A novel lumped L-C ladder method for computing switching overvoltages in EHV long shunt-compensated cables

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The Laplace domain is a well-known tool in order to study circuit transients. When dealing with power transmission lines with uniformly distributed parameters the usual transmission matrix or ABCD matrix can be also written in Laplace domain. This involves voltage and current dependence upon spatial and temporal independent variables. In case of an insulated cable line (ICL) energization, the voltage at no-load end represents one of the most important switching overvoltages. Therefore the possibility of having a reliable, simple, fast and self-implemented tool to determine the transient behaviour ICL energization can be important for power engineers.

ATP/EMTP-RV or other software are suitable and commercially-available tools in order to analyse transients in power systems. Notwithstanding, academia has always aimed at finding alternative tools which include self implementation in mathematical software environment. One of the most powerful tools for transient analysis is the Laplace transform where the time domain response is obtained by inverse Laplace transform (ILT). With regard to uniformly distributed transmission lines, this inversion can be hard and cumbersome since the function to be inverted is not rational (i.e. it is not a ratio of polynomials) but holds transcendental terms. In fact, the no-load voltage at receiving-end UR(s) is immediately given by setting IR(s)=0 so that:

$$U_R(s)=\frac{U(s)}{\left[cosh(s\tau)\cdot\left(2\frac{\ell_{sc}}{\ell_{sr}}+1\right)+sinh(s\tau)\cdot\left(\frac{Z_c^2\ell_{sc}+s^2\ell_{sr}^2\ell_{sc}+Z_c^2\ell_{sr}}{sZ_c\ell_{sr}}\right)\right]} \quad (1)$$

where U(s) is the Laplace transform of the supplying generator. The switching overvoltages due to the shunt compensated cable energization are given by the ILT of (1). Unfortunately, it is not analytically possible since it has transcendental terms. Consequently, a numerical inverse Laplace transform (NILT) is necessary and has been ideated by the authors and implemented in Matlab. The proposed NILT is based on the residue theorem of the complex analysis. Differently, this paper proposes to study switching overvoltages by representing the ICL as a cascade of n cells constituted of lumped L-C ladder (with acronym LLCL) each representing a d/n length of the cable line so achieving the model of fig. 1. The number n can be chosen arbitrarily but precise results can be obtained even with n=2. At no load the receiving-end voltage is linked to the term M1,1(s) of the whole transmission matrix M (computed as a product of the transmission matrices representing the different two-port networks) and it holds only polynomials i.e. it is a rational functions whose ILT is immediate.

By assuming an EHV (400kV) 2500 mm^2 single-core cable system with ℓ= 0,576 mH/ km, c=240 nF/ km and d=30 km shunt compensated with ℓsr= 5,25 H and with ℓsc= 76,8 mH, it is possible to obtain the transient overvoltages shown in fig. 2. The EMTP-RV model has been chosen as reference and the NILT and LLCL have been compared with it. Despite its extreme simplicity, in the evaluation of the peak overvoltage LLCL method gives an overestimate of 1,07% (1,701 p.u. versus 1,683 of EMTP-RV).

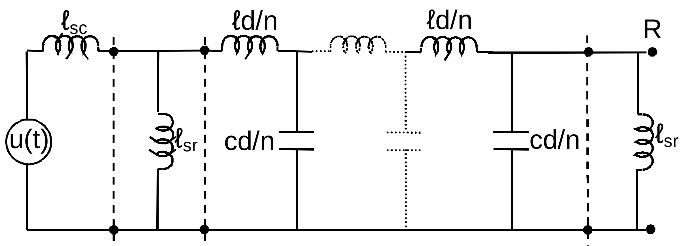

Figure 1 EHV shunt compensated ICL represented by a cascade of lumped L-C ladder

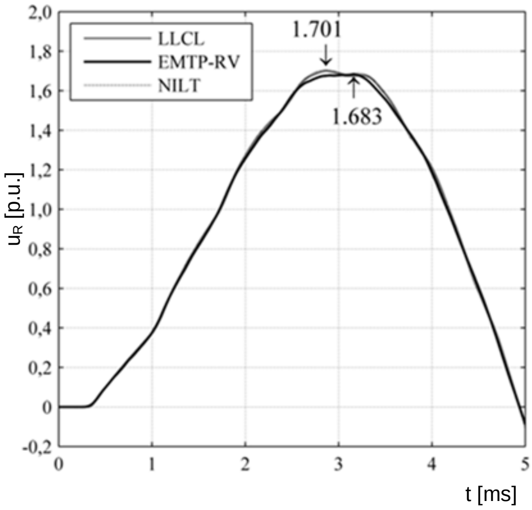

Figure 2 Transient overvoltage comparison in an EHV shunt compensated ICL