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# OVERHEAD LINE SWITHCING CONSIDERING CIRCUIT BREAKER STANDARD DEVIATION TIMES

BY

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**Abstract.** The switching of electrical equipment in normal operation conditions should be performed in optimal moments with regard to the variation of the voltage and current waveforms. Deviations from these ideal conditions will result in disruptive transient regimes, which, depending on their severity, can lead to equipment malfunctions or insulation damage. This paper continues a previous research study regarding the impact of the real switching moment regarding the known ideal conditions on various types of equipment. Previous efforts have concentrated on the study of the behavior of capacitor banks, power transformers and underground cable lines when switching is performed in different points on the voltage sine wave. This paper continues the research by studying high voltage overhead lines in the same conditions. The voltage and current waveforms are measured and analyzed for different switching times, using the EMTP software package. A comparison discussion with the previous results highlights the main findings.

**Keywords:** overhead electrical lines, controlled switching, transient regimes, standard deviation, software simulation.

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## 1. Introduction

The classic electricity transmission systems rely on high voltage overhead lines. Operational configuration changes and contingencies require planned and unplanned switching of several types of high-power equipment, including lines. Equipment switching is accompanied by transient overvoltages and overcurrents, which must be considered when evaluating the risk of failure (Sadovic and Sadovic, 2007).

The mitigation of transient overvoltages is achieved in power substations by the surge arresters, which minimize the transient voltage caused by switching surges and lightning strikes.

The switching disturbances can create short transients, that can have disruptive effects, which are increasingly higher when the switching moment is farther from the optimal point. To address these effects, a widely used technique is the controlled switching that takes into consideration all the relevant parameters that can influence the connection and disconnection times of circuit breakers.

The studied problem was proposed in the literature, starts with (Samitz-Ove *et al.*, 2002) which concluded that even with extremely precise circuit breakers, the only use of controlled switching does not always result in the achievement of the necessary overvoltage levels. The operator would never be affected by the inevitable fluctuations in the circuit breakers' tolerating times over the course of their thirty-year lifespans, as well as the potential for mathematical approach inaccuracies.

The impact of various parameters on switching overvoltages are assessed in (Sanaye-Pasand *et al.*, 2019). According to the observations of various simulations, even if this type of relay is less effective than a preinsertion resistor, the acquired overvoltage limiting range is suitable for transmission lines without compensation. Surge arresters along the transmission line or a more complex switchsync relay are needed for long or compensated lines. Also, the controlled switching mechanism has been examined in (Deyhim and Ghanizdeh, 2019; Shafy *et al.*, 2016) in tandem with the impact of the pre-insertion resistor on energising a capacitor bank.

Recently, a heuristic-based neural networks approach for real time of the high voltage transmission overhead lines is proposed in (Bugaje *et al.*, 2023; Xiaodong *et al.*, 2022). Also, (Johnson *et al.*, 2020) proposed a k-nearest neighbors method for direct current optimal transmission switching. On the other side, (Yang *et al.*, 2022) the authors propose an optimal corrective transmission switching based on the correction time.

The research presented in this paper continues the work started by the authors in (Baiceanu *et al.*, 2022), which presented the effects of the deviation of the connection time from the optimal moment, when switching capacitor batteries, power transformers and electrical cables. The negative effects of the switch connection times were evaluated for each equipment type and the improvements obtained by using controlled switching were highlighted. This paper continues the study for the connection of high voltage overhead lines. A case study is modelled in the EMTP software, and the results are presented, comparing the results with the previous findings.

The rest of the paper is structured as follows. Chapter 2 presents the theoretical approach used in the study. In Chapter 3, the results obtained in the simulation are presented and discussed. The paper ends with conclusions and literature references.

## 2. Methodology

Controlled switching aims to send the actuation signal for the breaker poles at the optimal moment in time, so that the amplitude of the transient regime is minimal, reducing the stress placed on the equipment. The controlled switching of non-linear electrical equipment such as overhead power transmission lines is an efficient method of reducing the transient voltages and currents resulting from the switching operation.

When controlled switching is used, it must consider the parameters that influence the uniformity and accuracy of the physical manoeuvres, such as:

- The energy stored in breaker springs, hydraulic or pneumatic mechanisms
- The nominal characteristics of the arc extinguishing medium
- The operating conditions, including the ambient temperature and the control voltage used
- The age of the equipment, including the number of previous manoeuvres in normal and contingency conditions and the interval between manoeuvres.

In Table 1 are presented the critical parameters that influence the switching time of a three-phase circuit breaker assumed to have a single-phase actuation mechanism.

In a preliminary stage, an analysis regarding the closing time of a circuit breaker was performed for a number of 11 different breakers, when using classic switching, in the absence of control. The results have shown an average connection time of 43.25 ms, with a standard deviation of ±1.1 ms, as depicted in Fig. 1. This deviation was used as reference value in the controlled connection study. However, it should be noted that when considering a known type of circuit breaker, its specific deviation time must be used for obtaining accurate switching control.

**Table 1**
*The operating parameters of circuit breakers and their influence over the switching time (Munteanu et al., 2006)*

| Parameters | Classic switch | | SF6 switch / actuation mechanism | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Hydraulic | | Spring | | Pneumatic | |
| | disconn. | conn. | disconn. | conn. | disconn. | conn. | disconn. | conn. |
| Temperature control within a range of -40$^0$C +40$^0$C | 50 µs/$^0$C | 75 µs/$^0$C | 3 µs/$^0$C | 70 µs/$^0$C | 30 µs/$^0$C | 70 µs/$^0$C | ±1.0 ms | ±1.5 ms |
| Voltage control within a range of -15% +10% | No data | No data | ±0.5 ms | ±1.5 ms | ±0.5 ms | ±0.5 ms | ±1 ms | ±1.5 ms |
| Available energy, variable in a range of ±5% | No data | No data | ±0.5 ms | -3ms - + 2.5 ms | ±0.5 ms | -3ms - + 2.5 ms | No data | No data |
| Number of switchings | ±1 ms | +1.5 ms | ±1 ms | ±2.5 ms | ±1.5 ms | +2.5 ms | +1.5 ms | +1 ms |
| Very rare operation for a duration of 10-year reference | ±1 ms | ±1.5 ms | No data | ±10 ms | No data | ±10 ms | No data | No data |

The simulation was performed on a 110 kV line model created using the EMTP software package, whose one-line diagram is presented in Fig. 2. The line has a length of 7 km, uses a 300 mm$^2$ OL-Al conductor, and its load is minimal, to simulate near no-load conditions used in real world line switching scenarios. The simulation of the uncontrolled switching performed on this line shows the voltage and current profiles of the transient regime presented in Fig. 3 and 5.

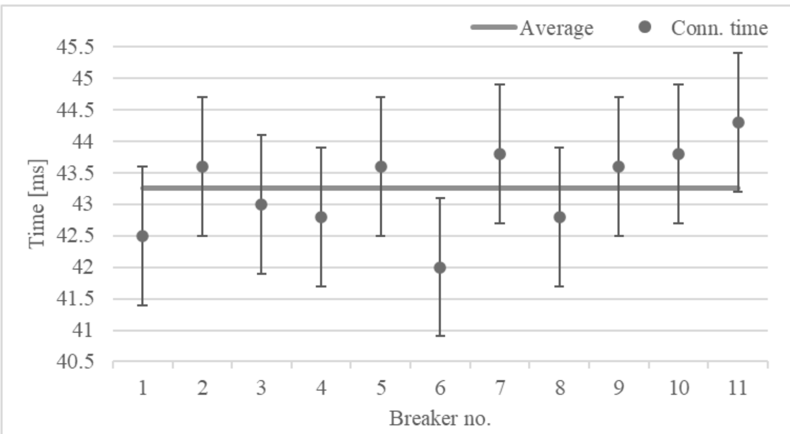


Fig. 1 – Closing time analysis for uncontrolled closing.

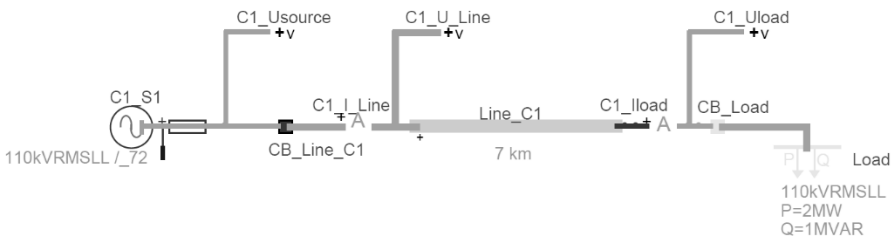


Fig. 2 – The EMTP one-line diagram of a 110 kV transmission line model.

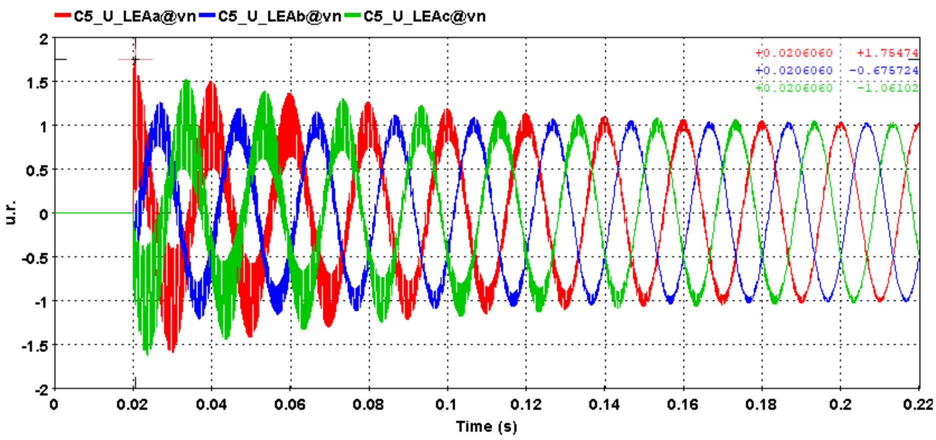


Fig. 3 – The voltage profile of the uncontrolled closing simulation

The no-load scenario is the worst case of switching, in terms of overvoltage value. In this case, the peak voltage value reaches 1.75 p.u. at connection time, and decreases to the rated voltage value in a time interval of 180 ms.

The corresponding transient current waveforms are presented in Fig. 4. The peak current reaches a value of 6.42 p.u.

The FFT analyses for voltage and current a significant distortion caused by a higher-order oscillatory transient harmonic, for which the FFT diagram depicted in Fig. 6 for the transient current shows a harmonic amplitude of 12.28 A and 4.1 kHz, which creates a transient component on the voltage waveform, as seen in Fig. 5, mostly visible in the evolution of the voltage seen in Fig. 3.

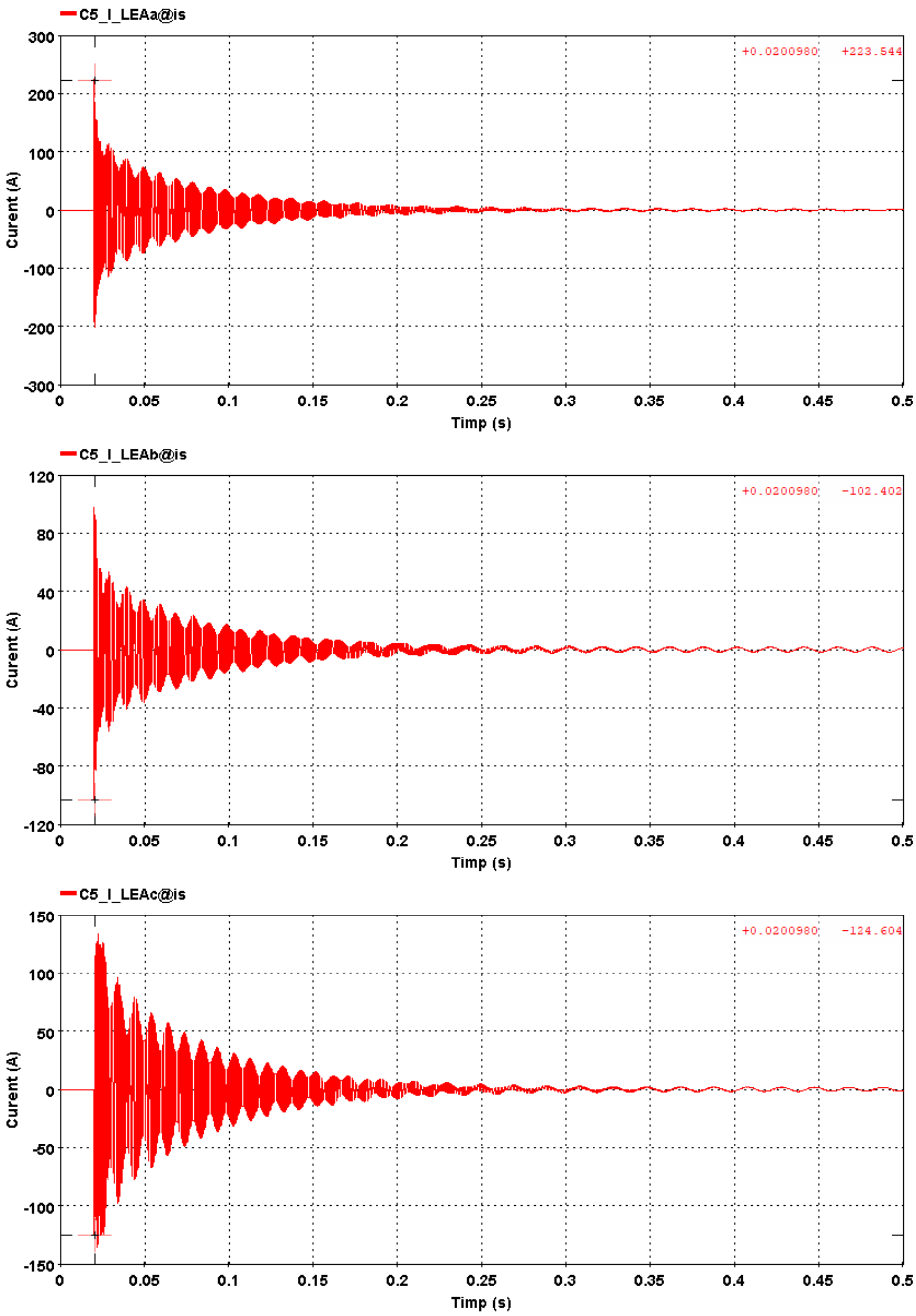


Fig. 4 – The phase current waveforms in the uncontrolled closing simulation.

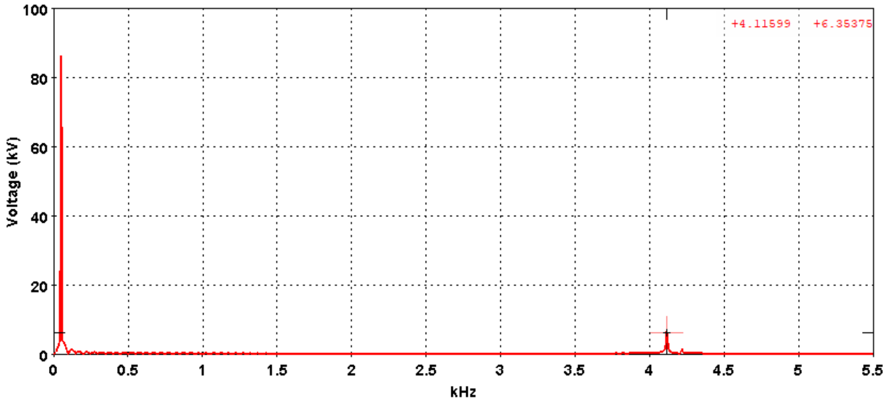


Fig. 5 – The FFT analysis for the uncontrolled closing transient voltage waveform.

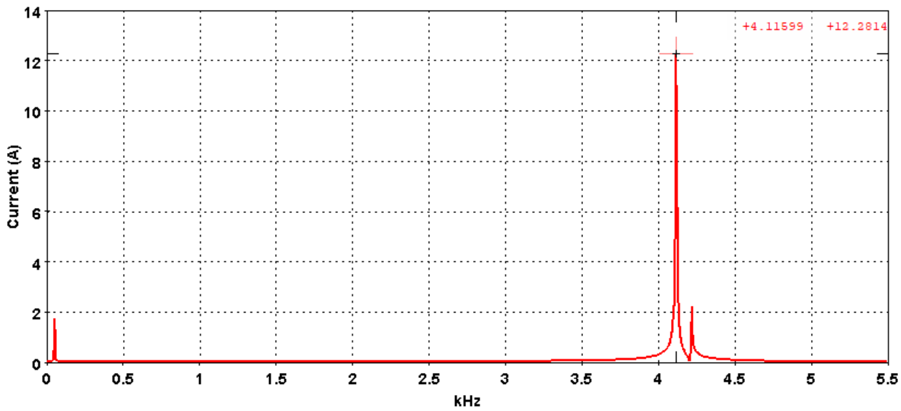


Fig. 6 – The FFT analysis for the uncontrolled closing transient current waveform.

The results of the simulation show the opportunity of using controlled connection for mitigating the harmonic disturbances of the transient regime, and to reduce the overcurrent and overvoltage seen in the reference test case in the moment of connection.

## 3. Case study

The controlled switching was simulated on the EMTP model described in the previous chapter, using the optimal connection points on the voltage waveform, taken from the literature (Der Sluis, 2001), and presented in Table 2. The transformer connection type and short line length are used to model a real HV supply from an industrial site.

**Table 2**

*Optimal connection points for the phases of an electrical line, according to (Der Sluis, 2001)*

| Equipment | Connection Type | Phase A | Phase B | Phase C |
|---|---|---|---|---|
| Line | Yg | $0^0$ | $120^0$ | $54^0$ |

After running the simulation, the optimal transient voltage and current waveforms are those presented in Fig. 7 and 9, and the corresponding Fourier analyses are presented in Fig. 8 and 10.

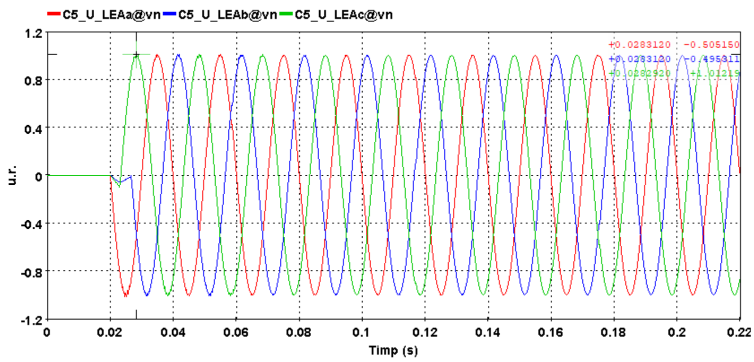


Fig. 7 – The voltage profile of the uncontrolled closing simulation.

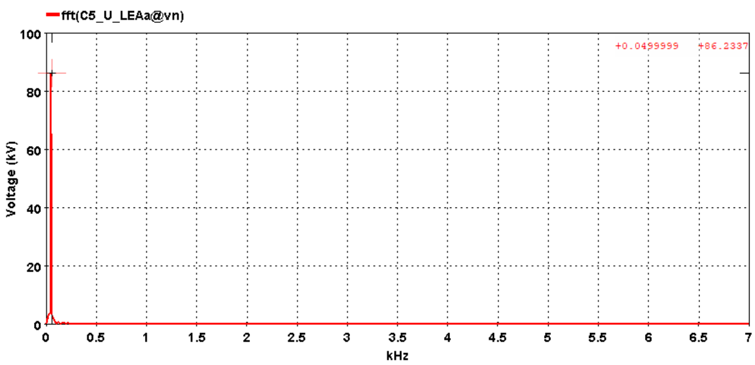


Fig. 8 – The FFT analysis for the controlled closing transient voltage waveform.

The controlled switching of the line results into reduced amplitudes for the phase currents, as seen in Fig. 9. In this simulation, the maximum amplitude does not exceed 1.78 p.u. The FFT analysis of the current waveform shows a transient component having a frequency of 4.11 kHz, but which does not affect the amplitude of the transient voltage, that shows a negligible transient increase, as Fig. 7 shows.

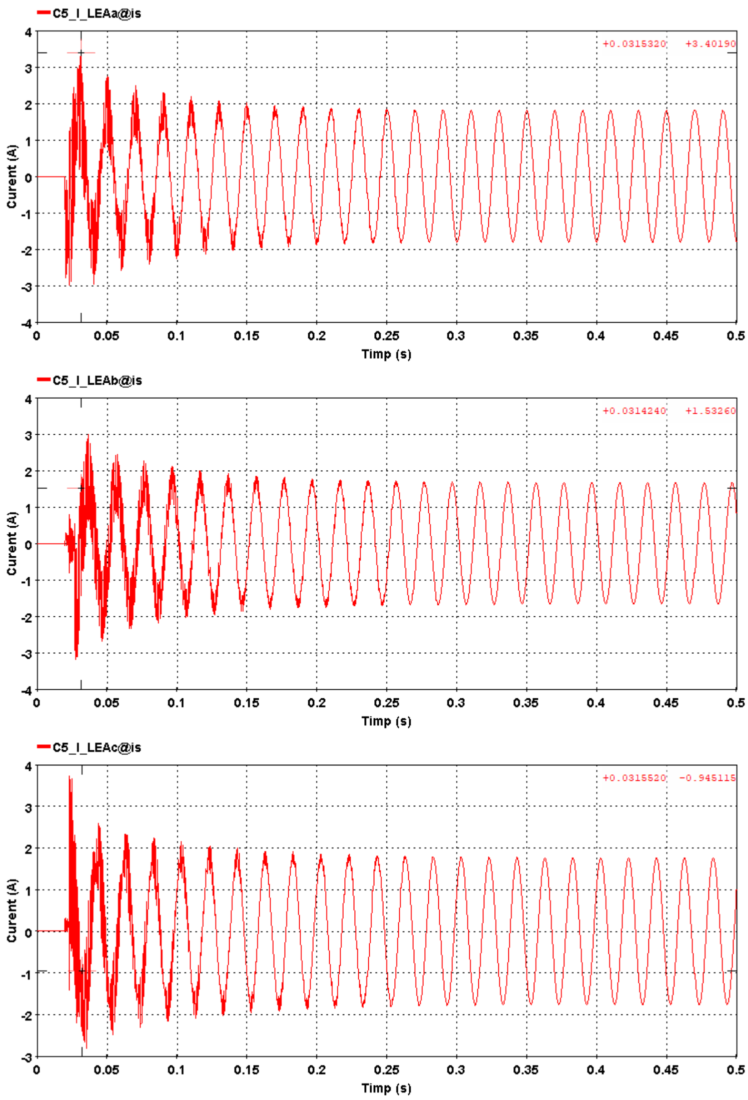


Fig. 9 – The phase current waveforms in the controlled closing simulation.

In the following stage of the study, were analysed the effects of changing the connection point on the voltage waveform on the maximum amplitude of the transient voltage and current. The points chosen on the voltage waveform cover an entire period of the signal, as depicted in Fig. 11. The results are shown in Fig. 12 for the maximum voltage amplitude transients and in Fig. 13 for the maximum current transients.

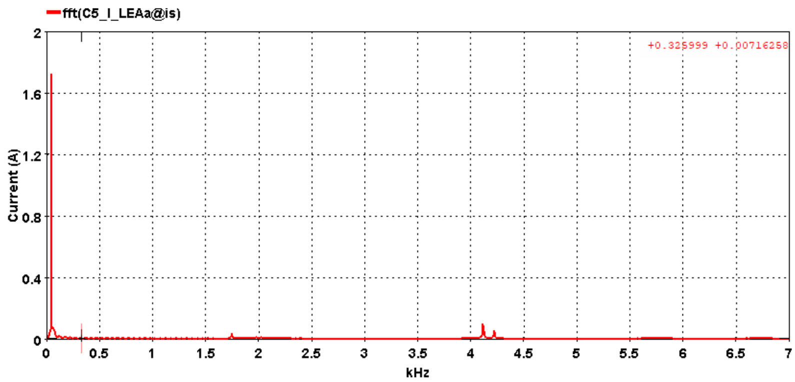


Fig. 10 – The FFT analysis for the controlled closing transient current waveform.

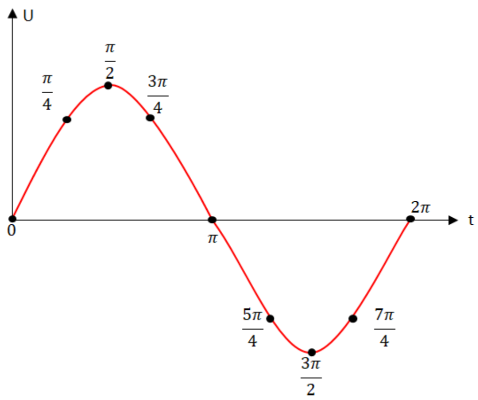


Fig. 11 – The points on the voltage waveform used in the analysis for evaluating the maximum voltage and current transients.

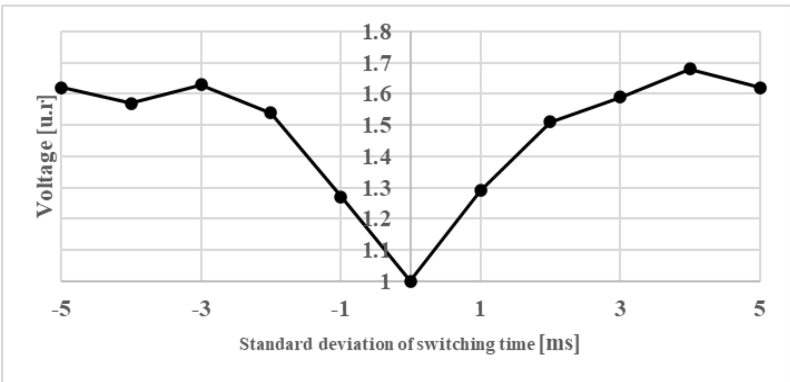


Fig. 12 – Voltage evolution, in p.u., produced after closing of the overhead power line at different times of standard deviation from the optimal closing point.

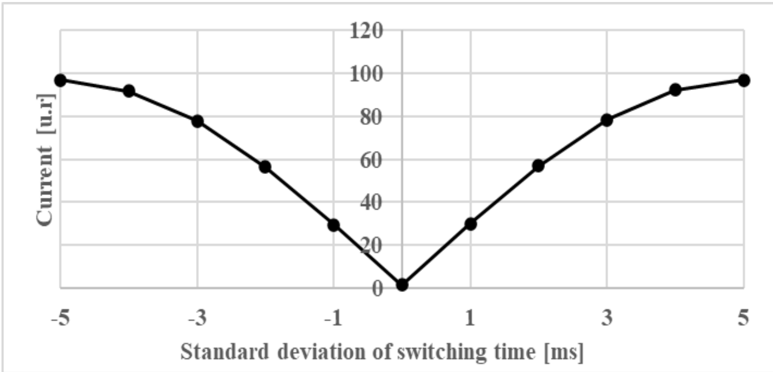


Fig. 13 – Current evolution, in p.u., produced after closing of the overhead power line at different times of standard deviation from the optimal closing point.

With increasing switching time standard deviation, the amplitudes of transient disturbances increase, as can be seen in the detail shown in Fig. 14, where the overhead power line connection current evolutions at different times, i.e. +4 ms – -5 m, are highlighted compared to the optimal connection time.

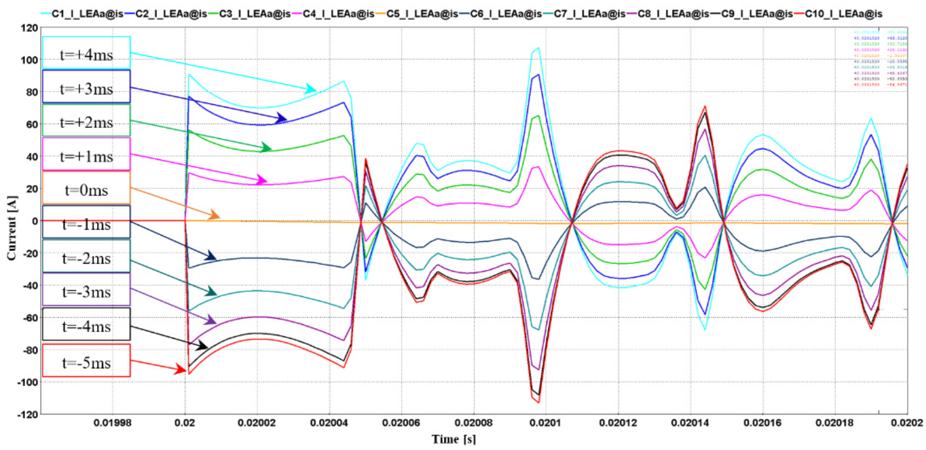


Fig. 14 – The initial current, in effective value, occurring at the closing of the overhead power line, at different times of closing compared to the optimum time.

The voltage disturbances created by the overhead power line connection, in the cases analysed, are plotted on the superimposed CBEMA and ITIC curves to give an overview of their speed and amplitude, this plot is shown in Fig. 15.

As can be seen in Fig. 15, in the case of uncontrolled switching, the overvoltage occurring exceeds the limit of the safety zone characterized by the

ITIC and CBEMA curves, endangering the proper operation of the electrical equipment. The proposed solution of controlled switching of the LEA has the advantage of reducing the amplitude of the transient current and eliminating overvoltages.

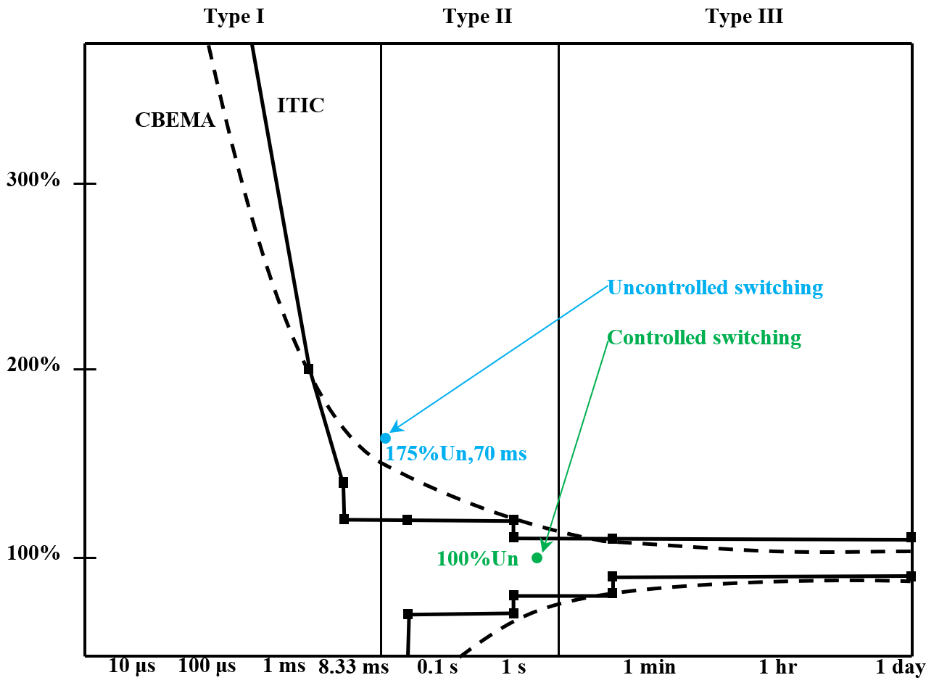


Fig. 15 – Voltage variations, created by the overhead power line closing, reprezented on the ITI-CBEMA curve.

## 4. Conclusion

The paper analyzed the impact of deviations in the switching time of circuit breakers in controlled overhead power line connections and presented the transient regimes occurring during this time.

Controlled switching of overhead power lines is an effective method for mitigating transient regimes that may occur during line connections. In the first part of the presented case study, the benefits of controlled switching are highlighted by performing a simulation in EMTP. It can be observed how the amplitudes of transient regimes, as well as overcurrent components, are reduced when overhead power lines are switched. However, achieving controlled switching with high precision requires taking several parameters into account that can lead to changes in the switching times of circuit breakers.

The case study analyzed demonstrates that the greater the deviation from the optimal switching time, the more pronounced the transient regimes that occur during overhead power line connections.

In the last part of the case study, the two types of overhead power line connections (controlled and uncontrolled) are compared using the ITIC and CBEMA curves.

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## COMUTAREA LINIILOR ELECTRICE AERIENE LUÂND ÎN CONSIDERARE DEVIAȚIA ÎNTRERUPĂTORULUI

(Rezumat)

Comutarea echipamentelor electrice în condiții normale de funcționare trebuie să se realizeze în momente optime în ceea ce privește variația formelor de undă de tensiune și de curent. Abaterile de la aceste condiții ideale vor duce la apariția unor regimuri tranzitorii perturbatoare care, în funcție de gravitatea lor, pot duce la defecțiuni ale echipamentului sau la deteriorarea izolației. Această lucrare continuă un studiu de cercetare anterior privind impactul momentului real de comutare în raport cu condițiile ideale cunoscute asupra diferitelor tipuri de echipamente. Eforturile anterioare s-au concentrat asupra studiului comportamentului bateriilor de condensatoare, al transformatoarelor de putere și al liniilor de cabluri subterane atunci când comutarea se realizează în diferite puncte ale sinusoidei de tensiune. Această lucrare continuă cercetările prin studierea liniilor aeriene de înaltă tensiune în aceleași condiții. Formele de undă ale tensiunii și curentului sunt generate și analizate pentru diferiți timpi de comutare, utilizând pachetul software EMTP. O discuție comparativă cu rezultatele anterioare evidențiază principalele constatări.