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Application of line surge arresters for voltage uprating and compacting of overhead transmission lines

Božidar Filipović-Grčić*, Ivo Uglešić, Ivica Pavić

Faculty of Electrical Engineering and Computing, University of Zagreb, 10000 Zagreb, Croatia

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ABSTRACT

This paper discusses the possibility of using line surge arresters (LSAs) for the reduction of switching overvoltages (SOVs) on voltage uprated transmission lines. The method for the selection of LSA energy class and determination of optimum installation locations was proposed. The method was applied in case of improving the overvoltage protection of the transmission line uprated from 220 kV to 400 kV.

The possibility of compacting a 400 kV transmission line by installing LSAs was considered. Since a risk of flashover increases due to the reduction of insulation clearances, an algorithm that estimates the risk of flashover was developed and applied in case of compacting a 400 kV transmission line.

1. Introduction

In recent years, with the increase of power demand, the need for transmitting large amounts of power over long distances has also increased. The uprating of existing overhead transmission lines has become a popular option for electric utilities to address the increasing demand for power [1,2]. Uprating the transmission lines by increasing voltage allows a considerable increase in power transfer capability, but consequently it increases switching overvoltages (SOVs) which makes them one of the main factors in the insulation coordination of high voltage transmission lines and substations.

SOVs are of a concern in transmission networks with rated voltages of 420 kV and above, especially regarding long transmission lines. In these high voltage networks the switching impulse withstand voltage of the equipment is about 2–3 p.u., so SOVs have to be kept under control [3]. The amplitudes of SOVs during the closing or re-closing of the transmission line depend on the difference between the supply voltage and the line voltage at the instant of energizing, and are related to traveling wave phenomena on the line. For long transmission lines, the most severe SOVs occur in the case of three-phase reclosing with trapped charge on the line. Three-phase reclosing normally occurs after the clearing of a single-phase or three-phase fault on the line. Therefore, reclosing occurs with more or less trapped charge corresponding to DC voltage on the healthy phases. Such trapped charge may normally be neglected in cases with inductive voltage transformers connected to the line ends, while in cases with capacitive voltage transformers, the trapped charge may remain on the line for a considerable time, up to several seconds [4]. SOVs can endanger the external insulation because it has the lowest breakdown strength under overvoltages with front time in the range 50–500 μs, which is typical for SOVs. Therefore, all equipment designed for operating voltages above 300 kV should be tested under laboratory simulated switching surges [5].

The most used techniques for reducing SOVs are the installation of circuit breakers equipped with closing resistors, controlled switching and application of surge arresters [6,7]. In recent years, several large utilities have experienced problems with the long term mechanical reliability of closing resistor mechanisms (especially in older circuit breakers) with adverse impact on the overall system reliability and have begun to examine alternative approaches to SOV control. The effectiveness of controlled switching depends on several factors, the most important of which is the circuit breaker operating time consistency [8]. The breakers with a deviation in operating times of less than ±1 ms and with steep rate of decay of dielectric strength are best suited for controlled switching applications [9].

This paper presents the method of uprating and compacting overhead transmission lines by installing LSAs. The method consists of two parts: (1) selection of LSA energy class and determination of optimum installation locations for controlling SOVs and

* Corresponding author. Tel.: +385 1 6129 714; fax: +385 1 6129 890.
E-mail addresses: bozidar.filipovic-grcic@fer.hr (B. Filipović-Grčić), ivo.uglesic@fer.hr (I. Uglešić), ivica.pavic@fer.hr (I. Pavić).

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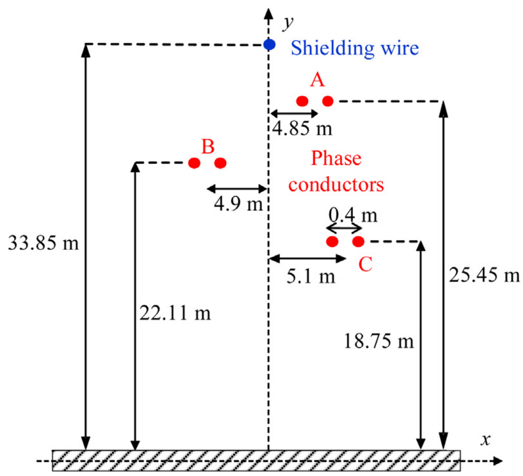

Fig. 1. Conductor arrangement at tower and average heights above the ground.

(2) estimation of risk of insulation flashover when reducing the insulation clearances. The method was applied in case of uprating the existing 220 kV transmission line to 400 kV and in case of compacting the 400 kV transmission line.

2. Description of model in EMTP-RV software

2.1. Transmission line

EMTP-RV software was used for the simulation of SOVs. The line considered is a single circuit 220 kV line equipped with a single shield wire, uprated to 400 kV without major modifications of the design of the towers. Phase conductors are bundled and consist of 2 sub-conductors separated by a distance of 0.4 m. The line is 350 km long. The position of conductors at tower and their average heights above ground are shown in Fig. 1. Characteristics of conductors are given in Table 1. The transmission line has an average span length 250 m, average sag length 11.5 m and measured switching impulse withstand voltage of the glass insulator strings 790 kV.

The transmission line was modeled by a frequency dependent model in EMTP-RV software. This model represents the true nature of a transmission line by considering the line parameters as distributed and frequency dependent. The line resistance and inductance are evaluated as functions of frequency, as determined by skin effect and ground return conditions. For soils with a relatively low ground resistivity, in the considered case 100 Ωm, the frequency dependence of soil parameters was not taken into account since it has only a reduced effect. The insulator flashover was not observed and therefore the frequency dependency of the grounding was not modeled. Capacitive voltage transformers are connected at line ends. In this case, the level of SOVs in some cases may exceed the switching withstand voltage of the insulator strings.

Table 1
Characteristics of conductors.

Conductors	Phase conductors	Shield wire
Type	Aluminum Conductor Steel Reinforced (ACSR)	Alloy AlMgSi 0.5/Aluminum Clad Steel Conductor (ACSC)
Cross section (mm^2)	490/65	95/55
External diameter (mm)	30.6	16.0
DC resistance (Ω/km)	0.059	0.3412

Table 2
Parameters of the equivalent network.

Source voltage (line voltage)	420 kV
Positive sequence resistance	2.71 Ω
Zero sequence resistance	6.17 Ω
Positive sequence inductance	89.55 mH
Zero sequence inductance	127.93 mH

Table 3
Nonlinear *U*–*I* characteristics of surge arresters.

I (A)	*U* (kV)	
	Energy class 4	Energy class 3
100	593	605
300	616	629
500	627	634
700	635	648
900	642	653
1000	644	654
2000	667	680
3000	684	706

2.2. Equivalent network and surge arresters

The equivalent 400 kV network was modeled by a voltage source behind Thevenin equivalent impedance. The parameters of the equivalent network, determined from short circuit currents at 400 kV level, are shown in Table 2.

Surge arresters were modeled according to the nonlinear *U*–*I* characteristics shown in Table 3.

Surge arresters with rated voltage U_r = 330 kV and energy classes 3 (7.8 kJ/kV) and 4 (12 kJ/kV) were considered in simulations.

2.3. Computations of switching overvoltages in EMTP-RV

The international standard [3] gives the typical values of $U_{2\%}$ SOVs, i.e. the values of the phase-to-earth overvoltages having a 2% probability of being exceeded. Switching operations such as line energization and re-closure or circuit breaker opening due to a line-to-ground fault are considered to be producing a large magnitude of SOVs. The most severe SOVs will occur in case of three-phase reclosing with trapped charge present on the line. Therefore, this case was considered in the statistical overvoltage analysis.

In order to obtain $U_{2\%}$ overvoltage profiles along the line length, the statistical calculation of SOVs was performed. The circuit for simulation of three-phase reclosing with trapped charge is shown in Fig. 2.

Voltage sources at the end of the line with amplitude of 1 p.u., corresponding to the maximum system AC voltage of 420 kV, are switched off by CB 2 at t = 20 ms. The maximum trapped charge of 1.18 p.u. remains in the phase A which is firstly switched-off due to the electromagnetic coupling of the other phases and due to the Ferranti effect. The voltages at the end of the line during the three-phase reclosing with trapped charge and without surge arresters are shown in Fig. 3.

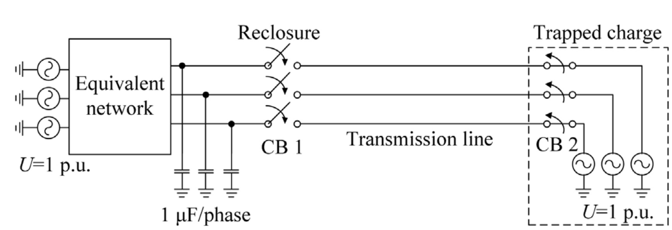

Fig. 2. Equivalent circuit for the simulation of three-phase reclosing with trapped charge.

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