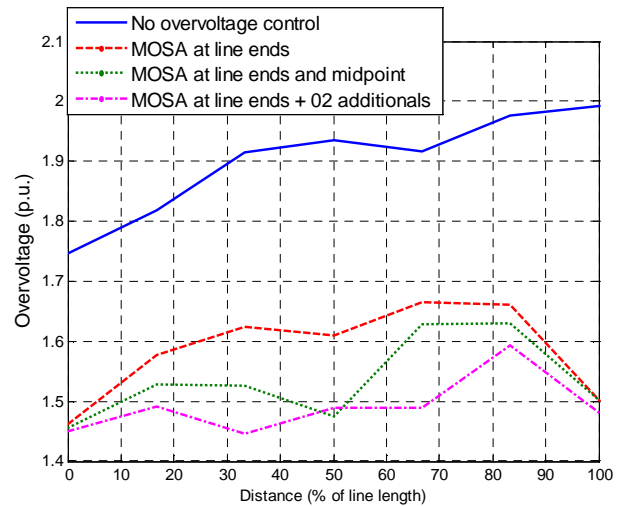


Fig. 7. Overvoltage profile along the line with 70% shunt compensation using arrester  $U_r=360$  kV Class 3.

It can be observed in Table II that the energy absorption capacity of the arresters has not been exceeded in any simulation, even in the cases of arrester with  $U_r = 360$  Class 3 (2.8 MJ). The energy absorption levels are far below the arresters capability.

TABLE II  
ENERGY CONSUMPTION

Rated Arrester	Energy (MJ)	95% Shunt Compensation Energy (MJ)	70% Shunt Compensation Energy (MJ)
420 kV	6,5	0,006	0,120
396 kV	6,1	0,061	0,391
360 kV	2,8	0,266	0,815

#### IV. SYNCHRONIZED CIRCUIT-BREAKER

Controlled switching is the method of switching each pole individually at the optimal point-of-wave to reduce the switching overvoltage. This is achieved by special control circuit that initiate commands based on information from the system and the characteristics of the circuit breakers. [8,9]

For this work, the synchronized circuit-breaker control was implemented using the components SEQUENCERS that are part of a special group of PSCAD/EMTDC control elements with two variants:

- The closing order was given when the voltage of each phase crosses consecutives zero;
- After the first phase voltage crosses zero the others phases were closed with  $60^\circ$  delay. (Phases A, C and B successively)

Theoretically these two conditions are not the same during the switching due to transient. In the specific case of the system in study the difference is minimum as shown in

Fig. 8, at the receiving terminal, i.e. in B5. In Fig. 9 it is presented the voltage profile for the two cases when a line is 95 % shunt compensated.

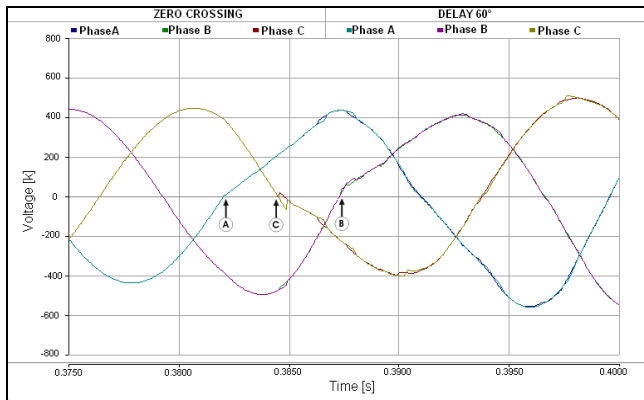


Fig. 8. Voltage waveform differences for the two modalities of circuit-breaker pole synchronized closing.

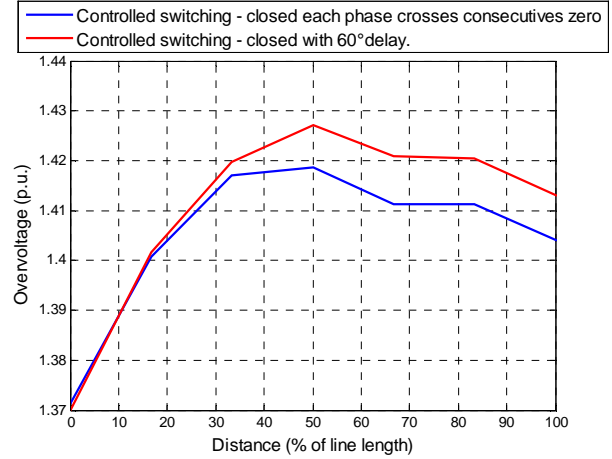


Fig. 9. Overvoltage profile along the line with different instants of closing breakers.

In Fig. 10 and Fig. 11 the voltage waveform at receiving end is presented for line energization without mitigation method and with synchronized switching. It can be observed that not only the overvoltage was reduced with the synchronized switching but also the waveform has low harmonic content.

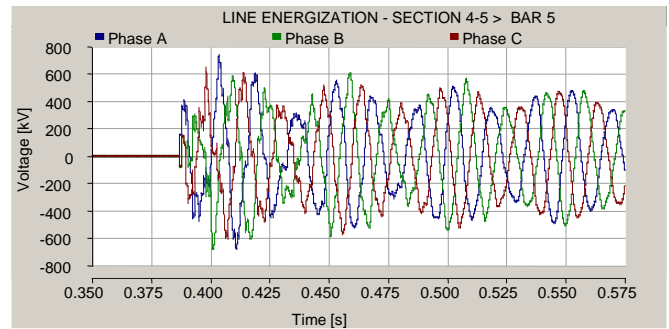


Fig. 10. Receiving end. Line energization without overvoltage control.

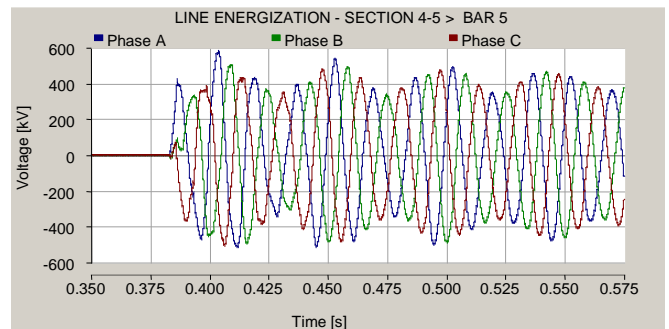


Fig. 11. Receiving end. Line energization with synchronized controlled switching.

The benefits brought by the controlled switching are presented in Fig. 12 and Fig. 13. The reduction of overvoltages by controlled switching was important. The overvoltage in the remote terminal is reduced in 21 % and 16 %, reaching values of 1.41 and 1.66 p.u. for the line with shunt compensation of 95 % and 70 % , respectively.

In the system studied this method presented a better performance for the line with 95 % of shunt compensation. A consequence of controlled switching application is that the arresters are generally less stressed and the required energy dissipation capability is reduced accordingly.

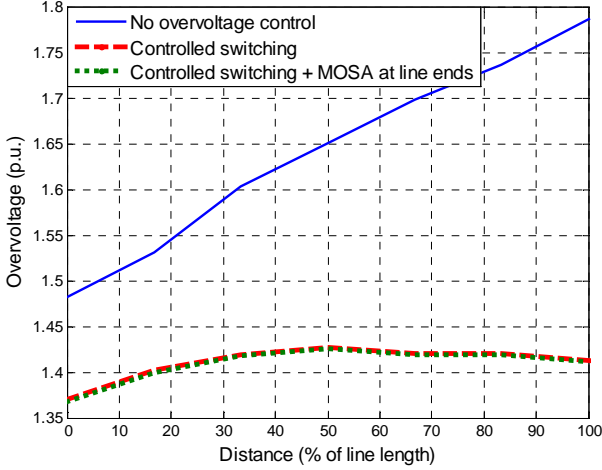


Fig. 12. Overvoltage profile along the line with 95 % shunt compensation using controlled switching.

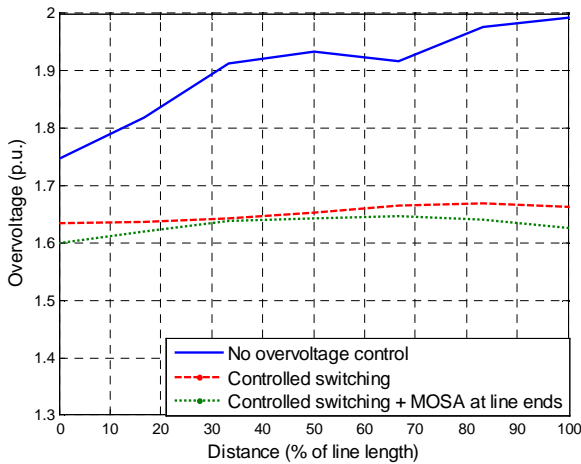


Fig. 13. Overvoltage profile along the line with 70% shunt compensation using controlled switching

## V. PRE-INSERTION RESISTOR

For EHV systems it has been common practice for many years to equip circuit-breakers with pre-insertion resistors as a means of controlling system transient interactions during closing or re-closing operations. This is still a common practice in Brazil where almost all existing and new transmission lines have this kind of breaker specified.

The closing resistors are inserted in series with the line, normally being short-circuited after 8 to 10 ms – thereby damping the transient overvoltages. In the present case, an actual 400-Ω resistor, with an insertion time of 8 ms, was installed.

Using pre-insertion resistor, the overvoltage in the remote

terminal was reduced in 25 % and 15 %, reaching values of 1.34 and 1.69 p.u for the line with shunt compensation of 95 % and 70 %, respectively (Fig. 14 and Fig. 15).

In the system in study this method presents a better performance for the line with 95 % of compensation shunt.

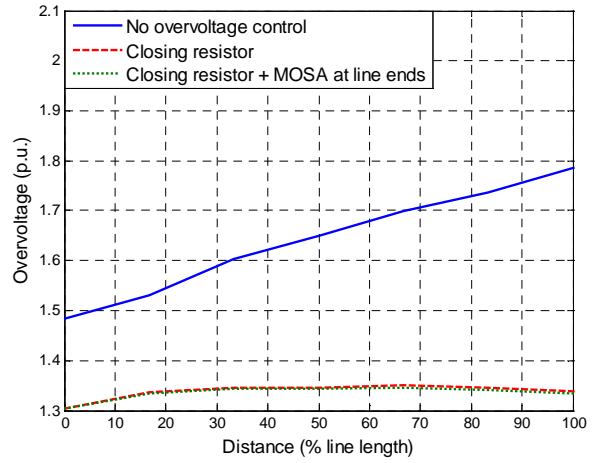


Fig. 14. Overvoltage profile along the line with 95 % shunt compensation using pre-insertion resistor.

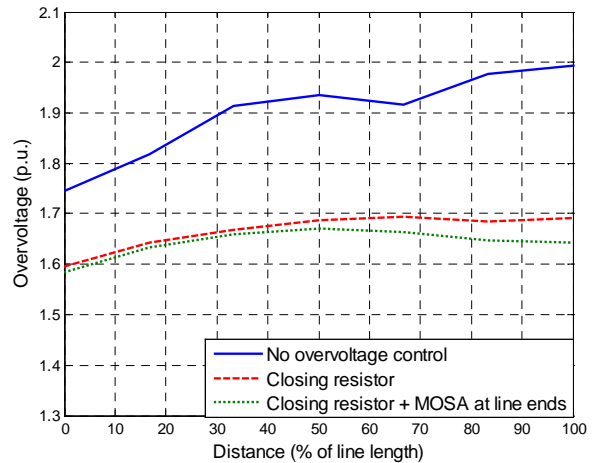


Fig. 15. Overvoltage profile along the line with 70 % shunt compensation using pre-insertion resistor.

## VI. CONCLUSIONS

Switching overvoltage limitation at the energization maneuver of a 500 kV transmission trunk was achieved through the use of line surge arresters and controlled circuit breaker closing. These techniques can replace the use of circuit breaker with pre-insertion resistor and its associated problems.

The high-energy dissipation capability of modern metal oxide surge arresters copes with lines switching requirements. It can be observed that the energy absorption capacity of the arresters has not been exceeded in any simulation, but the maximum operating voltage of the system and the temporary overvoltages shall be carefully considered for the arrester specification

This paper does not refer to three-phase reclosing operation, which will be analyzed in future works. Due to trapped charges the optimum instant for closing the circuit-breaker poles occurs when the voltages on both sides of the arrester poles have almost the same value. It is necessary then to monitor voltages at both pole terminals.

In the specific case analyzed the difference for the two synchronized switching variants analyzed was very low.

The generalization of results is not recommendable, reliable prediction of line switching overvoltages asks for digital simulations in which the specific line and network under consideration shall be carefully modeled.

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## VIII. BIOGRAPHIES

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