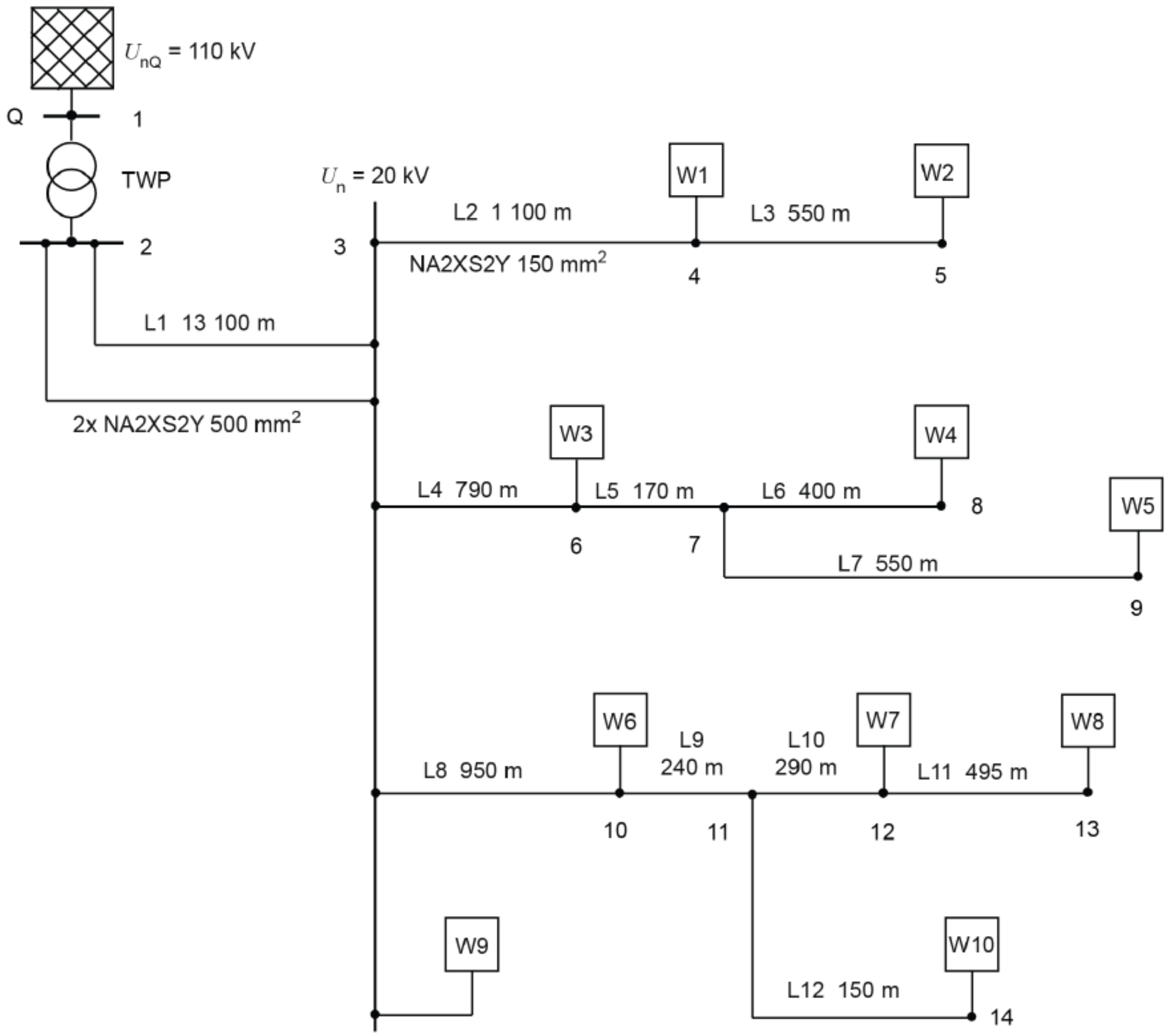

U_{nQ} = 110 kV
Q
1
TWP
2
U_n = 20 kV
3
L2 1 100 m
NA2XS2Y 150 mm²
W1
4
L3 550 m
W2
5
L1 13 100 m
2x NA2XS2Y 500 mm²
W3
L4 790 m
6
L5 170 m
7
L6 400 m
W4
8
L7 550 m
W5
9
W6
L8 950 m
10
L9
240 m
11
L10
290 m
W7
12
L11 495 m
W8
13
W9
L12 150 m
W10
14

Data	Formulae (IEC 60909-0:2016) and calculation	Impedance Ω
Network feeder Q $U_{nQ} = 110 kV$ $I''_{kQ} = 10,5 kA$ $c_Q = c_{max} = 1,1$ $R_Q = 0,1\, X_Q$	(6) $Z_{Qt} = \frac{c_Q U_{nQ}}{\sqrt{3} \cdot I''_{kQ}} \cdot \frac{1}{t_r^2} = \frac{1,1 \cdot 110\ kV}{\sqrt{3} \cdot 10,5\ kA} \cdot \left(\frac{20\ kV}{110\ kV}\right)^2$ $X_{Qt} = \frac{Z_{Qt}}{\sqrt{1+(R_Q/X_Q)^2}}$; $R_{Qt} = 0,1\, X_{Qt}$ $\underline{Z}_{Qt} = R_{Qt} + jX_{Qt}$	$Z_{Qt} = 0,219\,9$ $\underline{Z}_{Qt} = 0,021\,9 + j0,218\,8$
Transformer TWP $S_{rTWP} = 31,5 MVA$ $U_{rTWPHV} = 110 kV$ $U_{rTWPLV} = 20 kV$ $u_{kr} = 12 \%$ $u_{Rr} = 0,6 \%$	(7) $Z_{TWP} = \frac{u_{kr}}{100\ \%} \cdot \frac{U^2_{rTWPLV}}{S_{rTWP}} = \frac{12\ \%}{100\ \%} \cdot \frac{(20\ kV)^2}{31,5\ MVA}$ (8) $R_{TWP} = \frac{u_{Rr}}{100\ \%} \cdot \frac{U^2_{rTWPLV}}{S_{rTWP}} = \frac{0,6\ \%}{100\ \%} \cdot \frac{(20\ kV)^2}{31,5\ MVA}$ (9) $X_{TWP} = \sqrt{Z^2_{TWP} - R^2_{TWP}}$ $\underline{Z}_{TWP} = R_{TWP} + jX_{TWP}$ (12a) $K_T = \frac{0,95 \cdot c_{max}}{1+0,6 \cdot x_{TWP}} = \frac{0,95 \cdot 1,1}{1+0,6 \cdot 0,11985} = 0,9749$ $\underline{Z}_{TWPK} = K_T \underline{Z}_{TWP}$	$Z_{TWP} = 1,523\,8$ $R_{TWP} = 0,076\,2$ $X_{TWP} = 1,521\,9$ $\underline{Z}_{TWP} = 0,076\,2 + j1,521\,9$ $\underline{Z}_{TWPK} = 0,074\,3 + j1,483\,7$
Wind Power Station Units WD $S_{rWD} = 2,5 MVA$ $U_{rWD} = U_{rTWDHV} = 20 kV$ $i_{WDmax} = 388 A$ $I_{kWDmax} = 1,2 \cdot I_{rWD}$ [a] $\kappa_{WD} = 1,7$; $R_{WD} = 0,1\, X_{WD}$	(28) $Z_{WD} = \frac{\sqrt{2} \cdot \kappa_{WD} \cdot U_{rTWDHV}}{\sqrt{3} \cdot i_{WDmax}} = \frac{\sqrt{2} \cdot 1,7 \cdot 20\ kV}{\sqrt{3} \cdot 0,388\ kA}$ (29) $\underline{Z}_{WD} = (R_{WD}/X_{WD} + j) \cdot \frac{Z_{WD}}{\sqrt{1+(R_{WD}/X_{WD})^2}}$	$Z_{WD} = 71,548\,7$ $\underline{Z}_{WD} = 7,119\,4 + j71,193\,6$
Wind Power Station Units WF $S_{rWF} = 2,5 MVA$ $U_{rWF} = 20 kV$ $I_{skWF} = I_{kWFmax} = 1,3 \cdot I_{rWF}$ [b]	$I_{rWF} = \frac{S_{rWF}}{\sqrt{3} \cdot U_{rWF}} = \frac{2,5\ MVA}{\sqrt{3} \cdot 20\ kV} = 72,17\ A$ $I_{skWF} = I_{kWFmax} = 1,3 \cdot I_{rWF} = 1,3 \cdot 72,17\ A = 93,82\ A$	$Z_{WF} = \infty$
Cable L1 NA2XS2Y 500 mm² $R' = 0,0681\ \Omega/km$ $X' = 0,102\ \Omega/km$	Two parallel cables: $\underline{Z}_{L1} = \frac{1}{2} \cdot (0,0681 + j\,0,102)\ \Omega/km \cdot 13,1\ km$	$\underline{Z}_{L1} = 0,446\,1 + j0,668\,1$
Cable L2 to L12 NA2XS2Y 150 mm² $R' = 0,211\ \Omega/km$ $X' = 0,122\ \Omega/km$	$\underline{Z}_{L2}$ = (0,211 + j0,122) Ω/km·1,1 km $\underline{Z}_{L3}$ = (0,211 + j0,122) Ω/km·0,55 km $\underline{Z}_{L4}$ = (0,211 + j0,122) Ω/km·0,79 km $\underline{Z}_{L5}$ = (0,211 + j0,122) Ω/km·0,17 km $\underline{Z}_{L6}$ = (0,211 + j0,122) Ω/km·0,4 km $\underline{Z}_{L7}$ = (0,211 + j0,122) Ω/km·0,55 km $\underline{Z}_{L8}$ = (0,211 + j0,122) Ω/km·0,95 km $\underline{Z}_{L9}$ = (0,211 + j0,122) Ω/km·0,24 km $\underline{Z}_{L10}$ = (0,211 + j0,122) Ω/km·0,29 km $\underline{Z}_{L11}$ = (0,211 + j0,122) Ω/km·0,495 km $\underline{Z}_{L12}$ = (0,211 + j0,122) Ω/km·0,15 km	$\underline{Z}_{L2}$ = 0,232 1 + j0,134 2 $\underline{Z}_{L3}$ = 0,116 1 + j0,067 1 $\underline{Z}_{L4}$ = 0,166 7 + j0,096 3 $\underline{Z}_{L5}$ = 0,035 9 + j0,020 7 $\underline{Z}_{L6}$ = 0,084 4 + j0,048 8 $\underline{Z}_{L7}$ = 0,116 1 + j0,067 1 $\underline{Z}_{L8}$ = 0,200 4 + j0,115 9 $\underline{Z}_{L9}$ = 0,050 6 + j0,029 3 $\underline{Z}_{L10}$ = 0,061 2 + j0,035 4 $\underline{Z}_{L11}$ = 0,104 4 + j0,060 4 $\underline{Z}_{L12}$ = 0,031 6 + j0,018 3

***Note all cables except ZL1 are neglected on purpose.**

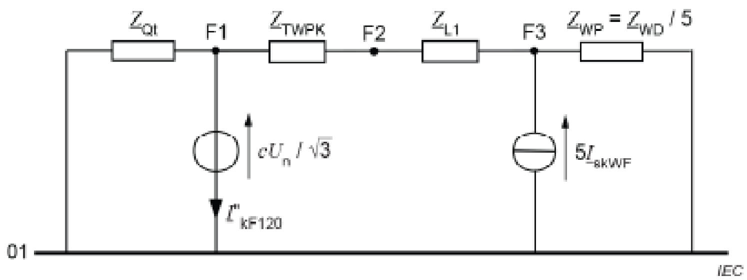


Figure 19 – Equivalent circuit diagram for the calculation of the short-circuit current at the location F1 without the consideration of the internal wind power plant cables (values are related to the 20 kV voltage level), variant 3

The absolute elements of the 3 by 3 nodal impedance matrix in the 20 kV voltage level are:

$$\boldsymbol{Z} = \begin{bmatrix} 0{,}217\,1 & 0{,}197\,6 & 0{,}188\,2 \\ 0{,}197\,6 & 1{,}531\,8 & 1{,}459\,0 \\ 0{,}188\,2 & 1{,}459\,0 & 2{,}080\,6 \end{bmatrix}\Omega$$

The partial short-circuit currents without the influence of the wind power station units WF becomes with $Z_{kF\boldsymbol{i}} = Z_{ii}$ (i = 1...3):

$$I''_{kF1WFO} = \frac{cU_n}{\sqrt{3}\cdot Z_{kF1}}\cdot\frac{U_{nQ}}{U_n}\cdot\frac{1}{t^2_{rTWP}} = \frac{1{,}1\cdot 20\,kV}{\sqrt{3}\cdot 0{,}217\,1\,\Omega}\cdot\frac{110\,kV}{20\,kV}\cdot\left(\frac{20\,kV}{110\,kV}\right)^2 = 10{,}637\,kA$$

$$I''_{kF2WFO} = \frac{cU_n}{\sqrt{3}\cdot Z_{kF2}} = \frac{1{,}1\cdot 20\,kV}{\sqrt{3}\cdot 1{,}531\,8\,\Omega} = 8{,}292\,kA$$

$$I''_{kF3WFO} = \frac{cU_n}{\sqrt{3}\cdot Z_{kF3}} = \frac{1{,}1\cdot 20\,kV}{\sqrt{3}\cdot 2{,}080\,6\,\Omega} = 6{,}105\,kA$$

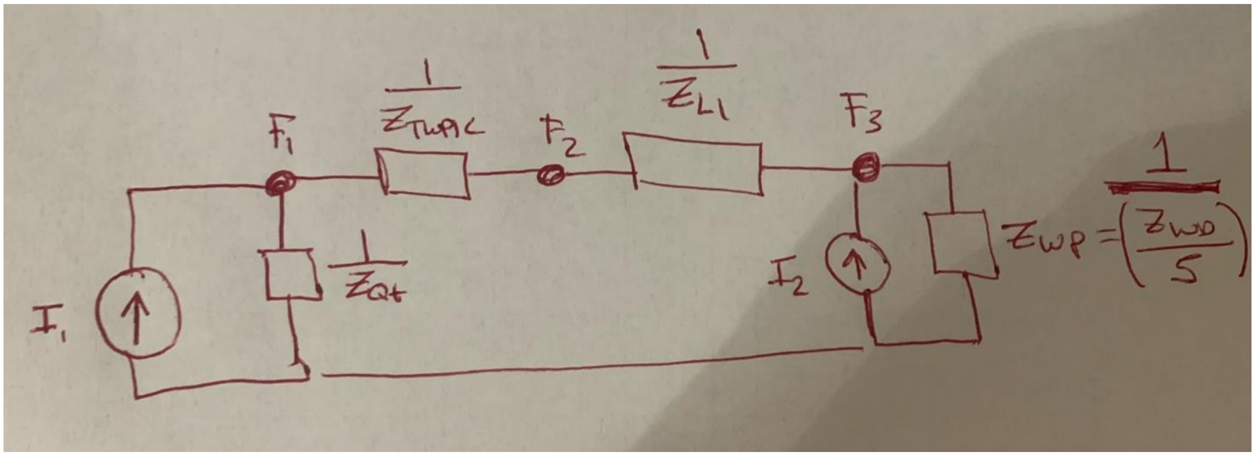
The partial short-circuit currents of the five wind power station units WF for short circuits at F1 to F3 are:

$$I''_{kF1WF} = \frac{Z_{13}}{Z_{11}}\cdot 5\cdot I_{skWF}\cdot\frac{1}{t_{rTWP}} = \left|\frac{\underline{Z}_{WP}}{\underline{Z}_{TWPK}+\underline{Z}_{L1}+\underline{Z}_{WP}}\right|\cdot 5\cdot I_{skWF}\cdot\frac{1}{t_{rTWP}} = 0{,}406\,7\,kA\cdot\frac{1}{5{,}5} = 0{,}073\,9\,kA$$

$$I''_{kF2WF} = \frac{Z_{23}}{Z_{22}}\cdot 5\cdot I_{skWF} = \left|\frac{\underline{Z}_{WP}}{\underline{Z}_{L1}+\underline{Z}_{WP}}\right|\cdot 5\cdot I_{skWF} = 0{,}446\,8\,kA$$

$$I''_{kF3WF} = \frac{Z_{33}}{Z_{33}}\cdot 5\cdot I_{skWF} = 0{,}469\,1\,kA$$

My Admittance Network:



My Y Matrix:

$Z_{QtIECOhm} = 0.022 + 0.219i$ $\quad XFMRZ\_IEC_{ohm} = 0.074 + 1.484i$ $\quad \dfrac{Z_{WD\_ohm}}{5} = 1.424 + 14.239i$

$Z_{L1\_L1B\_Cables\_Ohm} = 0.446 + 0.668i$

$$Y_{11} := -1\cdot\left(\frac{1}{Z_{QtIECOhm}} + \frac{1}{XFMRZ\_IEC_{ohm}}\right) \qquad Y_{12} := \left(\frac{1}{XFMRZ\_IEC_{ohm}}\right) \qquad Y_{13} := 0$$

$$Y_{21} := \left(\frac{1}{XFMRZ\_IEC_{ohm}}\right) \qquad Y_{22} := -1\cdot\left(\frac{1}{Z_{QtIECOhm}} + \frac{1}{Z_{L1\_L1B\_Cables\_Ohm}}\right) \qquad Y_{23} := \left(\frac{1}{Z_{L1\_L1B\_Cables\_Ohm}}\right)$$

$$Y_{31} := 0 \qquad Y_{32} := \left(\frac{1}{Z_{L1\_L1B\_Cables\_Ohm}}\right) \qquad Y_{33} := -1\cdot\left(\frac{1}{\frac{Z_{WD\_ohm}}{5}} + \frac{1}{Z_{L1\_L1B\_Cables\_Ohm}}\right)$$

$$Y := \begin{pmatrix} |Y_{11}| & |Y_{12}| & |Y_{13}| \\ |Y_{21}| & |Y_{22}| & |Y_{23}| \\ |Y_{31}| & |Y_{32}| & |Y_{33}| \end{pmatrix}$$

$$Zmat := Y^{-1} = \begin{pmatrix} 0.1954 & -0.0293 & 0.0279 \\ -0.0293 & 0.2271 & -0.2163 \\ 0.0279 & -0.2163 & 0.9712 \end{pmatrix}$$