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

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## ABSTRACT

*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 space and time 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 can be extremely important for PES engineers both for validation of commercial software (e.g. Electromagnetic Transient Program - Reconstructed Version, with acronym EMTP-RV) and for understanding the different roles played by each parameter in the transient.*

## KEYWORDS

Switching overvoltages, Insulated cables, Inverse Laplace Transform, ladder circuit.

## INTRODUCTION

ATP/EMTP-RV or other software are suitable and 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 [1-3] 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. Therefore the use of numerical inverse Laplace transform (NILT) becomes necessary. Some contributions have tried to overcome the use of NILT by means of line modelling constituted by one PI lumped circuit [4].

Differently, this paper proposes to study switching overvoltages by representing the transmission line as a cascade of n cells constituted of lumped L-C ladder (with acronym LLCL). The use of R-C ladder circuit [5] has been proposed in circuit theory end chiefly applied to microwave contest [6] but in this specific application a L-C ladder representation gives a straightforward and powerful tool to easily compute the switching overvoltages in shunt-compensated long extra-high voltage (EHV) cables.

## THE COMPLETE SOLUTION OF THE SYSTEM WITH UNIFORMLY DISTRIBUTED PARAMETER CABLE LINE

Let us consider the energization at no-load of an EHV cable line with length *d* which is shunt compensated at both ends. The energizing grid is represented by its equivalent circuit i.e. a cosine generator *u(t)* with a series inductance $\ell_{sc}$ which can be computed by the knowledge of the three-phase short-circuit current at the sending-end port.

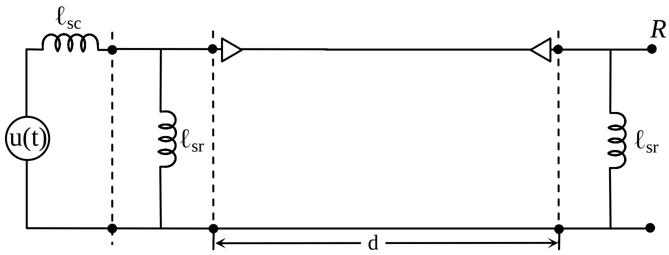


**Fig. 1 EHV shunt compensated cable line**

The transmission matrix of the ideal ICL (in EHV ICL, typical values of the ratio $r/(\omega\ell)$ and $g/(\omega c)$ are 0,07 and 0,0007 respectively) can be written in Laplace domain,

$$\boldsymbol{M}(d,s)=\begin{bmatrix} cosh(s\cdot d\cdot k(s)) & Z_c\, sinh(s\cdot d\cdot k(s)) \\ \dfrac{sinh(s\cdot d\cdot k(s))}{Z_c} & cosh(s\cdot d\cdot k(s)) \end{bmatrix} \quad (1)$$

where $Z_c=\sqrt{\dfrac{\ell}{c}}$ is the characteristic impedance and

$k(s)=s\cdot\sqrt{\ell c}$ is the propagation constant.

By posing $\tau=d\sqrt{\ell\cdot c}$, (1) can be re-written as in (2):

$$\boldsymbol{M}(d,s)=\begin{bmatrix} cosh(s\tau) & Z_c\, sinh(s\tau) \\ \dfrac{sinh(s\tau)}{Z_c} & cosh(s\tau) \end{bmatrix} \quad (2)$$

By means of (2), it is possible to compute the whole transmission system pertaining to the cascade of four two-port networks (TPNs) i.e. the elementary TPN of series impedance $Z_{sc}=s\ell_{sc}$ with matrix $\boldsymbol{M_{sc}}$, the elementary TPN of shunt admittance $Y_{sr}=1/(s\ell_{sr})$ with matrix $\boldsymbol{M_{sr}}$, the TPN of cable line with matrix in (2) and the elementary TPN of shunt admittance $Y_{sr}=1/(s\ell_{sr})$ at receiving-end with matrix $\boldsymbol{M_{sr}}$. Once the equivalent transmission matrix (which is given by the ordered product of each transmission matrix) has been computed,the no-load voltage at receiving-end $U_R(s)$ is immediately given by setting $I_R(s)=0$ so that: