Impact of high cable shares on transient energizing overvoltages, inrush currents and energy absorptions in hybrid high-voltage transmission systems

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ABSTRACT

With an increasing cable share in the European EHV networks an investigation of the overall impact of high cable shares on transient energizing overvoltages is necessary. This is done by means of statistical simulations of energizations of hybrid high-voltage transmission lines with EMTP-ATP-Draw. Starting from one hundred percent overhead lines, cable share is increased up to one hundred percent for different transmission line configurations. During this process different network parameters such as grid self-frequency and short-circuit power are varied. Key research variables are line voltages, cable sheath voltages, circuit breaker currents and energy absorptions of phase surge arresters and sheath voltage limiters.

KEYWORDS

Transient overvoltages, cable systems, switching surges, EMTP-ATP-Draw, surge arrester, energy absorption, energizing overvoltages, hybrid transmission lines, circuit-breaker inrush currents, sheath voltages

1. INTRODUCTION

Future high voltage transmission systems are going to be set up in cable technology more frequently (i.e. in the German extra high volgtage (EHV) networks [1]). Even though there is an increasing cable share to be found in transmission systems, experience and simulation results of transient overvoltages for cable shares up to one hundred percent with included grid representation of surrounding cables are still missing. Due to high cable capacitances, low surge impedances and low surge propagation speeds, compared to overhead lines, there is an impact to be expected on switching surges. Previous research has focused on specific pilot projects with dedicated grid conditions whereas generic simulation results regarding high overall cable percentages are still missing, as well as a generalized assessment of transient overvoltages in cable systems, including cable sheath voltages and energy absorption of surge arresters (e.g. [2], [3], [4]). For this purpose an overall line model has been established, which is presented in section 2 together with simulation models of both overhead lines (OHL) and cables (CA), as well as phase surge arresters (SA), sheath voltage limiters (SVL), inductive voltage transformers (IVT) and circuit breakers (CB) and their data. Afterwards the influence of line lengths, cable shares and system configurations with a fixed grid equilvalent is studied. This is followed by an analysis of the impact of a high overall cable share at different grid short-circuit levels. This includes impact assessment of local bus inductivities, time step widths and grid equivalent circuits. Both analyses are carried out by means of energizing studies with CB closing time distributions and case peak evaluations of resulting key parameters in combination with specific parameter waveforms.

2. SIMULATION MODEL AND DATA

As the key investigation is focused on the overall influence of a higher cable share, the simulation model is restricted to a singular hybrid transmission line, as shown in Fig. 1, terminated by a substation.

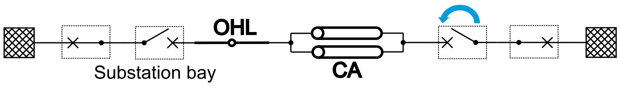

Fig. 1: Overall simulation model (C1)

The tansmission line, consisting of one or more cable- and overhead line sections, is varied in number and order of segments as follows:

- Config. No.: C1 (CA/OHL) - C2 (OHL/CA) - C3 (OHL/CA/OHL) - C4 (OHL/CA/OHL/CA/OHL)
- Line length (km): 15 – 30 – 45 – 60 – 75 – 90
- Cable share (%): 0 – 20 – 40 – 60 – 80 – 100

The order of cable and overhead lines is given as seen from the energizing circuit breaker on the right hand side. For all configurations the cable sections consist of two parallel cable systems, to establish an equal ampacity. Cable share is equally distributed between different cable sections. For further evaluation a numbering of "Configuration-No. C - Line length l in km - Cable share S in %" is established. For instance, "1-90-80" stands for configuration number one with a line of 90 km length with 72 km long cable section near the energizing circuit breaker. The simulated transmission line is connected to a substation together with a grid equivalent representing the surrounding EHV grid. Each substation bay consists of a CB, IVT, and SA. Transitions between CA and OHL also include SA and IVT. Compensation reactors are disregarded to focus on cable influences and will be investigated later. All elements are explained further on.

Grid model

Prior investigations on energizing overvoltages in hybrid high-voltage transmission lines have been either focusing on a specific surrounding grid (i.e. [4], [5], [6]) or on a simplified short-circuit impedance (i.e. [2]). Both approaches neglect possible influences of a higher cable share in surrounding grid areas and the resulting decline of grid self frequencies. For this reason a simplified grid equivalent was chosen according to Balzer and Neumann, which includes capacitive influences (see Fig. 2) [8]. Although it is recommended by IEC 60071-4 to represent transmission lines up to a distance of two substations for switching studies, by this means it is possible to include grid influences on the one hand and to keep the model parameters as simple as possible to analyse the influences of different grid parameters on the other hand ([7], [8]). All parameters can directly be calculated from existing network information with equations (1) to (4).