Impact of modelling of transmission network components on the emission limits for distorting loads in HV system

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Contents

Frequency scan analysis

$$[Y_f] = \begin{bmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & \ddots & \vdots \\ Y_{n1} & \cdots & Y_{nn} \end{bmatrix}$$

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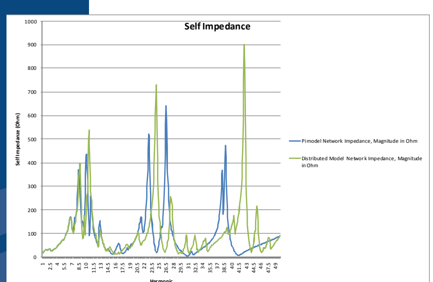
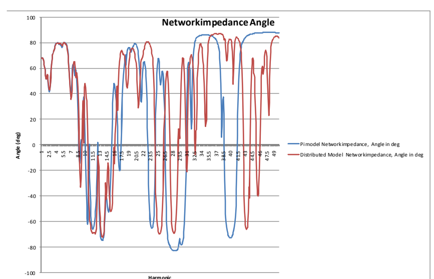
Frequency scan analysis

Self impedance (Pi line model / Distributed parameters line model)



Network impedance Angle (Pi line model / Distributed parameters line model)



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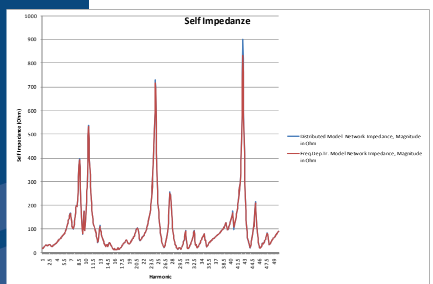
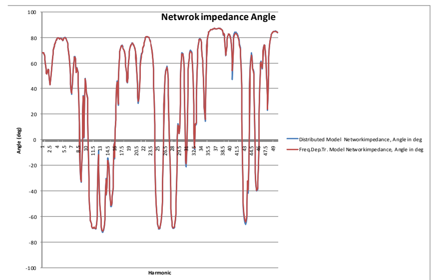
Transformer leakage admittance: $Y_{th} = \dfrac{1}{R\sqrt{h} + jX_l h}$

Self Impedance (Distributed line model / Freq. dep. resistance of Tr.)



Network Impedance Angle (Distributed line model / Freq. dep. resistance of Tr.)



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The skin effect of the transmission line

$$Z_c = \frac{j\omega\mu_0}{2\pi}\frac{1}{x_e}\frac{J_0(x_e)N_0'(x_i) - N_0(x_e)J_0'(x_i)}{J_0'(x_e)N_0'(x_i) - N_0'(x_e)J_0'(x_i)}$$

$$x_e = j\sqrt{j\omega\mu_0\sigma_c}\, r_e \qquad x_i = j\sqrt{j\omega\mu_0\sigma_c}\, r_i \qquad \omega = 2\pi f$$

- r_e the external radius of conductor (m)
- r_i the internal radius of conductor (m)
- J_0 is the Bessel function of the first kind and zero order
- J'_0 is the derivative of the Bessel function of the first kind and zero order
- N_0 is the Bessel function of the second kind and zero order
- J'_0 is the derivative of the Bessel function of the second kind and zero order
- σ_c is the conductivity of the conductor material at the average conductor temperature
- f is frequency (Hz)
- μ_0 is the permeability of free space

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Correction factors for skin effect in overhead lines

	Voltage (kV)	Harmonic order	Resistance
NGC	400, 275	h≤4.21 4.21<h ≤7.76 h>7.76	$R_1\left(1+\frac{3.45h^2}{192+2.77h^2}\right)$ $R_1(0.806+0.105h)$ $R_1(0.267+0.485\sqrt{h})$
NGC	132		$R_1\left(1+\frac{0.6465h^2}{192+0.518h^2}\right)$
EDF	400, 225	h≤4 4<h<8 h>8	$R_1\left(1+\frac{3.45h^2}{192+2.77h^2}\right)$ $R_1(0.864-0.024\sqrt{h}+0.105h)$ $R_1(0.267+0.485\sqrt{h})$
EDF	150, 90		$R_1\left(1+\frac{0.646h^2}{192+0.518h^2}\right)$

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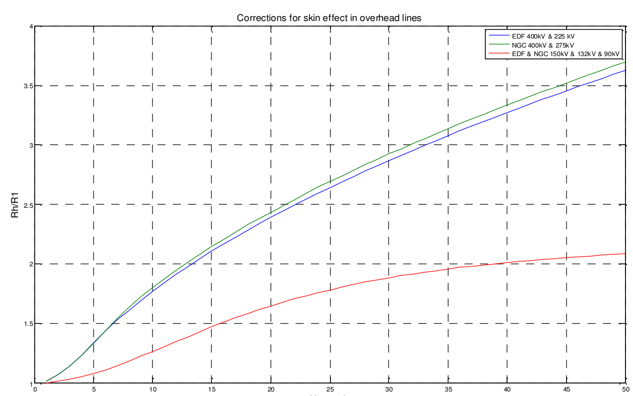
Correction for skin effect in overhead lines according to EDF & NGC



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$$k(f) = (1 - a) + a * (\frac{f}{f_{nom}})^b$$

	Voltage (kV)	Coefficient a	Coefficient b
NGC	400, 275	0.2401	0.6434
NGC	132	0.0985	0.6562
EDF	400, 225	0.2286	0.6486
EDF	150, 90	0.0985	0.6562

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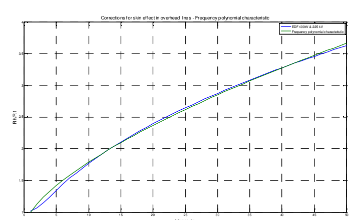
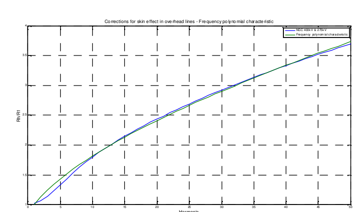
Correction for skin effect in over headlines - EDF 400 kV & 225 kV / Frequency polynomial function

Correction for skin effect in over headlines - NGC 400 kV & 275 kV / Frequency polynomial function





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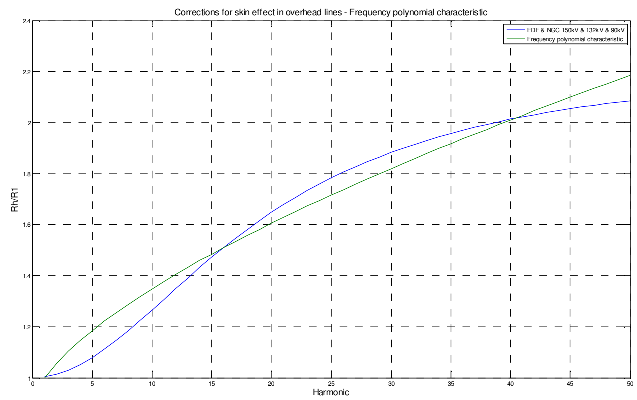
Correction for skin effect in over headlines - EDF / NGC 150 kV / 132 kV and 90 kV - Frequency polynomial function



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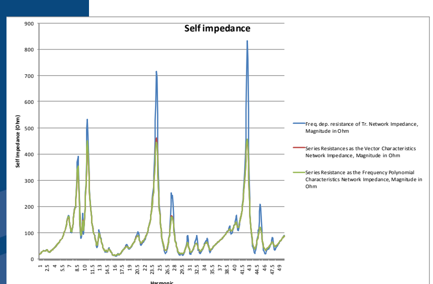
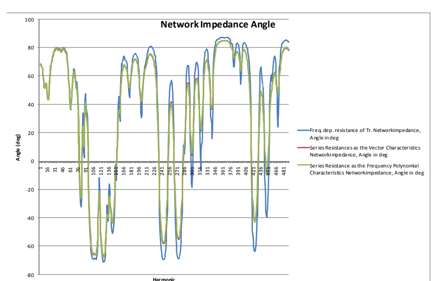
The skin effect in over headlines

Self impedance taking into account skin effect of the series resistance of the transmission lines



Network Impedance Angle taking into account skin effect of the series resistance of the transmission lines



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Conclusions related to the self impedances of the busbar concerning different modelling approaches of the skin effect:

- There is no significant impact of the modelling of the skin effect on the complex self impedance for harmonics lower than 8^{th} harmonic.
- The impact of the skin effect on the self impedance of the busbar increase with the order of the harmonic.
- Skin effect has the biggest impact on the busbar self impedance at resonant frequencies. At resonant frequencies, the amplitude of the self impedance can be reduced up to 50% if the skin effect of the transmission lines has been modelled. Taking this into account the modelling of the skin effect of transmission lines can be seen as being critical for all frequency scan analysis.
- Modelling of skin effect does not have any impact on the resonance frequencies of the self impedances
- There are no significant differences between two analysed modelling methodologies of the skin effect: the frequency polynomial functions and vector characteristics. The frequency polynomial function is simpler and much easier to apply which is a major advantage of this methodology.
- We notice that modelling of skin effect has an impact on the network impedance angle; however we are not able to identify any importance of this on the filter design or harmonic allocation.

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Emission limits for distorting loads in HV - EHV systems

- Stage 1

$$\frac{S_{Di}}{S_{SC}} \leq 0.1 - 0.4\,\%\ (HV) \qquad \frac{S_{Di}}{S_{SC}} \leq 0.1 - 0.2\,\%\ (EHV)$$

- Stage 2

$$S_t = S_{t1} + K_{h2-1}S_{t2} + K_{h3-1}S_{t3} + \cdots$$

- 1 is the considered node and 2, 3, … the other nodes
- S_{t1}, S_{t2}, S_{t3}, … the total available power of the network at the point of common coupling (total supply capability)
- h harmonic order
- K_{h2-1}, K_{h3-1}, K_{h4-1}, … the influence coefficients. The influence coefficient $\boldsymbol{K_{hj-i}}$ is the harmonic voltage of order ***h*** which is caused at node ***i*** when 1 p.u. harmonic voltage of order ***h*** is applied at node ***j.***

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$$E_{UHi} = \frac{(L^{\alpha}_{hHV} - B^{\alpha}_{h})^{\frac{1}{\alpha}}}{K_{hi-j}} \sqrt[\alpha]{\frac{S_i}{(S_t - S_B)} \frac{1}{F_{HV}}}$$

- E_{UHi} is the voltage emission limit of a consumer ***i*** at harmonic ***h***
- L_{hHV} is the planning level of the h[th] harmonic in HV or EHV systems see Standard
- S_i is the rating of the consumer
- α is the summation law exponent, see Standard
- F_{HV} is the coincidence factor for HV loads, typical values are between 0.4 and 1.
- B_h is the background harmonic level higher than normal share
- S_B is the already connected power responsible for background level B_h
- K_{hi-j} is the greatest influence coefficient greater than 1.

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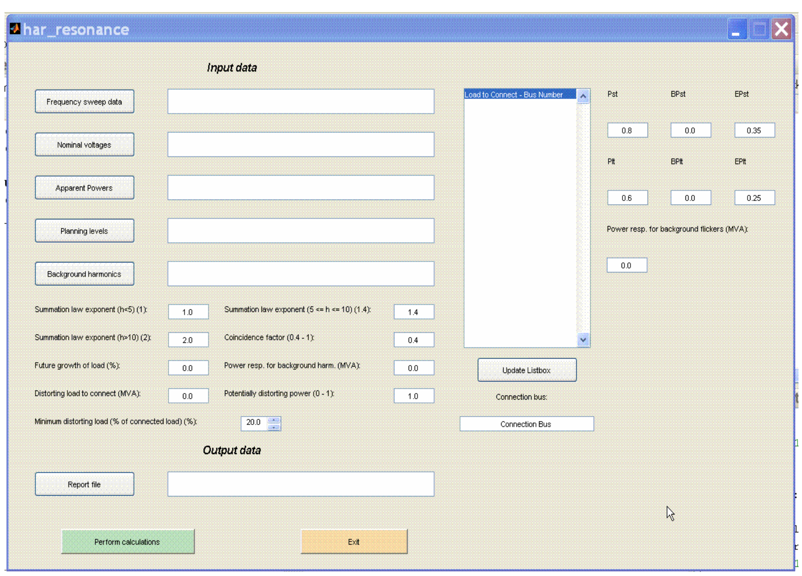
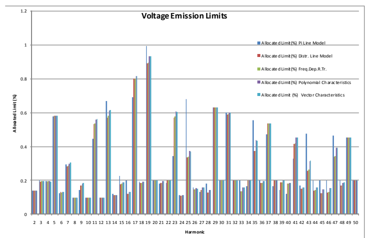
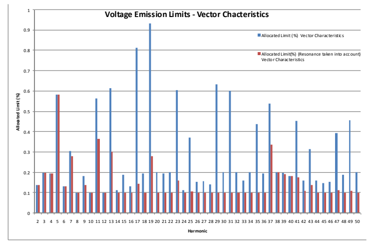
Current and voltage emission limits PowerFactory and Matlab scripts



Voltage emission limits, 40 MVA load

Voltage emission limits with and without resonance effect, 40 MVA load





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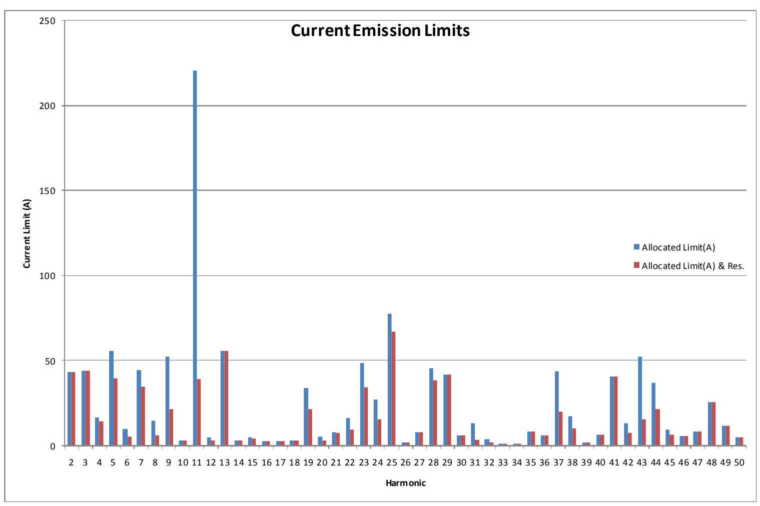

Current emission, 40 MVA load

E_{IHi} is the current emission limit of a consumer ***i*** at harmonic ***h***

Z_{hi} is the self impedance at node ***i*** at harmonic ***h***

$$E_{IHi} = \frac{E_{Uhi}}{Z_{hi}}$$

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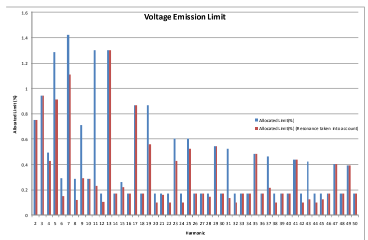
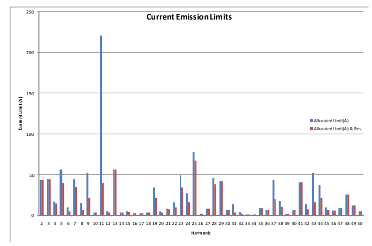
Voltage emission limits, 500 MVA load

Current emission limits, 500 MVA





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Conclusions

Questions

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