Validering af model

Voltage drop calculation

Windfarm

$S_{wind} := 5.51 \cdot 10^3\ kV \cdot A$ $\quad V_{wind} := 33\ kV$ $\quad \chi'_{dwind} := 0.33$ $\quad pf_{wind} := 0.9$

$c := 1.1$ $\quad X''Rratio := 10$

$\phi_{wind} := \text{acos}\left(pf_{wind}\right) = 0.451$

$$Kg_{wind} := 1 \cdot \frac{c}{1 + \chi'_{dwind} \cdot \sin\left(\phi_{wind}\right)} = 0.962$$

$$X'_{dwind} := \chi'_{dwind} \cdot Kg_{wind} \cdot \frac{{V_{wind}}^2}{S_{wind}} = 62.721\ \Omega \qquad R_g := \frac{X'_{dwind}}{X''Rratio} = 6.272\ \Omega$$

Synkron generator

$S_{pp} := 6.01 \cdot 10^3\ kV \cdot A$ $\quad V_{pp} := 33\ kV$ $\quad \chi'_{dpp} := 0.232$ $\quad pf_{pp} := 0.8$

$\phi_{pp} := \text{acos}\left(pf_{pp}\right) = 0.644$

$$Kg_{pp} := 1 \cdot \frac{c}{1 + \chi'_{dpp} \cdot \sin\left(\phi_{pp}\right)} = 0.966$$

$$X'_{dpp} := \chi'_{dpp} \cdot Kg_{pp} \cdot \frac{{V_{pp}}^2}{S_{pp}} = 40.591\ \Omega \qquad R_{pp} := \frac{X'_{dpp}}{X''Rratio} = 4.059\ \Omega$$

$$Z_{pp} := R_{pp} + X'_{dpp} \cdot 1\text{i} = (4.059 + 40.591\text{i})\ \Omega$$

Transformer 15MVA 33/150kV

$S_{T1} := 15 \cdot 10^3\ kV \cdot A$ $\quad V_{T1HV} := 150\ kV$ $\quad V_{T1LV} := 33\ kV$ $\quad U_{kT1} := 0.0802$

$P_{T1} := 50\ kW$

$$Z_{T1} := U_{kT1} \cdot \frac{{V_{T1HV}}^2}{S_{T1}} = 120.3\ \Omega \qquad I_{T1} := \frac{S_{T1}}{V_{T1HV} \cdot \sqrt{3}} = 57.735\ A$$

$$R_{T1} := \frac{P_{T1}}{3 \cdot {I_{T1}}^2} = 5\ \Omega \qquad X_{T1} := \sqrt{{Z_{T1}}^2 - {R_{T1}}^2} = 120.196\ \Omega$$

$$Z_{T1} := R_{T1} + X_{T1} \cdot 1\text{i} = (120.3 \angle 87.618°)\ \Omega$$

Transformer 15MVA 150/60kV

$S_{T2} := 15 \cdot 10^3 \ kV \cdot A$ $\quad V_{T2HV} := 150 \ kV$ $\quad V_{T2LV} := 60 \ kV$ $\quad U_{kT2} := 0.0802$

$P_{T2} := 50 \ kW$

$$Z_{T2} := U_{kT2} \cdot \frac{{V_{T2HV}}^2}{S_{T2}} = 120.3 \ \Omega \qquad I_{T2} := \frac{S_{T2}}{V_{T2HV} \cdot \sqrt{3}} = 57.735 \ A$$

$$R_{T2} := \frac{P_{T2}}{3 \cdot {I_{T2}}^2} = 5 \ \Omega \qquad X_{T2} := \sqrt{{Z_{T2}}^2 - {R_{T2}}^2} = 120.196 \ \Omega$$

$$Z_{T2} := R_{T2} + X_{T2} \cdot 1\mathrm{i} = (120.3 \angle 87.618°) \ \Omega$$

Transformer 15MVA 60/10kV

$S_{T3} := 15 \cdot 10^3 \ kV \cdot A$ $\quad V_{T3HV} := 60 \ kV$ $\quad V_{T3LV} := 10 \ kV$ $\quad U_{kT3} := 0.0802$

$P_{T3} := 50 \ kW$

$$Z_{T3} := U_{kT3} \cdot \frac{{V_{T3HV}}^2}{S_{T3}} = 19.248 \ \Omega \qquad I_{T3} := \frac{S_{T3}}{V_{T3HV} \cdot \sqrt{3}} = 144.338 \ A$$

$$R_{T3} := \frac{P_{T3}}{3 \cdot {I_{T3}}^2} = 0.8 \ \Omega \qquad X_{T3} := \sqrt{{Z_{T3}}^2 - {R_{T3}}^2} = 19.231 \ \Omega$$

$$Z_{T3} := (R_{T3} + X_{T3} \cdot 1\mathrm{i}) = (19.248 \angle 87.618°) \ \Omega$$

Transformer 2.5MVA 10/0.4kV

$S_{T4} := 2.5 \cdot 10^3 \ kV \cdot A$ $\quad V_{T4HV} := 10 \ kV$ $\quad V_{T4LV} := 0.4 \ kV$ $\quad U_{kT4} := 0.06$

$P_{T4} := 19 \ kW$

$$Z_{T4} := U_{kT4} \cdot \frac{{V_{T4HV}}^2}{S_{T4}} = 2.4 \ \Omega \qquad I_{T4} := \frac{S_{T4}}{V_{T4HV} \cdot \sqrt{3}} = 144.338 \ A$$

$$R_{T4} := \frac{P_{T4}}{3 \cdot {I_{T4}}^2} = 0.304 \ \Omega \qquad X_{T4} := \sqrt{{Z_{T4}}^2 - {R_{T4}}^2} = 2.381 \ \Omega$$

$$Z_{T4} := (R_{T4} + X_{T4} \cdot 1\mathrm{i}) = (0.304 + 2.381\mathrm{i}) \ \Omega$$

Transmission cable 150kV

$R_{150kV} := 0.194 \frac{\Omega}{km}$ $X_{150kV} := 0.4 \frac{\Omega}{km}$ $L_{c150kV} := 50\ km$

$R_{c150kV} := R_{150kV} \cdot L_{c150kV} = 9.7\ \Omega$ $X_{c150kV} := X_{150kV} \cdot L_{c150kV} = 20\ \Omega$

$Z_{c150kV} := R_{c150kV} + X_{c150kV} \cdot 1i = (22.228 \angle 64.127°)\ \Omega$

Transmission cable 60kV

$R_{60kV} := 0.8342 \frac{\Omega}{km}$ $X_{60kV} := 0.43 \frac{\Omega}{km}$ $L_{c60kV} := 20\ km$

$R_{c60kV} := R_{60kV} \cdot L_{c60kV} = 16.684\ \Omega$ $X_{c60kV} := X_{60kV} \cdot L_{c60kV} = 8.6\ \Omega$

$Z_{c60kV} := R_{c60kV} + X_{c60kV} \cdot 1i = (18.77 \angle 27.269°)\ \Omega$

Windfarm cable 33kV

$R_{33kV} := 0.1021 \frac{\Omega}{km}$ $X_{33kV} := 0.1445 \frac{\Omega}{km}$ $L_{c33kV} := 35\ km$

$R_{c33kV} := R_{33kV} \cdot L_{c33kV} = 3.574\ \Omega$ $X_{c33kV} := X_{33kV} \cdot L_{c33kV} = 5.058\ \Omega$

$Z_{c33kV} := R_{c33kV} + X_{c33kV} \cdot 1i = (6.193 \angle 54.756°)\ \Omega$

Distribution cable 10kV

$R_{10kV} := 0.1571 \frac{\Omega}{km}$ $X_{10kV} := 0.31 \frac{\Omega}{km}$ $L_{c10kV} := 10\ km$

$R_{c10kV} := R_{10kV} \cdot L_{c10kV} = 1.571\ \Omega$ $X_{c10kV} := X_{10kV} \cdot L_{c10kV} = 3.1\ \Omega$

$Z_{c10kV} := R_{c10kV} + X_{c10kV} \cdot 1i = (3.475 \angle 63.125°)\ \Omega$

Byer

$P_{by} := 0.5\ MW$ $\quad Q_{by} := 0.242\ MW$ $\quad S_{by} := \sqrt{P_{by}^{\ 2} + Q_{by}^{\ 2}} = 0.555\ MW$ $\quad V_{by} := 0.333\ kV$

$$Z_{by} := \frac{V_{by}^{\ 2}}{S_{by}} = 0.2\ \Omega$$

$R_{by} := Z_{by} \cdot \frac{P_{by}}{S_{by}} = 0.18\ \Omega$ $\quad X_{by} := \sqrt{Z_{by}^{\ 2} - R_{by}^{\ 2}} = 0.087\ \Omega$

$$Z_{by} := R_{by} + X_{by} \cdot 1i = (0.2 \angle 25.827°)\ \Omega$$

Equivalent circuit

Source impedance

$a_1 := \frac{V_{T1LV}}{V_{T1HV}} = 0.22$ $\quad a_2 := \frac{V_{T2LV}}{V_{T2HV}} = 0.4$ $\quad a_3 := \frac{V_{T3LV}}{V_{T3HV}} = 0.167$ $\quad a_4 := \frac{V_{T4LV}}{V_{T4HV}}$

$$Z_{pp'} := Z_{pp} \cdot \left(\frac{1}{a_1}\right)^2 \cdot a_2^{\ 2} \cdot a_3^{\ 2} = (0.373 + 3.727i)\ \Omega$$

$$Z_{T1'} := Z_{T1} \cdot a_2^{\ 2} \cdot a_3^{\ 2} = (0.022 + 0.534i)\ \Omega$$

$$Z_{c150kV'} := Z_{c150kV} \cdot a_2^{\ 2} \cdot a_3^{\ 2} = (0.043 + 0.089i)\ \Omega$$

$$Z_{T2'} := Z_{T2} \cdot a_2^{\ 2} \cdot a_3^{\ 2} = (0.022 + 0.534i)\ \Omega$$

$$Z_{c60kV'} := Z_{c60kV} \cdot a_3^{\ 2} = (0.463 + 0.239i)\ \Omega$$

$$Z_{T3'} := Z_{T3} \cdot a_3^{\ 2} = (0.022 + 0.534i)\ \Omega$$

$$Z_{source} := Z_{T1'} + Z_{c150kV'} + Z_{T2'} + Z_{c60kV'} + Z_{T3'} = (2.014 \angle 73.461°)\ \Omega$$

Load impedance

$$Z_{by'} := Z_{by} \cdot \left(\frac{1}{a_4}\right)^2 = (124.766\angle 25.827°)\ \Omega$$

$$Z_{load} := Z_{c10kV} + \frac{1}{\left(Z_{c10kV} + \frac{1}{\left(Z_{c10kV}+Z_{T4}+Z_{by'}\right)^{-1} + \left(Z_{T4}+Z_{by'}\right)^{-1}}\right)^{-1} + \left(Z_{T4}+Z_{by'}\right)^{-1} + \left(Z_{c10kV} + \frac{}{\left(Z_{c10kV}+Z\right.}\right.}$$

$$Z_{load} = (24.724 + 15.665i)\ \Omega$$

Spændingsfald

Beregning

$$V_{10kVact} := V_{T4HV} \cdot \frac{Z_{load}}{Z_{load} + Z_{source}} = (9.498\angle -2.462°)\ kV$$

Simulering

$$V_{10kVsim} := (9.452\angle -2.465\ deg)\ kV$$

$$V_{10kVpu} := 0.945$$

SC calculation

Synkron gennerator kortslutningsimpedans

$S_{pp} := 6.01 \cdot 10^3 \ kV \cdot A$ $\quad V_{pp} := 33 \ kV$ $\quad \chi''_{dpp} := 0.12$ $\quad pf_{pp} := 0.8$

$$S_{ppSC} := \frac{S_{pp}}{\chi''_{dpp}} = 50.083 \ MW$$

$$\phi_{pp} := \mathrm{acos}\left(pf_{pp}\right) = 0.644$$

$$Kg_{pp} := 1 \cdot \frac{c}{1 + \chi''_{dpp} \cdot \sin\left(\phi_{pp}\right)} = 1.026$$

$$X''_{dpp} := \chi''_{dpp} \cdot Kg_{pp} \cdot \frac{{V_{pp}}^2}{S_{pp}} = 22.312 \ \Omega \qquad R_{pp} := \frac{X''_{dpp}}{X''Rratio} = 2.231 \ \Omega$$

$$Z_{ppSC} := R_{pp} + X''_{dpp} \cdot 1\mathrm{i} = (2.231 + 22.312\mathrm{i}) \ \Omega$$

System kortslutningsimpedans

$$Z_{ppSC'} := Z_{ppSC} \cdot \left(\frac{1}{a_1}\right)^2 \cdot {a_2}^2 \cdot {a_3}^2 = (0.205 + 2.049\mathrm{i}) \ \Omega$$

$$Z_{SC} := Z_{ppSC'} + Z_{T1'} + Z_{c150kV'} + Z_{T2'} + Z_{c60kV'} + Z_{T3'} = (4.055 \angle 78.936°) \ \Omega$$

Beregning

$$I_{SCact} := \left|\frac{c \cdot V_{T3LV}}{\sqrt{3} \cdot Z_{SC}}\right| = 1.57 \ kA$$

Simulering

$$I_{SCsim} := 1.57 \ kA$$