CIGRE B4-57_ONE-SIDE SPECTRAL METHOD FOR LINE FAULT LOCATION IN HVDC LINE

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2nd October 2017

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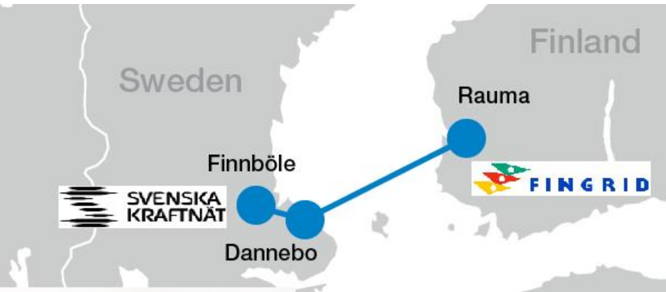
The relevance of HVDC technology development in Russian power industry

- Remoteness of generation facilities from the consumers
- High levels of short-circuit currents in metropolises
- Power supply of oil platforms (through water barriers)
- Issue of the RES connection
- Aging of existing network equipment
- Losses on power transmission
- Issue of modernization and development of Russian UES

Problem statement: HVDC transmissions with water barriers crossing

Fenno-Skan 1 & 2
AC voltage 400 kV
DC voltage Pole 1: 400 kV
Pole 2: 500 kV
Length of DC cable 200 km
Length of DC overhead line:
33 km (Finnish side)
70 km (Swedish side)



Skagerrak
AC voltage: 150, 300, 400 kV
DC voltage: 250 (Pole 1&2), 350 (Pole 3), 450 kV (Pole 4)
Length of DC cables: 104 (land), 121, 140 km (submarine)
Length od DC overhead line: 113 km

Baltic Cable
AC voltage: 400 kV
DC voltage: 450 kV
Length of DC cable: 250 km
Length of DC overhead line: 12 km

Short-circuit in HVDC line

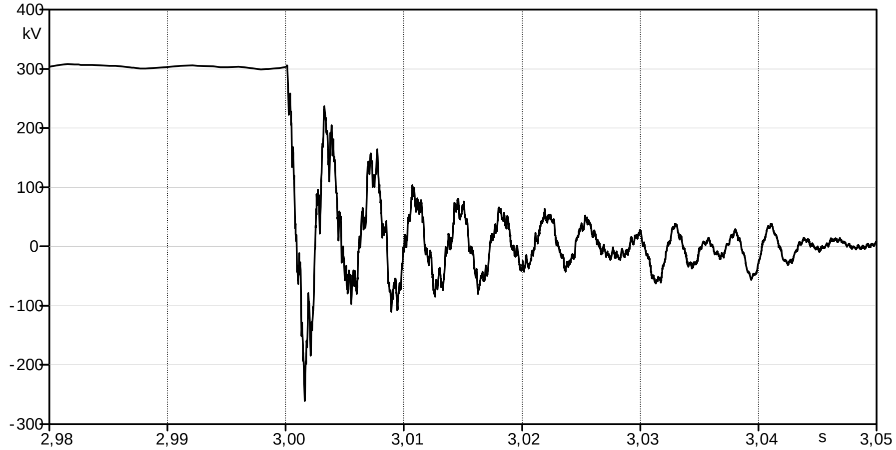


Fig. 1 Waveform of transient pole-to-ground voltage under a short circuit mode in the model of HVDC line

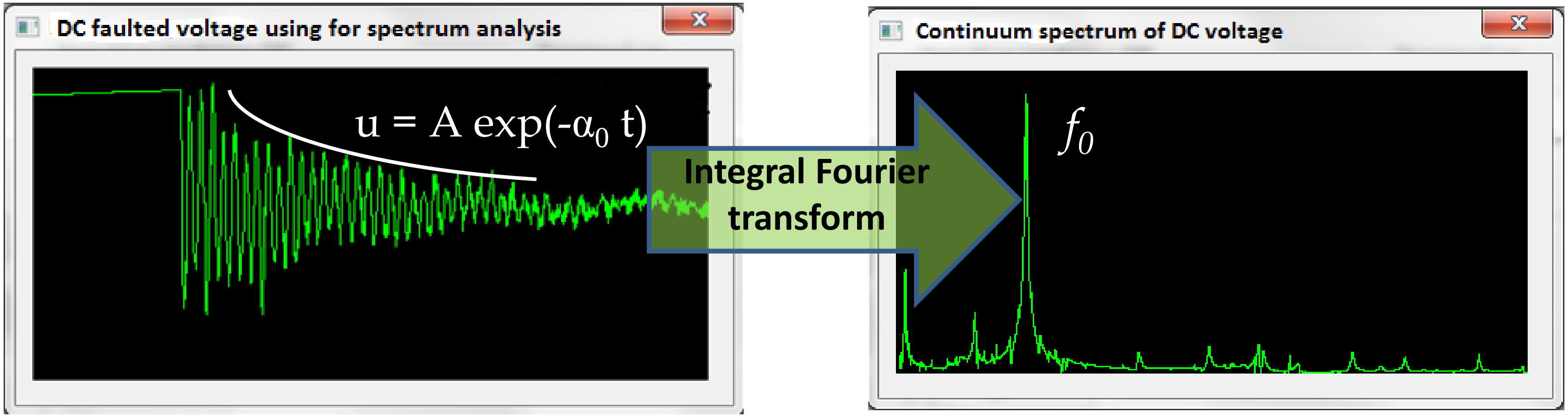


Fig. 2 Integral Fourier Transform for LFL issue

2nd October 2017

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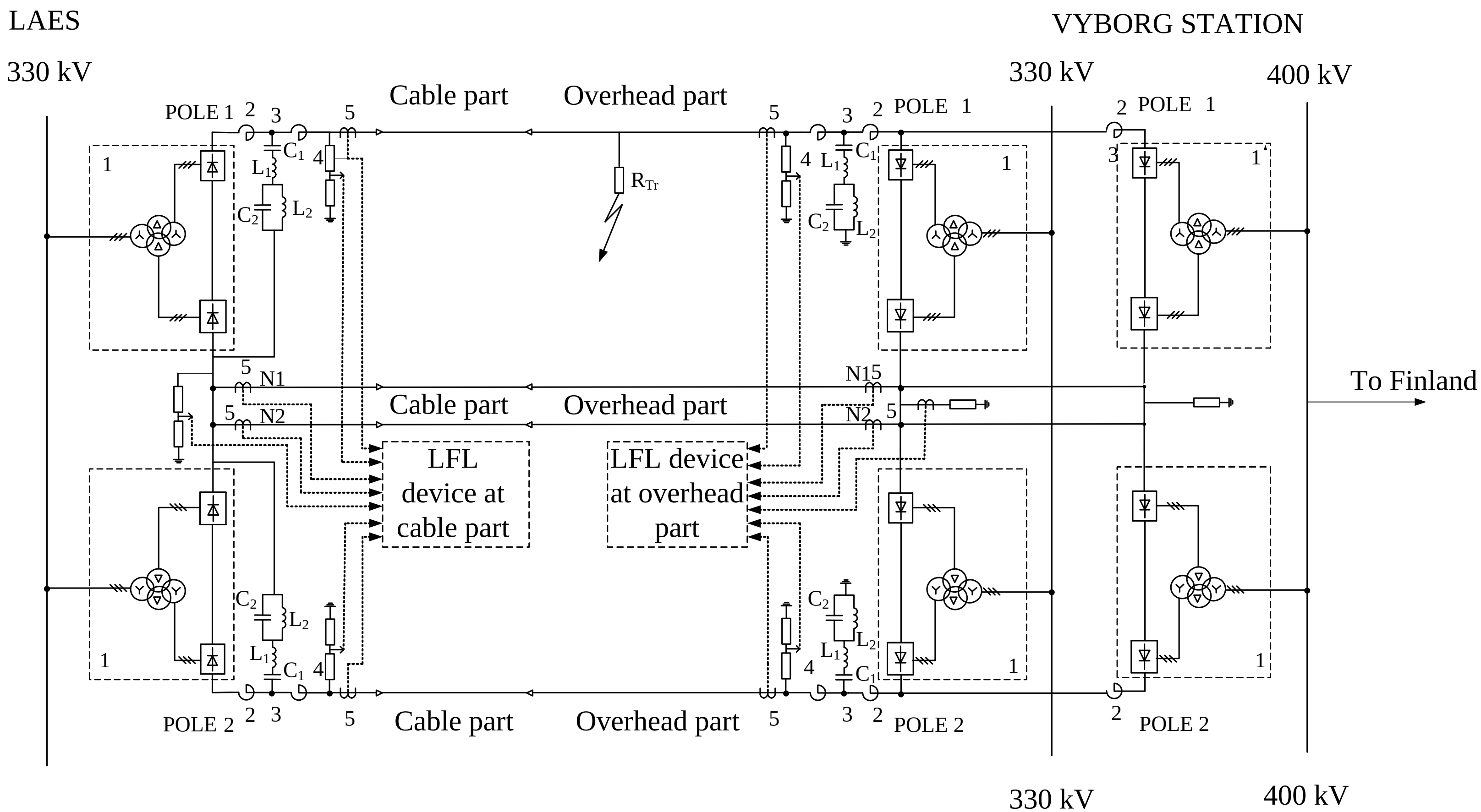
Equivalent scheme of LAES-2 – Vyborg HVDC system



LFL spectral algorithm

Quadric equation relative to the fault distance in case when the information about the fault is gathered from the LFL side, located at the faulted part of HVDC line:

$$\frac{2}{\pi}\dot{p}_0 C_0 \dot{D}\cdot\left(R_0+\frac{2}{\pi}\dot{p}_0 L_0\right)\cdot l_X^2 + \left[\frac{2}{\pi}\dot{p}_0\cdot\left(\dot{Y}_{F-C}L_0 + R_{Tr}C_0\dot{D}\right)+\dot{Y}_{F-C}R_0\right]\cdot l_X + \dot{Y}_{F-C}R_{Tr}+\dot{D}=0 \qquad (1)$$

where $\dot{D}=1+\dot{p}_0 L_r \dot{Y}_{F-C}$ $\quad \dot{Y}_{F-C}=\dot{Y}_{Filter}+\dot{Y}_{Conv}$ $\quad \dot{Y}_{Conv}=\dfrac{1}{\dot{p}_0 L''_{Conv}}$ $\quad \dot{Y}_{Filter}=\dfrac{\dot{p}_0 C_1\cdot\left(\dot{p}_0^{\,2}L_2C_2+1\right)}{\dot{p}_0^{\,2}L_2C_1+\left(\dot{p}_0^{\,2}L_1C_1+1\right)\cdot\left(\dot{p}_0^{\,2}L_2C_2+1\right)}$ $\quad p_0=-\alpha_0+j2\pi f_0$

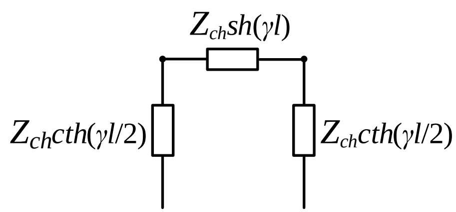


Fig.3 Equivalent circuit of the HVDC line unfaulted segment

$$Z_{ch}=\sqrt{\frac{L_{0\,un}}{C_{0\,un}}};\quad \gamma=j\omega\sqrt{L_{0\,un}C_{0\,un}}$$

Quadric equation relative to the fault distance in case when the information about the fault is gathered from the LFL side, located at the unfaulted part of HVDC line

$$\frac{2}{\pi}\dot{p}_0 C_0 \dot{Z}_1\cdot\left[\left(R_0+\frac{2}{\pi}\dot{p}_0 L_0\right)\cdot\left(\dot{Z}_2\dot{Y}_{F-C}+\dot{D}\dot{F}\right)\right]\cdot l_X^2+\left[\left(R_0+\frac{2}{\pi}\dot{p}_0L_0\right)\cdot\left(\dot{Z}_1\dot{Y}_{F-C}\dot{F}+\dot{D}\dot{E}\right)+\frac{2}{\pi}\dot{p}_0C_0\dot{Z}_1R_{Tr}\cdot\left(\dot{Z}_1\dot{Z}_2\dot{Y}_{F-C}+\dot{D}\dot{F}\right)\right]\cdot l_X + \qquad (2)$$

$$+\dot{F}\cdot\left(\dot{Z}_1\dot{Y}_{F-C}R_{Tr}+\dot{D}\dot{Z}_1\right)+\dot{Y}_{F-C}+\dot{D}R_{Tr}\dot{E}=0$$

where $\quad \dot{Z}_1=\dot{Z}_{ch}cth\left(\gamma l/2\right), \dot{Z}_2=\dot{Z}_{ch}sh\left(\gamma l\right) \quad \dot{E}=2\dot{Z}_1+\dot{Z}_2 \quad \dot{F}=\dot{Z}_1+\dot{Z}_2$

EMTP-ATP model of DC line

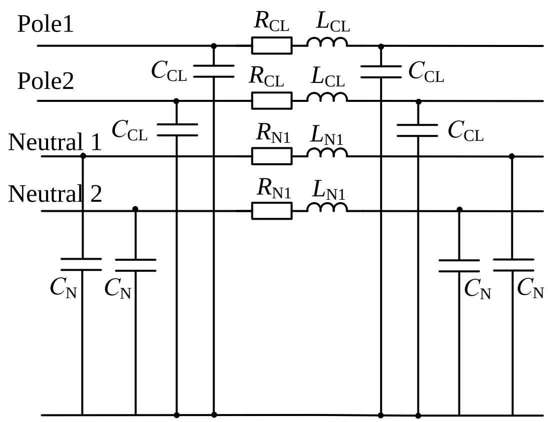


Fig.4 Equivalent scheme of the cable line Pi-cell

Parameters of the equivalent cable line Pi-cell

Pi-cell length, km	Pole wire parameters: *R*, Ohm; *L*, mHn	Neutral wire parameters: *R*, Ohm; *L*, mHn	Capasitances *C*, µF
$l_{CL\ Pi\text{-}cell}=1$	$R_{CL}=0{,}019$ $L_{CL}=0{,}502$	$R_{N1}=0{,}0068$ $L_{N1}=0{,}274$	$C_{CL}=0{,}301$ $C_N=0{,}517$

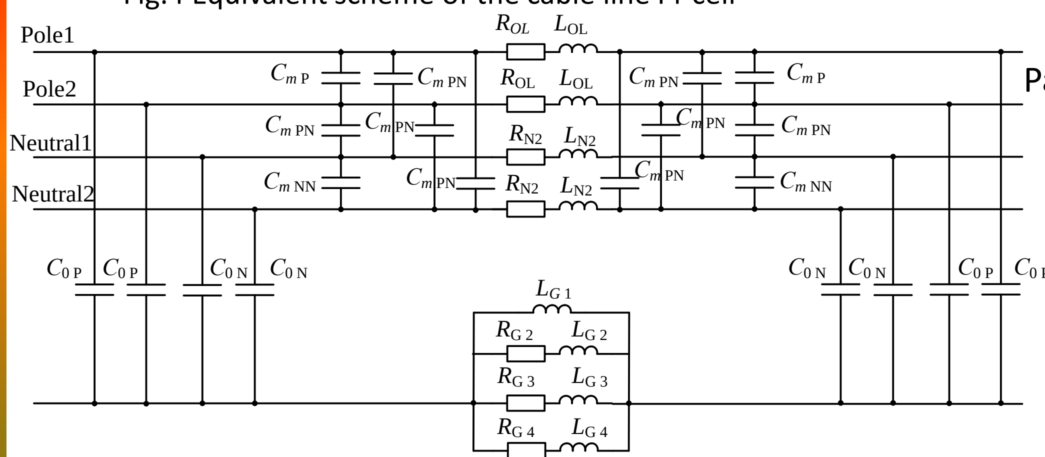


Fig.5 Equivalent scheme of the overhead line Pi-cell

Parameters of the equivalent overhead line Pi-cell

Pi-cell length, km	Pole wire parameters: *R*, Ohm; *L*, mHn	Neutral wire parameters: *R*, Ohm; *L*, mHn	Capasitances *C*, µF
$l_{OL\ Pi\text{-}cell}=2{,}48$	$R_{OL}=0{,}026$ $L_{OL}=1{,}048$	$R_{N2}=0{,}021$ $L_{N2}=0{,}952$	$C_{CL}=0{,}301$ $C_N=0{,}517$

Parameters of the equivalent ground wire R-L-circuits

Cell number, n	R_n, Ohm/km	L_n, mHn/km	*f*, Hz
1	0	2,0	0
2	0,118	1,046	100
3	7,08	1,064	10000
4	35,4	0,263	20000

Results of testing proposed one-side LFL algorithm in digital model of HVDC line

Faulted segment	Result at the faulted side			Result at the unfaulted side		
	Real fault distance, km	Fault distance obtained from the proposed LFL algorithm, km	δ, %	Real fault distance, km	Fault distance obtained from the proposed LFL algorithm, km	δ, %
Overhead	9,93	10,12	0,46	57,07	57,4	0,78
Overhead	24,82	24,7	0,29	42,18	41,8	0,95
Overhead	34,72	34,4	0,45	32,28	31,5	1,16
Overhead	44,64	44,87	0,34	22,36	23,05	1,03
Overhead	62	62,3	0,44	5	5,6	0,89
Cable	6	5,93	0,17	35	35,5	1,22
Cable	17	17,2	0,49	24	23,85	0,37
Cable	25	24,8	0,48	16	15,63	0,9
Cable	33	33,74	0,63	8	7,6	0,98

Conclusions

- To solve the LFL issue in the HVDC line, consisted of both overhead and cable segments carrying out a detailed analysis of the frequency components of the informative signal is proposed. As an informative signal the transient voltage at the one side of DC line is considered.
- Calculation of the fault distance is considered in the view of the high harmonic filter on the DC side, installed in the midpoint of the smoothing reactor. For this purpose, total equivalent conductivity of the short-circuit line model is determined.
- The error of the proposed LFL spectrum method in considered cases of short-circuit does not exceed 1,22% of the length of a short-circuited segment of the line.
- In DC lines consisted of only two different segments it is recommended to use the LFL spectrum algorithm analyzing the information about the transient pole-to-ground voltage at the faulted segment side. In this case the error of LFL algorithm does not exceed 0,63% of the length of a short-circuited segment of the line.