RESEARCH REPORT

Power System Model for Resonance Studies

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Summary

This report details an example grid suitable for the following studies:

- Transients following energizing of transformers, capacitor banks, and cables.
- Spread of harmonics, i.e. calculation of transfer impedances. Note that emission is not included in the example grid.

The author has tried as much as possible to make the example grid realistic, and parts of the model are based on existing and/or planned transmission grids.

The example grid is characterized by its large share of cables at 400 and 220 kV, with a first resonance frequency between 100 and 150 Hz.

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1 Introduction

This report details an example grid suitable for the following studies:

- Transients following energizing of transformers, capacitor banks, cables and such
- Spread of harmonics (i.e. calculation of transfer impedances, note that emission is not included in the base model)

The author has tried as much as possible to make the example grid realistic, and parts of the model are based on existing and/or planned transmission grids.

2 Overview of the example grid

The example grid is partially based on an existing grid. The line types, tower configurations, cables etc. are also based on what is typical in the existing power system.

The example grid is characterized by its large share of cables at 400 and 220 kV, with a first resonance frequency between 100 and 150 Hz.

2.1 Topology

Figure 1 shows a single-line diagram of the example grid, including voltage levels 400 kV, 220 kV and 130 kV. The system is fed by large generation units (hydro and nuclear) located to the west and to the south, connected through long overhead lines. In the model they are modelled as network equivalents at buses G1 through G5. There is also a combined heat and power plant connected to bus G6. A more detailed diagram is shown in Appendix A, including the designated names of the lines and cables.

The 400 kV system is comprised of a mix of overhead lines and cables, with a total cable length exceeding 150 km. The central 220 kV system is comprised of cables with a total length of around 100 km.

Table 1 lists the overhead line (OHL) and cable (CA) branches in the 400 kV, 220 kV and 130 kV systems. Parameters used for modelling of the branches are presented in the subsequent sections.

Details about the downstream grid models (40 kV and below) are given in Chapter 10.

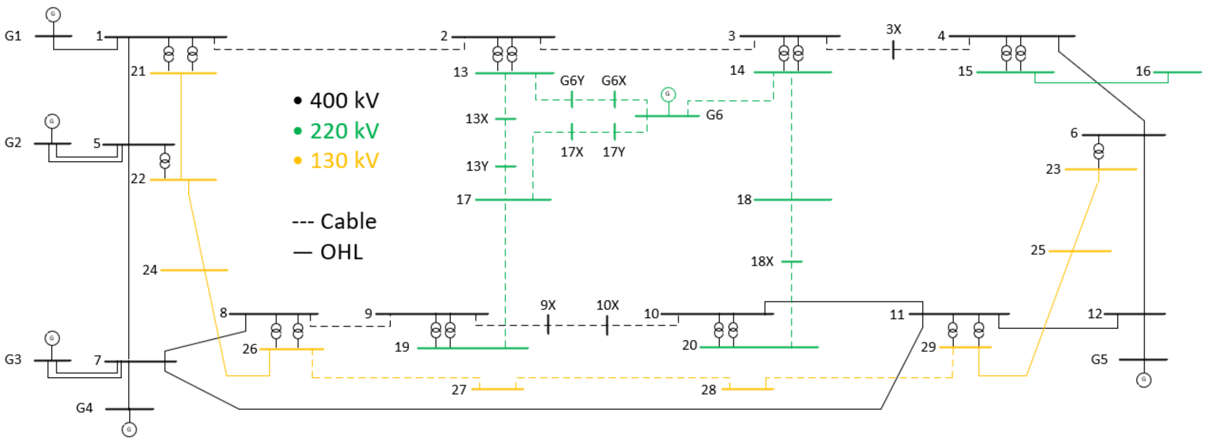

Figure 1 - Single-line diagram of the example grid for 400, 220 and 130 kV

Table 1 - List of overhead line (OHL) and cable (CA) branches at voltage levels 400, 220 and 130 kV

ID	Voltage (kV)	From bus	To bus	Length (km)
OHL G1	400	G1	1	52.8
OHL G2	400	G2	5	85.3
OHL G3	400	G3	7	78.5
OHL G4	400	G4	7	99.3
OHL G5	400	G5	12	76.5
OHL 1	400	1	5	25.3
OHL 2	400	5	7	41.6
OHL 3	400	7	8	47.7
OHL 4	400	7	11	67.2
OHL 5	400	10	11	11
OHL 6	400	11	12	8.5
OHL 7	400	6	12	27.1
OHL 8	400	4	6	9.7
OHL 9	220	15	16	23
OHL 10	130	21	22	28
OHL 11	130	22	24	25
OHL 12	130	24	26	25
OHL 13	130	23	25	20
OHL 14	130	25	29	18
CA 1	400	1	2	6.4
CA 2	400	2	3	13.5
CA 3A	400	3	3X	3.6
CA 3B	400	3X	4	5
CA 4	400	8	9	16.4
CA 5A	400	9	9X	4.4
CA 5B	400	9X	10X	5.6
CA 5C	400	10X	10	2.3
CA 6A	220	13	13X	2.1
CA 6B	220	13X	13Y	1.2
CA 6C	220	13Y	17	4.2

CA 7A	220	13	G6Y	5.3
CA 7B	220	G6Y	G6X	1.2
CA 7C	220	G6X	G6	3.7
CA 8	220	G6	14	11
CA 9A	220	17	17X	3.7
CA 9B	220	17X	17Y	3.2
CA 9C	220	17Y	G6	1.2
CA 10	220	14	18	4.4
CA 11	220	17	19	7
CA 12A	220	20	18X	3.6
CA 12B	220	18X	18	1.7
CA 13	130	26	27	25
CA 14	130	27	28	20
CA 15	130	28	29	15

3 Overhead lines

Table 2 presents a list of the overhead lines, including voltage level, length, phase conductor configuration, shield wire configuration and tower type.

Table 2 - Overhead lines

ID	Voltage [kV]	Length [km]	Conductor*	Shield wires	Tower type	Transposed
OHL G1	400	52.8	B	2xB	A	Y
OHL G2	400	85.3	A A	2xA	C	Y
OHL G3	400	78.5	A B	2xA	C	Y
OHL G4	400	99.3	A	2xA	A	Y
OHL G5	400	76.5	B	2xA	A	Y
OHL 1	400	25.3	B	2xA	A	N
OHL 2	400	41.6	A	2xA	A	N
OHL 3	400	47.7	A	2xA	A	Y
OHL 4	400	67.2	A	2xA	A	Y
OHL 5	400	11	C	2xA	A	N
OHL 6	400	8.5	A	2xA	A	N
OHL 7	400	27.1	B	2xA	A	N
OHL 8	400	9.7	A	2xA	A	N
OHL 9	220	23	D	2xA	B	N
OHL 10	130	28	D	-	D	N
OHL 11	130	25	D	-	D	N
OHL 12	130	25	D	-	D	N
OHL 13	130	20	D	-	D	N
OHL 14	130	18	D	-	D	N

**If two conductors are named, it means that there are two parallel lines in the corridor.*

3.1 Parameters

This section lists the primary parameters used in the modelling of overhead line conductors and earth/shield wires.

Table 3 - Conductors

Type	d [mm]	Strands (outer/core)	Strand d [mm]	DC-resistance [Ω]	Sub-conductors	Sub-conductor spacing [cm]
A	39.24	61	4.36	0.0337	2	60
B	36.18	61	4.02	0.0396	3	45
C	31.68	61	3.52	0.0517	2	45
D	31.68	54/7	3.52/3.52	0.0551	1	N/A

Table 4 - Shield wires

Type	Diameter [mm]	Strands [Al/Fe]	Strand diameter [mm]	DC-resistance [Ohm]
A	20.10	12/7	4.02/4.02	0.1890
B	23.2	32/7	3.16/3.52	0.1150

3.2 Tower models

This section presents the tower types used in the model, including all primary dimensions.

For tower types A and B, presented in Figure 2 and Figure 4 below, a maximum sag of 12 m for conductors and 10 m for shield wires have been used. For tower type C, presented in Figure 5 below, a sag of 10 m was used for the conductors.

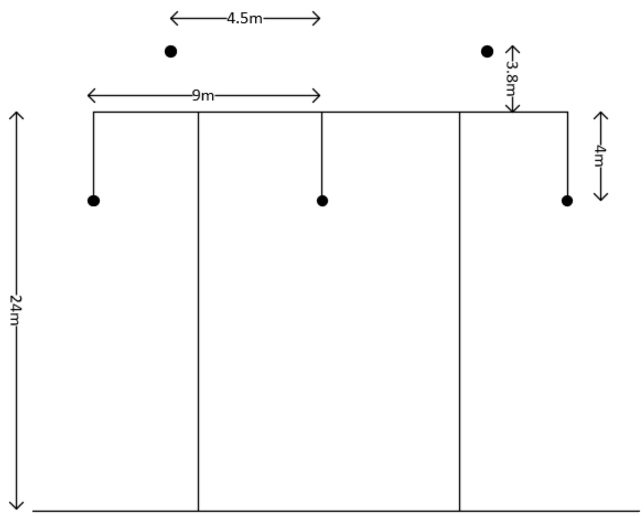

Figure 2 - Tower type A, 400 kV

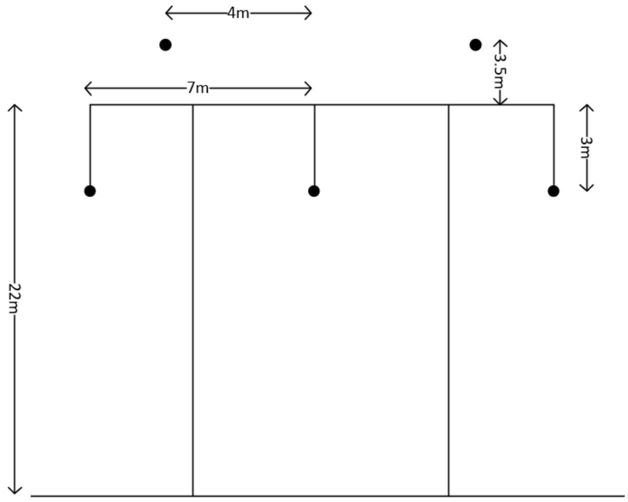

Figure 3 – Tower type B, 220 kV

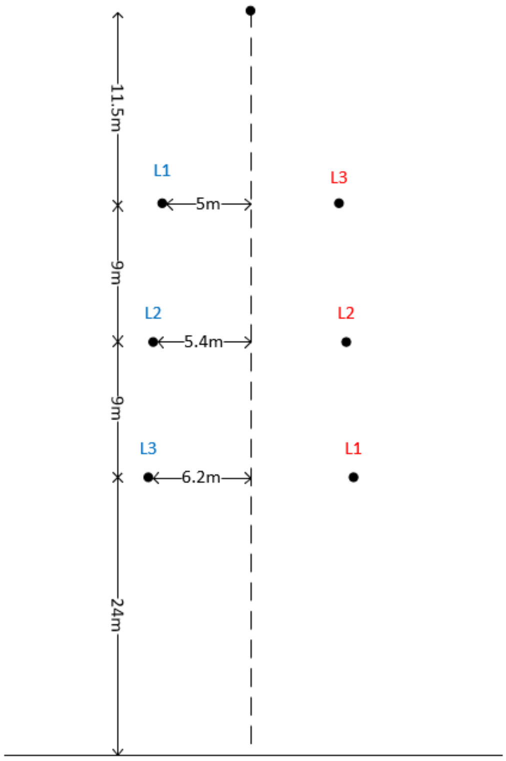

Figure 4 - Tower type C, 400 kV, including phase order for the two lines, coloured blue and red, respectively.

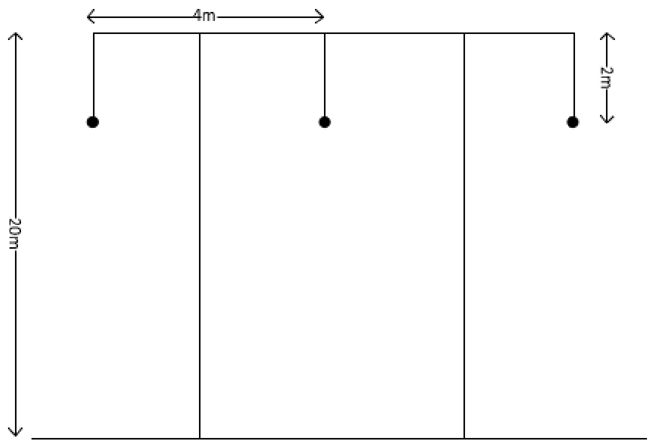

Figure 5 - Tower type D, 130 kV

3.3 Transposition of overhead lines

Figure 6 shows the transposition scheme used in the model. It is divided into 3 sections of equal length.

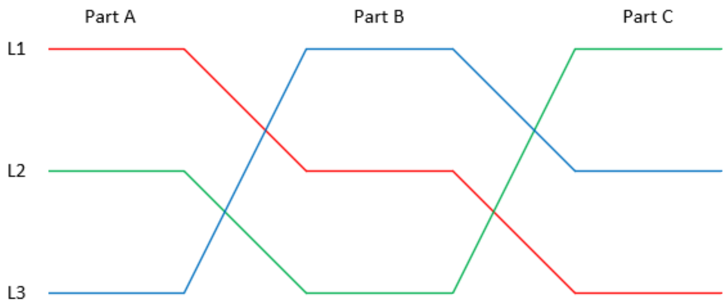

Figure 6 - Transposition scheme - 3 sections of equal length

4 Cables

Table 5 presents a list of cables, including voltage level, length and configuration. Details on cable parameters, laying and cross-bonding will be presented in the following sections.

Table 5 - Cables included in the model

ID	Voltage [kV]	Length [km]	Parallel cables	Cable type	Laying	Cross-bonding
CA 1	400	6.4	3	2500 mm^2 Cu	A	CB
CA 2	400	13.5	3	1600 mm^2 Al	D	BB
CA 3A	400	3.6	3	1600 mm^2 Al	D	BB
CA 3B	400	5	3	2500 mm^2 Cu	A	CB
CA 4	400	16.4	3	2500 mm^2 Cu	A	CB
CA 5A	400	4.4	3	2500 mm^2 Cu	A	CB
CA 5B	400	5.6	3	U-1200 mm^2 Al	F	BB
CA 5C	400	2.3	3	2500 mm^2 Cu	A	CB
CA 6A	220	2.1	3	2000 mm^2 Al	A	BB
CA 6B	220	1.2	3	U-2000 mm^2 Al	G	BB
CA 6C	220	4.2	3	1200 mm^2 Al	D	BB
CA 7A	220	5.3	3	2000 mm^2 Al	A	BB
CA 7B	220	1.2	3	U-2000 mm^2 Al	G	BB
CA 7C	220	3.7	3	1200 mm^2 Al	D	BB
CA 8	220	11	2	1200 mm^2 Al	E	BB
CA 9A	220	3.7	2	1200 mm^2 Al	E	BB
CA 9B	220	3.2	2	2000 mm^2 Al	B	CB
CA 9C	220	1.2	2	1200 mm^2 Al	E	BB
CA 10	220	4.4	2	1200 mm^2 Al	E	BB
CA 11	220	7	2	2000 mm^2 Al	B	BB
CA 12A	220	3.6	2	2000 mm^2 Al	B	BB
CA 12B	220	1.7	2	1200 mm^2 Al	E	BB
CA 13	130	25	1	1200 mm^2 Al	C	BB
CA 14	130	20	1	1200 mm^2 Al	C	BB
CA 15	130	15	1	1200 mm^2 Al	C	BB

4.1 Cable parameters

Table 6, Table 7 and Table 8 present cable parameters for the 400 kV, 220 kV and 130 kV cables.

Table 6 – 400 kV cable parameters

	2500 mm² Cu	1200 mm² Al	U-1200 mm² Cu
Cable useage	Ground	Tunnel	Sea
Core diameter [mm]	63	41.2	46
Semiconductive layer thickness [mm]	1.7	2.0	1.5
Insulation thickness [mm]	26	31	27
Semiconductive layer thickness [mm]*	2.7	2.0	1.5
Screen thickness [mm]	2.05	2.0	3.7
Armor bedding thickness [mm]	-	-	2.6
Armor thickness [mm]	-	-	5.0
Oversheath thickness [mm]*	7.0	6.6	4.0
DC-resistance of conductor at 20°C [Ω/km]	0.0072	0.0247	0.0151
DC-resistance of screen at 20°C [Ω/km]	0.0932	0.130	0.1680
DC-resistance of armor at 20°C [Ω/km]	-	-	0.0180
Relative permittivity of insulation	2.5	2.5	2.5
Relative permittivity of bedding	-	-	1.0
Relative permittivity of oversheath	2.4	2.4	1.0

**Including water blocking tape*

Table 7 - 220 kV cable parameters

	2000 mm² Al	1200 mm² Al	U-2000 mm² Al
Cable useage	Ground	Tunnel	Sea
Core diameter [mm]	55.2	42.7	56
Semiconductive layer thickness [mm]	0.8	1.8	2.0
Insulation thickness [mm]	23.3	25	23
Semiconductive layer thickness [mm]*	1.2	1.8	2.0
Screen thickness [mm]	2.0	2.0	3.3
Armor bedding thickness [mm]	-	-	4.8
Armor thickness [mm]	-	-	4.0
Oversheath thickness [mm]*	5.1	6.2	4.0

DC-resistance of conductor at 20°C [Ω/km]	0.015	0.025	0.020
DC-resistance of screen at 20°C [Ω/km]	0.125	0.280	0.175
DC-resistance of armor at 20°C [Ω/km]	-	-	0.016
Relative permittivity of insulation	2.5	2.5	2.5
Relative permittivity of bedding	-	-	2.7
Relative permittivity of oversheath	2.4	2.4	3

**Including water blocking tape*

Table 8 - 130 kV cable parameters

	1200 mm^2 Al
Cable useage	Ground
Core diameter [mm]	40.8
Semiconductive layer thickness [mm]	1.2
Insulation thickness [mm]	16.7
Semiconductive layer thickness [mm]*	1.2
Screen thickness [mm]	2.0
Armor bedding thickness [mm]	-
Armor thickness [mm]	-
Oversheath thickness [mm]*	4.1
DC-resistance of conductor at 20°C [Ω/km]	0.0247
DC-resistance of screen at 20°C [Ω/km]	0.20
DC-resistance of armor at 20°C [Ω/km]	-
Relative permittivity of insulation	2.5
Relative permittivity of bedding	-
Relative permittivity of oversheath	2.4

**Including water blocking tape*

Table 9 presents the data used for the earth wires.

Table 9 - Earth wire data

	50 mm^2 Cu
Conductor diameter [mm]	8
Resistivity [Ωm]	1.68e-8

4.2 Cable laying

This section presents the different cable configurations, including all primary dimensions.

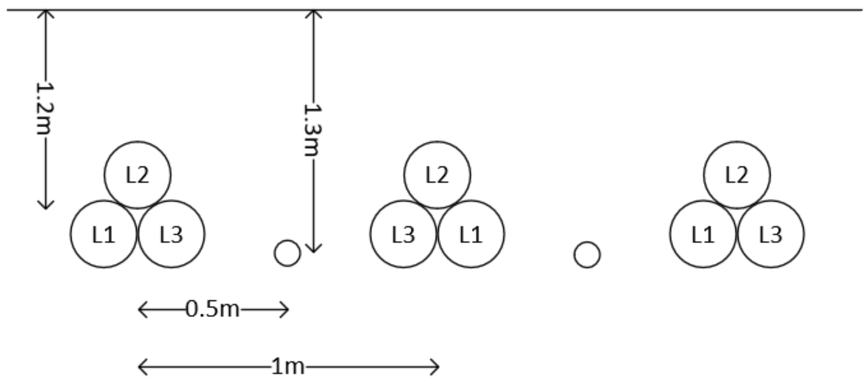

Figure 7 – Configuration A: Land cable, trefoil configuration with three cable groups and two earth wires

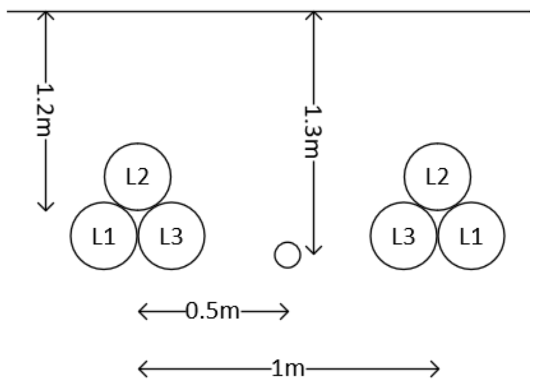

Figure 8 - Configuration B: Land cable, trefoil configuration with two cable groups cables and one earth wire

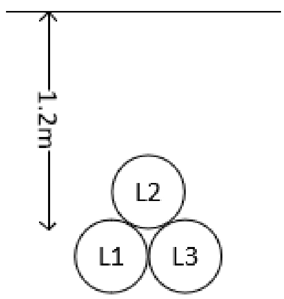

Figure 9 - Configuration C: Land cable, trefoil configuration with one cable group

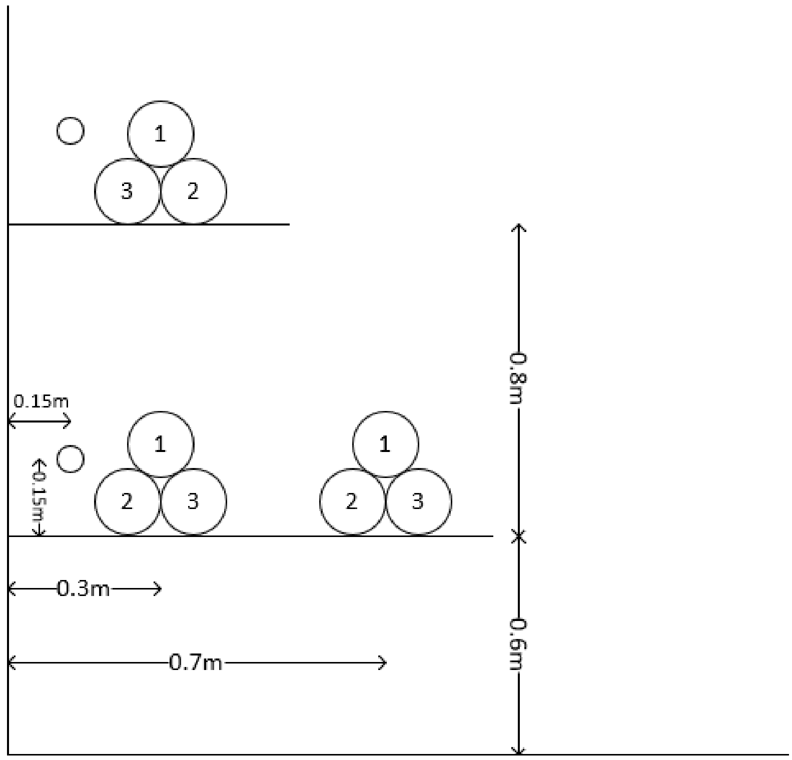

Figure 10 – Configuration D: Tunnel cable, trefoil configuration with three cable groups and two earth wires

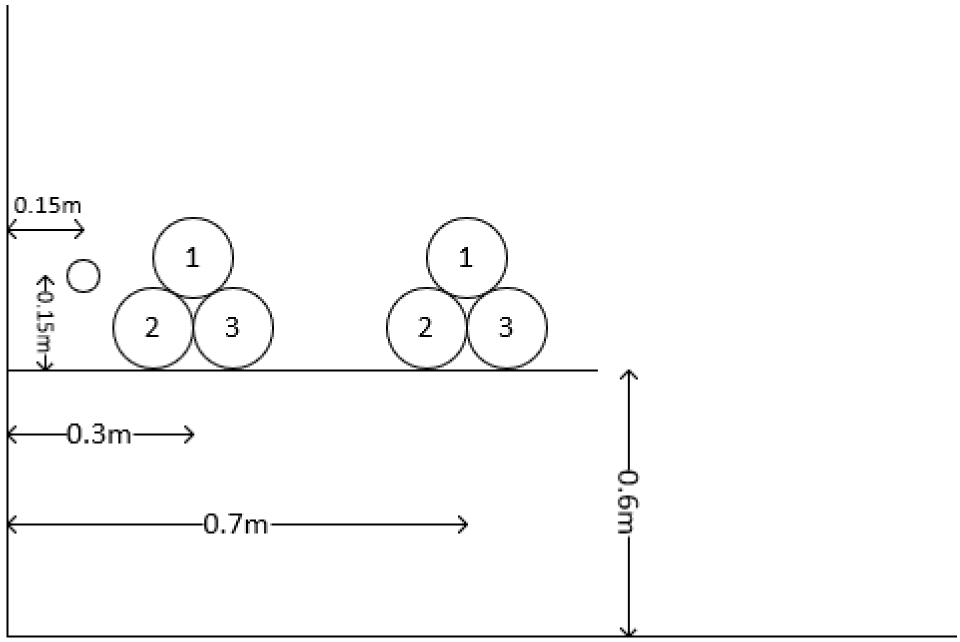

Figure 11 – Configuration E: Tunnel cable, trefoil configuration with two cable groups and one earth wire

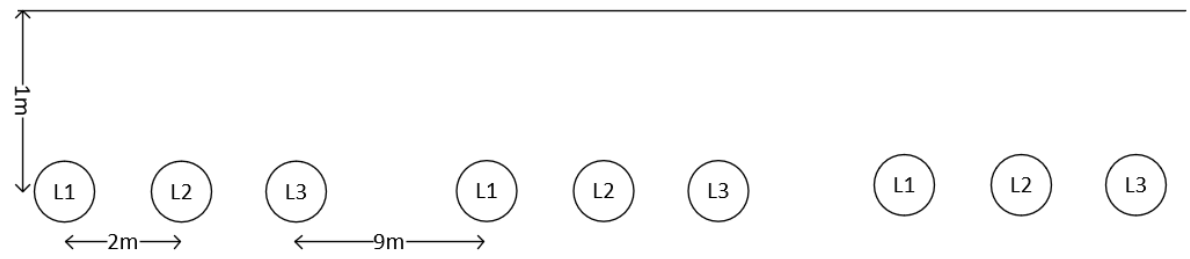

Figure 12 - Configuration F: Submarine cable, flat configuration

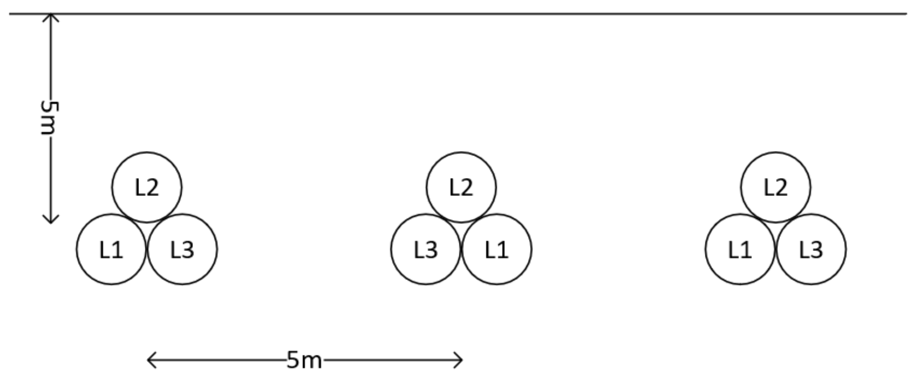

Figure 13 - Configuration G: Submarine cable, trefoil configuration

4.3 Cable screen bonding

Two cable screen bonding schemes are used in the example grid: Both-ends-bonded (BB) and Cross-bonding of the cable screens (CB).

For both-ends-bonded cables the cable screens are grounded at the station (cable ends) using a resistance of 0.1 Ω.

Figure 14 details the principle behind cross-bonding, where the cable screens are cross-bonded between the minor sections and connected to the earth wire and grounded after each major section. Table 10 presents details on the cross-bonding for each relevant cable section, including the average earthing resistance to be used for the grounding of the sheaths. In the station ends of the cables, a resistance of 0.1 Ω is used.

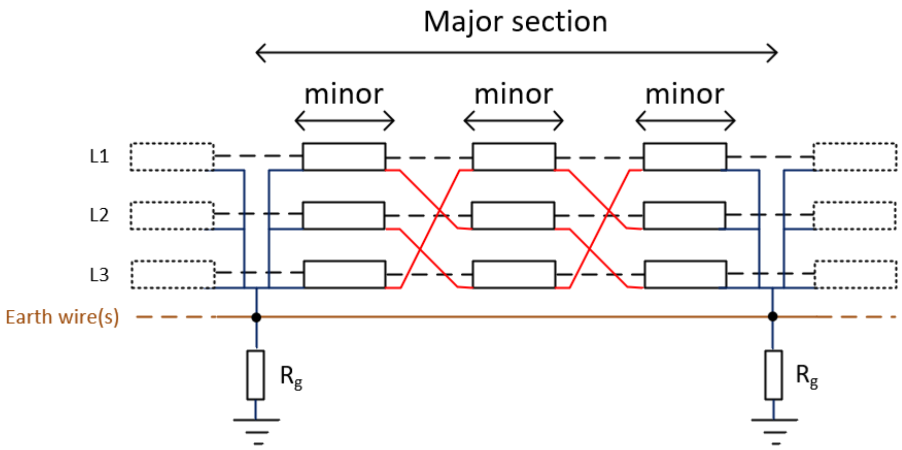

Figure 14 - Cross-bonding of cable screens, divided into minor and major sections

Table 10 – Cross-bonding details

ID	Major/minor sections	Minor section avg. length	Avg. earthing resistance [Ω]
CA 1	3/9	710 m	10
CA 3B	2/6	833 m	10
CA 4	5/15	1000 m	10
CA 5A	2/6	667 m	10
CA 5C	1/3	833 m	10
CA 9B	1/3	1067 m	10

5 Transmission transformers

Table 11 - List of transmission transformers

Bus	No. of transformers	Type	Grounding (Primary/Secondary)
1	2	B	Solid/Solid
2	2	A	T1: Solid/Isolated, T2: Solid/Solid
3	2	A	T1: Solid/Isolated, T2: Solid/Solid
4	2	A	Solid/Solid
5	1	B	Solid/Solid
6	1	B	Solid/Solid
8	2	B	Solid/Solid
9	2	A	T1: Solid/Isolated, T2: Solid/Solid
10	2	A	T1: Solid/Isolated, T2: Solid/Solid
11	2	B	Solid/Solid

Table 12 - Main data for the transmission transformer types

	A	B
Rating [MVA]	500	350
U1/U2 [kV]	410/225	410/145
u_k [%]	16	15
P_0 [kW]	150	100
P_k [kW]	1000	500
Type	2-winding, 5-limb	2-winding, 5-limb
Vector group	YNyn	YNyn

5.1 Core saturation characteristics

Table 13 shows the data used in this model.

Table 13 - Core saturation characteristics for different transformer types

	A	B
Voltage at knee point [p.u.]	1.14	1.14
Magnetizing current [%]	0.04	0.04
Air core reactance [p.u.]	0.3	0.3

6 Shunt elements

6.1 Capacitor banks

Due to the large share of cables, there are no capacitor banks at 400-130 kV. Capacitor banks at lower voltage levels are included in the downstream network models, as described in section 10.

6.2 Shunt reactors

Due to the large share of cables in the system, shunt reactors are used for compensation of the reactive power generated by the cables.

The reactors are of air-gap type; therefore, saturation is not considered since it is highly unlikely to be of any relevance for the studies detailed in section 1. It is also assumed that all reactors are five-legged; therefore, mutual coupling is not considered.

Table 14 shows a list of the reactors in the system, including their placement and rating.

Table 14 - Reactors included in the model

ID	Connection point	Voltage [kV]	Rating [MVAr]
X1	Bus 8	400	200
X2	Bus 8, connected to CA 4	400	3x100 (one per cable group)
X3	Bus 9	400	150
X4	Bus 9	400	150
X5	Bus 10, connected to CA 5	400	190
X6	Bus 1	400	150
X7	Bus 1	400	150
X8	Bus 2, connected to CA 2	400	150
X9	Bus 3	400	150
X10	Bus 3	400	150
X11	Bus 4	400	140
X12	Bus 6	400	150
X13	Bus 19	220	150
X14	Bus 20	220	150

7 HVDC link

An HVDC link is located at bus G3. The layout of the converter, including filters, is shown in Figure 15 and Figure 16, and the data for the filters is listed in Table 15. The HVDC converter transformers are modelled as reactors with 0.2 p.u. reactance. The data is based on a typical configuration for a 1000 MW HVDC Classic [1]. The converter impedance (at different operating points) has not been included in the model.

A voltage level of 400 kV was used for the calculation of filter values.

Table 15 – HVDC filter data

	11th order, Q = 56 MVAr	13th order, Q = 40 MVAr	24th HP, Q = 64 MVAr	Q = 64 MVAr
Resistance R [Ω]	N/A	N/A	N/A	N/A
Inductance L [H]	0.075	0.075	0.014	N/A
Capacitance C [uF]	1.1E-6	0.79E-6	1.27E-6	1.27E-6

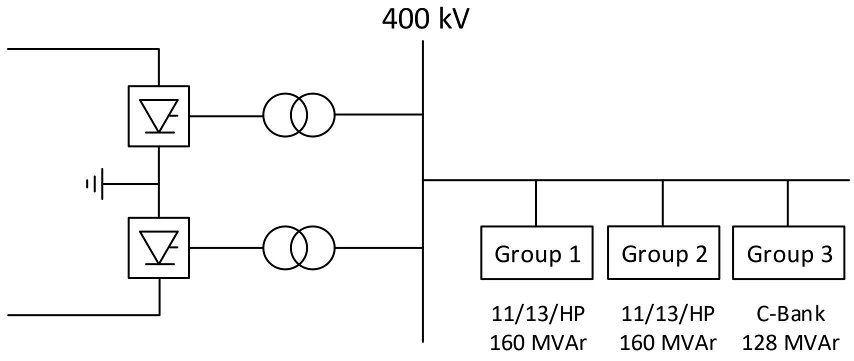

Figure 15 – HVDC layout, adopted from [1]

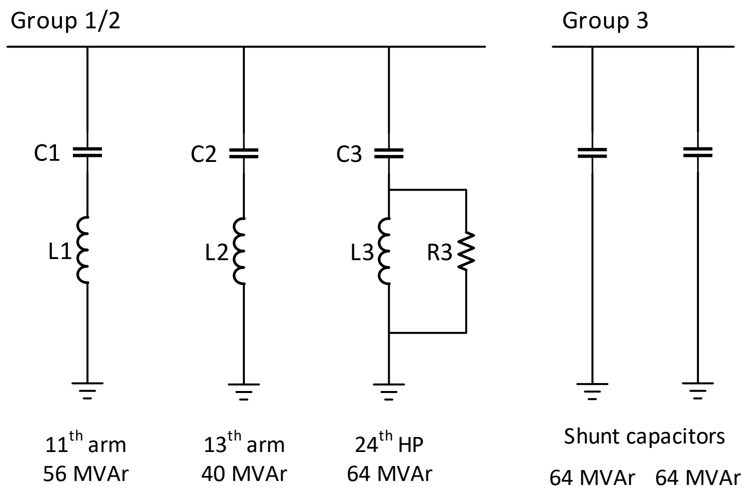

Figure 16 - Filter groups, adopted from [1]

8 Network equivalents

The external network is modelled as equivalents at buses G1-G6. The external network is mainly inductive, characterised by long overhead lines connected to remote generation. A local power plant is located at bus G6.

Table 16 - Equivalents

Equivalent	R_+ [Ω]	X_+ [Ω]	R_0 [Ω]	X_0 [Ω]
G1	1.5	42	3.7	32
G2	0.8	34	0.01	11
G3	2.5	13.9	3.1	19
G4	2	42	12	60
G5	2	42	12	60
G6	2.4	94	2.8	13

9 Earth resistivity

Table 17 describes the earth resistivity of different components in the example grid.

Table 17 - Earth resistivity for different components

Component	Earth resistivity [Ωm]
Overhead line	1500
Land cable	1500
Tunnel cable (tunnel walls)	10000
Submarine cable (fresh water)	100

10 Downstream grid models

This chapter presents the equivalent downstream network models used in the example grid. They have been developed based on [2] and [3], which describe reference distribution grids corresponding to an urban and a rural area respectively. The downstream network models are added to the example network in a modular fashion depending on the load level at the corresponding buses.

10.1 Equivalent urban network model

10.1.1 Overview

Figure 17 shows the layout of the grid model representing urban areas. It is fed by two power transformers. The maximum load of one feeder is around 5.6 MW, and the number of feeders and the transformer rating is adjusted depending on the total load at each node according to Table 18.

At each 20 or 10 kV busbar a capacitor bank is connected, if needed, to obtain a power factor of around 0.9.

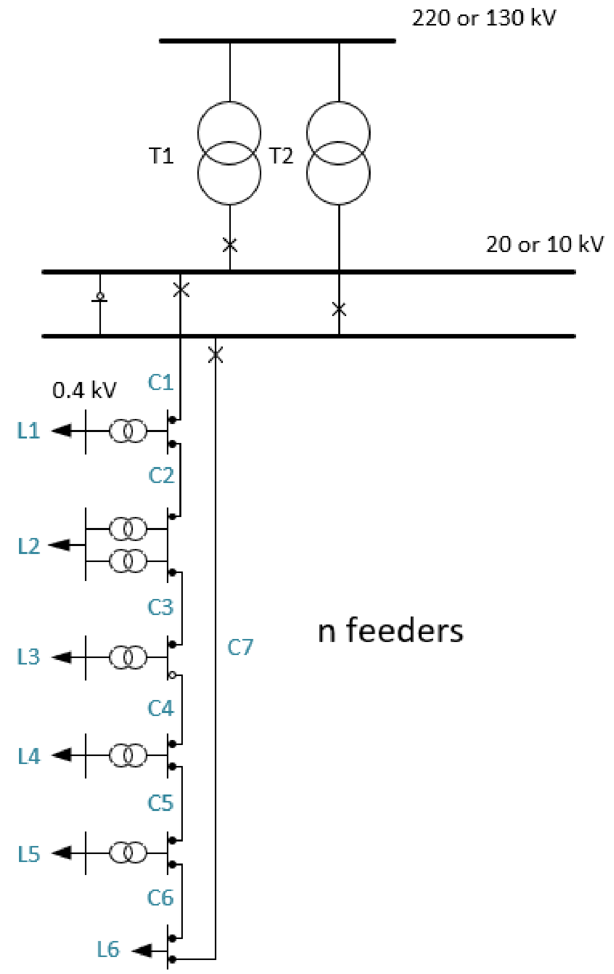

Figure 17 - Representative urban grid, adopted from [2] and [3].

Table 18 - Location and size – urban networks

Bus	Max load [MW]	Transformer rating [MVA]	Number of feeders
13	150	2x100	25
14	250	2x175	45
15	150	2x100	25
16	150	2x100	25
G6	300	2x210	55
17	175	2x120	30
18	100	2x70	20
19	250	2x175	45
20	100	2x70	20
21	150	2x100	25

22	70	2x50	15
23	250	2x175	45
24	150	2x100	25
25	100	2x70	20
26	350	2x245	60
27	100	2x70	20
28	100	2x70	20
29	300	2x210	55

10.1.2 Transformers

The rated voltage of the transformers depends on the location of the downstream network model, where it can be connected to either a 220 or 130 kV bus. If it is connected to a 220 kV bus, the transformer rated voltages are 230/22 and 22/0.4, and if it is connected to a 130 kV bus the rated voltages are instead 135/11 and 11/0.4.

Table 19 - Transformer data, urban networks

	Subtransmission transformers	Distribution transformers
Rating [MVA]	See Table 18	1
U1/U2 [kV]	230/22 or 135/11	22/0.4 or 11/0.4
u_k [%]	8	5.5
Copper losses [kW]	200	10
No-load losses [kW]	20	1
Magnetizing current [%]	0.1	0.2
Type	2-winding, 5-limb	2-winding, 5-limb
Vector group	YNyn	Dyn11
Grounding (primary/secondary)	Solid/Resonant	-/Solid
Tap changer	±9x1.67%	-

10.1.3 Cables

Table 20 - Cable parameters, urban networks

ID	Type	Length [km]	R [Ω/km]	L [mH/km]	C [μF/km]
C1, C7	240 Al	1.38	0.13	0.32	0.47
C2, C6	150 Al	1.38	0.21	0.34	0.39
C3-C5	95 Al	1.38	0.32	0.37	0.33

10.1.4 Loads

Table 21 - Loads, max and average, urban networks

ID	P_{max} [kW]	Q_{max} [kVAr]	P_{avg} [kW]	Q_{avg} [kVAr]
L1, L3-L5	877	497	313	177
L2	1045	592	379	215
L6	1093	619	398	225

10.2 Equivalent rural network models

10.2.1 Overview

Each equivalent rural network model is comprised of a simplified 40 kV regional network, comprising three 40/10 kV substations. The 40/10 kV substations are identical and made up of a combination of different 10 kV modules (B1-B3, described in more detail below). An example of an equivalent rural network model is given in Figure 18, with two modules of type B1 and one module of type B2 at each 10 kV busbar.

The rating of the transformers and the number and combination of 10 kV-modules is adjusted depending on the total load at each 130 kV node. At each 10 kV busbar a capacitor bank is connected, if needed, to obtain a power factor of around 0.9.

Table 22 details the position and total load of each equivalent rural network, the corresponding transformer ratings (given for T40 A, T40 B, T1 and T2), and the number of modules of each type connected to each 10 kV bus. Table 23 and Table 24 list the parameters of the 40 kV overhead lines and Figure 19 shows the 40 kV tower.

T40 A and T40 B are Wye-Wye with solid earthing on the primary and resonant earthing on the secondary. T1 and T2 are Wye-Wye with resonant earthing on both the primary and secondary. All 400 V transformers are Delta – Wye with solid earthing on the secondary.

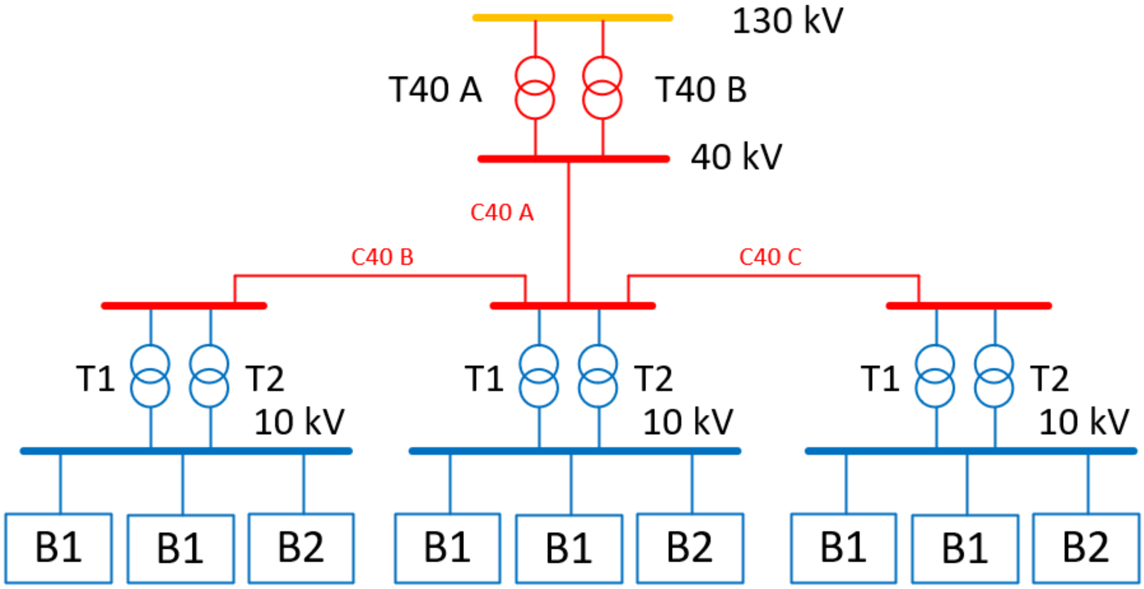

Figure 18 - Example of equivalent rural network

Table 22 – Location and size, equivalent rural networks

130 kV bus	Max. load [MW]	Transformer rating T40 A/B [MVA]	Transformer rating T1, T2 [MVA]*	B1*	B2 *	B3*
23	20	2x20	2x6	1	1	1
24	18	2x20	2x6	1	0	2
25	20	2x20	2x6	0	0	4

**Per 10 kV busbar*

Table 23 - 40 kV overhead lines

ID	Type	Length [km]
C40 A-C40 C	OHL	10

Table 24 - 40 kV overhead line parameters

Type	d [mm]	Strands (outer/core)	Strand d [mm]	DC-resistance [Ω]	Sub-conductors
40 kV OHL	19.88	24/7	3.14	0.1430	1

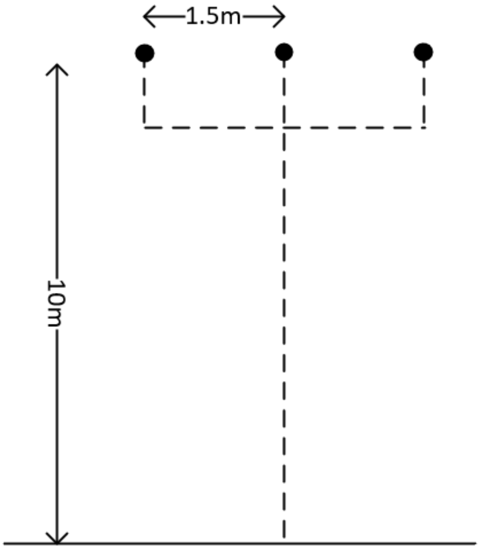

Figure 19 – 40 kV tower

10.2.1.1 Module B1

Module B1 consists of a combination of overhead lines and cables.

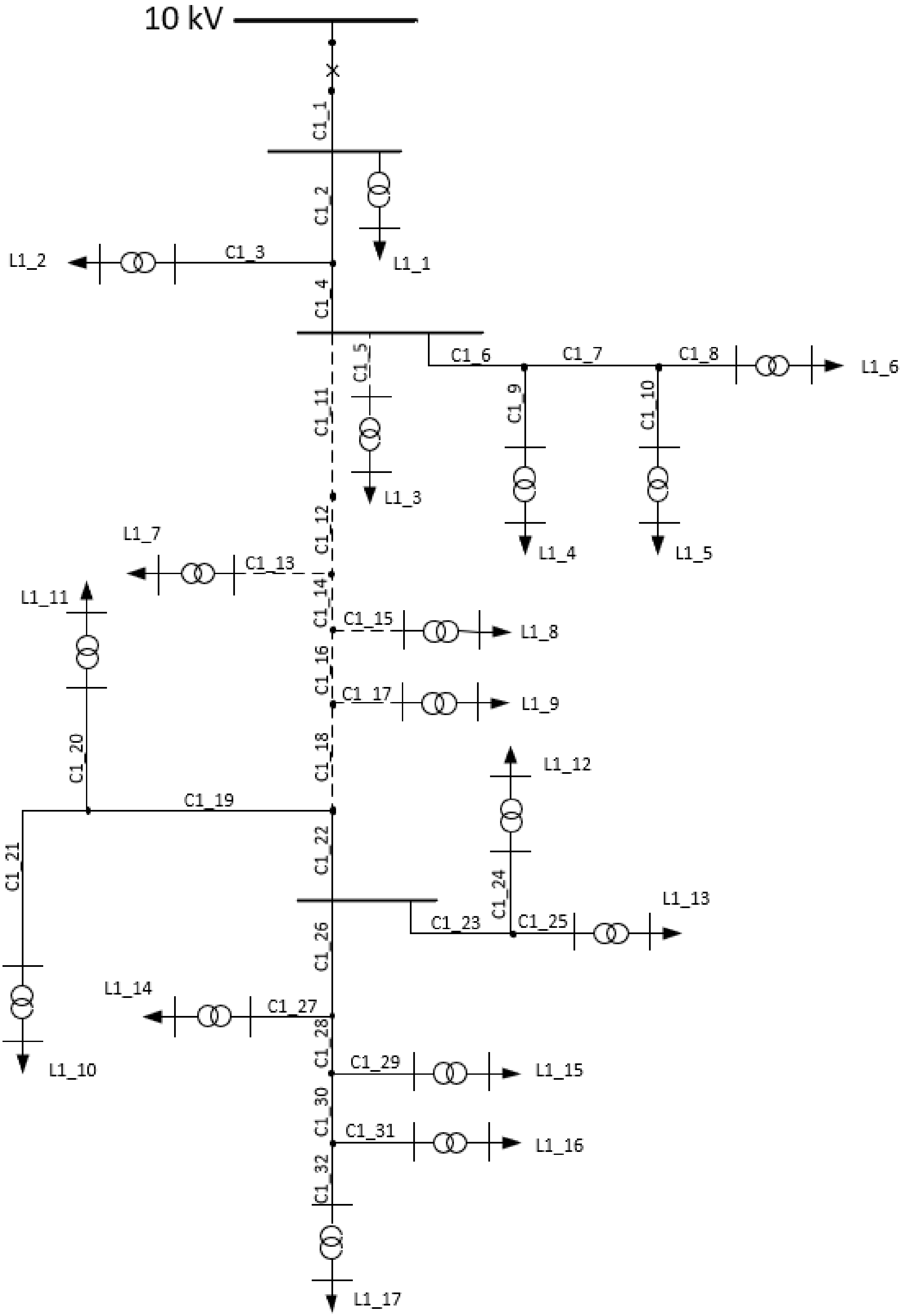

Figure 20 – Representative rural grid, module B1, adapted from [2] and [3]

10.2.1.2 Module B2

Module B2 consists of overhead lines only.

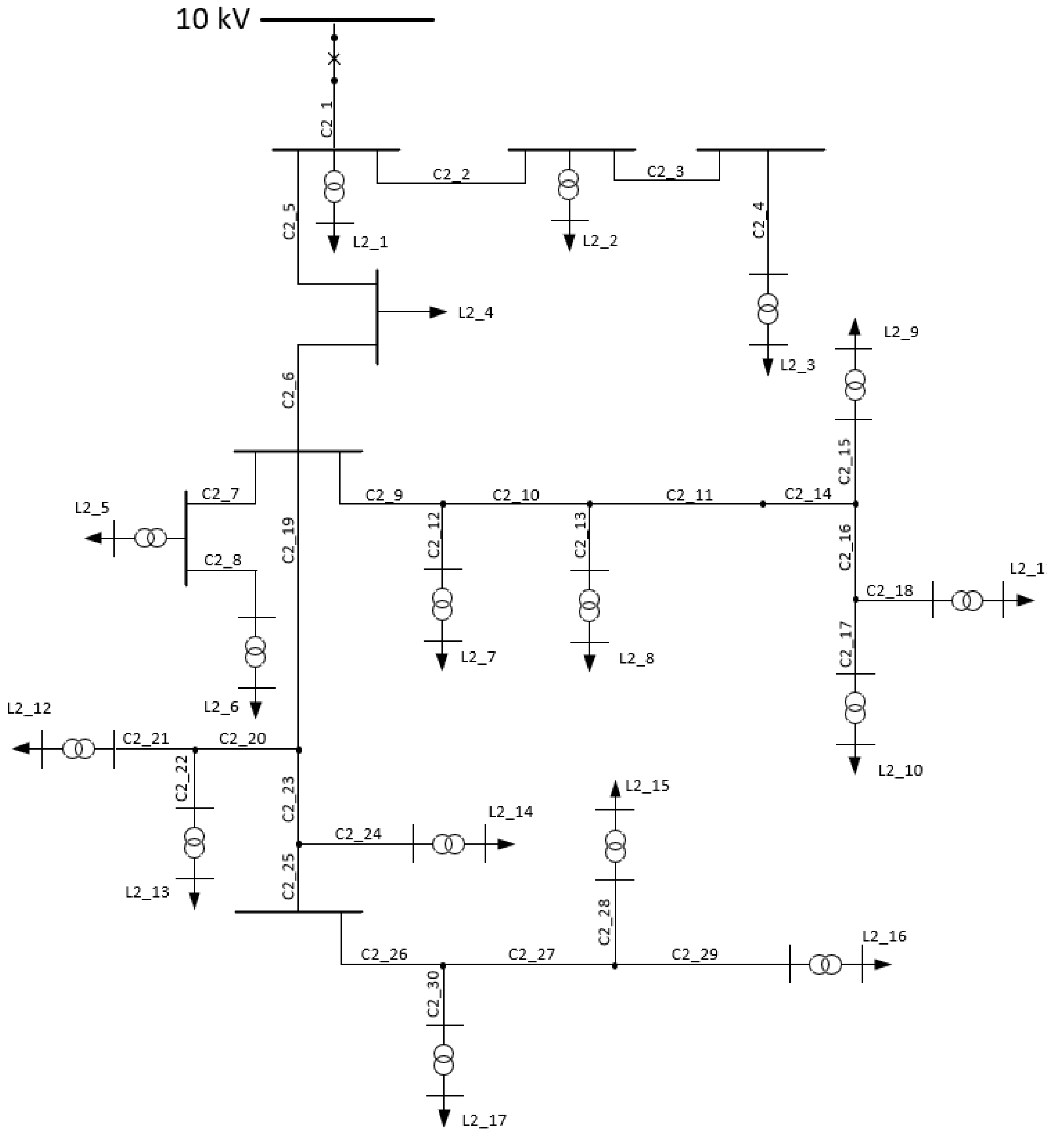

Figure 21 - Representative rural grid, module B2, adapted from [2] and [3]

10.2.1.3 Module B3

Module B3 consists of cables only.

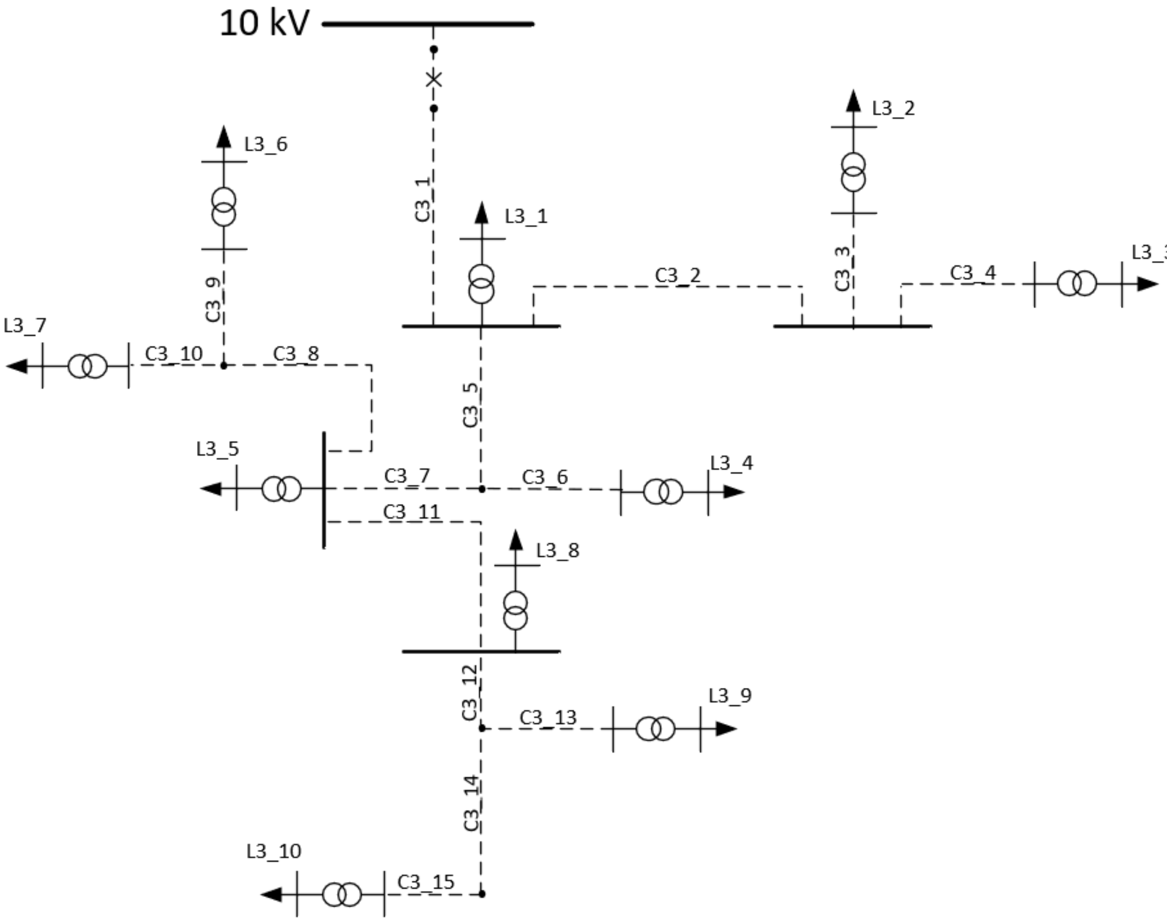

Figure 22 - Representative rural grid, module B3, adapted from [2] and [3]

10.2.2 Transformers

Table 25 - Transformer data, rural grids

	Subtransmission transformer (T40)	Power transformers (T1, T2)	Distribution transformers
Rating [MVA]	See Table 22	See Table 22	0.25
U1/U2 [kV]	135/44	44/11	11/0.4
u_k [%]	10	8	4
Copper losses [kW]	100	50	3
No-load losses [kW]	10	5	0.3
Magnetizing current [%]	0.1	0.1	0.3

Type	2-winding, 5-limb	2-winding, 5-limb	2-winding, 5-limb
Vector group	YNyn	YNyn	Dyn11
Grounding (primary/secondary)	Solid/resonant	Resonant/resonant	-/solid
Tap changer	±9x1.67%	±9x1.67%	-

10.2.3 Cables and lines

Table 26 - Cable and overhead line parameters

Type	R [Ω/km]	L [mH/km]	C [µF/km]
150 Al	0.21	0.34	0.39
95 Al	0.32	0.37	0.33
234 ACSR	0.14	1.10	-
157 ACSR	0.21	1.10	-
62 ACSR	0.54	1.10	-

Table 27 - Cables and overhead lines in module B1 (C1_1 – C1_32), B2 (C2_1 – C2_30) and B3 (C3_1 – C3_15).

ID	Type	Length [km]	ID	Type	Length [km]
C1_1	157 ACSR	0.1	C2_1	234 ACSR	0.3
C1_2	157 ACSR	0.3	C2_2	62 ACSR	0.7
C1_3	62 ACSR	0.3	C2_3	62 ACSR	0.6
C1_4	150 Al	0.3	C2_4	62 ACSR	0.8
C1_5	95 Al	1	C2_5	157 ACSR	0.6
C1_6	62 ACSR	0.7	C2_6	157 ACSR	0.4
C1_7	62 ACSR	0.8	C2_7	62 ACSR	0.6
C1_8	62 ACSR	0.7	C2_8	62 ACSR	0.7
C1_9	62 ACSR	0.5	C2_9	62 ACSR	0.5
C1_10	62 ACSR	0.8	C2_10	62 ACSR	0.8
C1_11	95 Al	0.8	C2_11	62 ACSR	0.4
C1_12	95 Al	0.5	C2_12	62 ACSR	0.3
C1_13	95 Al	0.5	C2_13	62 ACSR	0.4
C1_14	95 Al	0.5	C2_14	62 ACSR	0.4

C1_15	95 Al	0.5	C2_15	62 ACSR	0.7
C1_16	95 Al	0.8	C2_16	62 ACSR	0.7
C1_17	95 Al	0.4	C2_17	62 ACSR	0.7
C1_18	95 Al	0.6	C2_18	62 ACSR	0.7
C1_19	62 ACSR	0.9	C2_19	62 ACSR	0.8
C1_20	62 ACSR	0.7	C2_20	62 ACSR	1
C1_21	62 ACSR	0.7	C2_21	62 ACSR	0.6
C1_22	62 ACSR	0.6	C2_22	62 ACSR	0.5
C1_23	62 ACSR	0.8	C2_23	62 ACSR	0.6
C1_24	62 ACSR	0.4	C2_24	62 ACSR	0.6
C1_25	62 ACSR	0.3	C2_25	62 ACSR	0.6
C1_26	62 ACSR	0.6	C2_26	62 ACSR	0.7
C1_27	62 ACSR	0.6	C2_27	62 ACSR	0.8
C1_28	62 ACSR	0.3	C2_28	62 ACSR	0.8
C1_29	62 ACSR	0.6	C2_29	62 ACSR	0.8
C1_30	62 ACSR	0.6	C2_30	62 ACSR	0.6
C1_31	62 ACSR	0.7	C3_1	150 Al	0.4
C1_32	62 ACSR	0.8	C3_2	95 Al	1
			C3_3	95 Al	0.3
			C3_4	95 Al	0.7
			C3_5	150 Al	0.5
			C3_6	95 Al	0.9
			C3_7	150 Al	0.4
			C3_8	95 Al	0.4
			C3_9	95 Al	0.4
			C3_10	95 Al	0.6
			C3_11	95 Al	0.5
			C3_12	95 Al	0.5
			C3_13	95 Al	0.5
			C3_14	95 Al	0.5
			C3_15	150 Al	0.4

10.2.4 Loads

Table 28 – Max and average loads in module B1 (L1_1 – L1_17), B2 (L2_1 – L2_18) and B3 (L3_1 – L3_10)

ID	P_{max} [kW]	Q_{max} [kVAr]	P_{avg} [kW]	Q_{avg} [kVAr]
L1_1	258	145	77	43
L1_2, L1_5-L1_10, L1_13, L1_15, L1_17	154	88	41	23
L1_3-L1_4, L1_11-L1_12, L1_14, L1_16	109	62	27	15
L2_1, L2_5, L2_10	175	100	48	27
L2_2-L2_3, L2_6-L2_9, L2_11-L2_17	167	95	46	26
L2_4	303	172	93	53
L3_1, L3_7	175	100	48	27
L3_2, L3_4-L3_6, L3_8-L3_10	167	95	46	26
L3_3	190	108	53	30

11 References

[1] J. Arrillaga, "High Voltage Direct Current Transmission," 1998.

[2] O. Engblom and M. Ueda, "Representativa testnät för svenska distributionsnät," Elforsk rapport 08:42, Stockholm, 2008.

[3] J. Lundquist, "Optimalt gränssnitt mellan regionnät och lokalnät," Elforsk rapport 09:30, Stockholm, 2009.

Appendix A – Detailed single-line-diagram