CIGRE WG B4.57 and B4.58

DC GRID TEST SYSTEM

PART I:

LOAD FLOW MODEL in DIgSILENT PowerFactory

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Abstract

The CIGRE DC grid test system is a multi-terminal meshed HVDC grid developed jointly by CIGRE Working Groups B4.57 and B4.58. It was presented for the first time in 2013 [1] aiming to become a reference benchmark system through which different research programs can be carried out. This paper describes the DIgSILENT *PowerFactory* model of the CIGRE DC Grid Test System and its parameters as provided by [2] for load flow studies. Results of the steady-state power flow are given and plots generated from the steady-state solution are shown as a guide for final users.

1 General Description

The CIGRE DC grid test system consists of:

- Two onshore AC systems: system A (busbars: A0 and A1), and system B (busbars: B0, B1, B2 and B3).
- Four offshore AC systems: system C (busbars: C1 and C2), system D (busbar: D1), system E (busbar E1) and system F (busbar F1).
- Three DC grids: DCS1 (± 200kV monopolar HVDC point-to-point link between busbars A1 and C1), DCS2 (± 200kV monopolar five-terminal DC grid with busbars B2, B3, B5, E1 and F1) and DCS3 (± 400kV bipolar eight-terminal DC grid with busbars A1, C2, D1, E1, B1, B4 and B2).
- Eleven AC/DC converters which are the interface between the AC and DC grids. Five of them have bipolar configuration and the remaining six have monopolar configuration.
- Two DC/DC converters: Cd-E1, which enables a power exchange between 800kV and 400kV DC systems, and Cd-B1, which provides a connection between busbars B1 and E1.

Three different study cases have been implemented in DIgSILENT *PowerFactory* based on the CIGRE DC grid test system: “DCS1”, “DCS2” and “Full Test System”.

In the study case **“DCS1”,** a simple DC system has been modelled, providing a suitable model to perform investigations about single point-to-point links. Figure 1 shows the single line diagram of this system in DIgSILENT *PowerFactory*.

In the study case **“DCS2”,** the five-terminal DC system has been modelled, facilitating the study of a multi-terminal DC system. The single line diagram in DIgSILENT *PowerFactory* of this study case has been depicted in Figure 2.

The study case **“Full Test System”** includes the complete model of the CIGRE DC grid test system, where more complex investigations about DC grids can be done. The single line diagram of this system in DIgSILENT *PowerFactory* is shown in Figure 3.

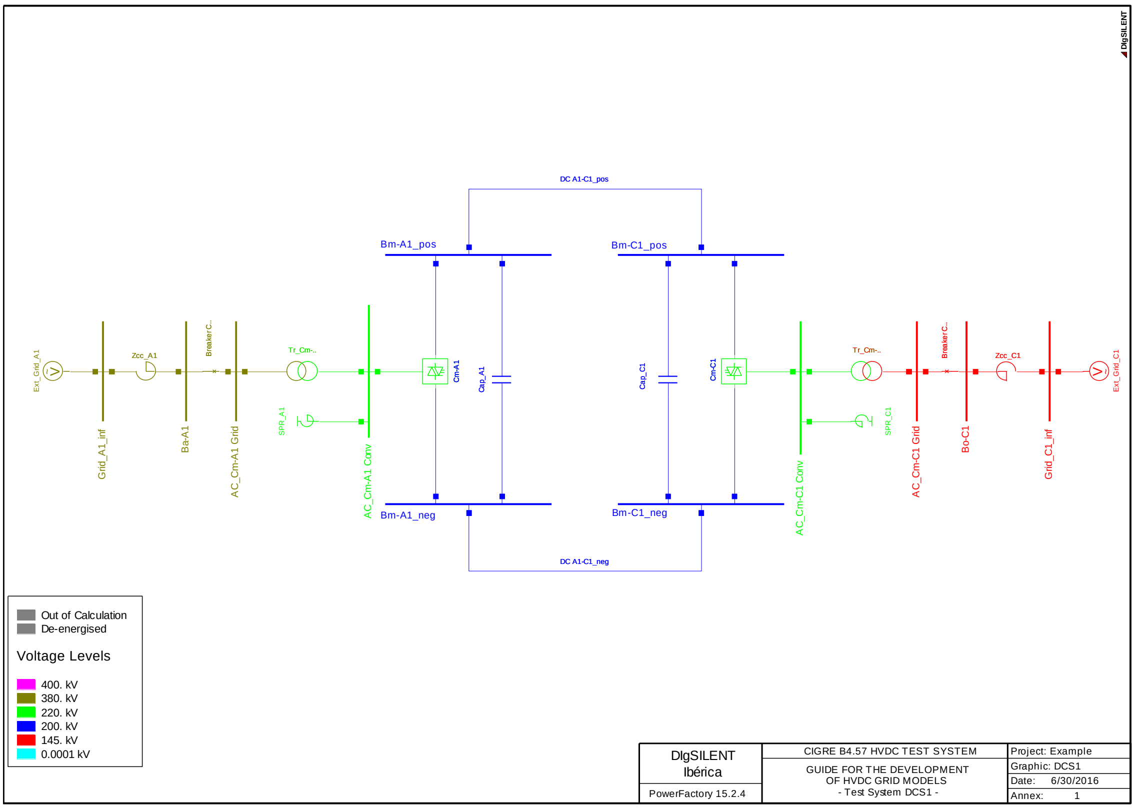

Figure 1: Single Line Diagram of "DCS1" in DIgSILENT PowerFactory

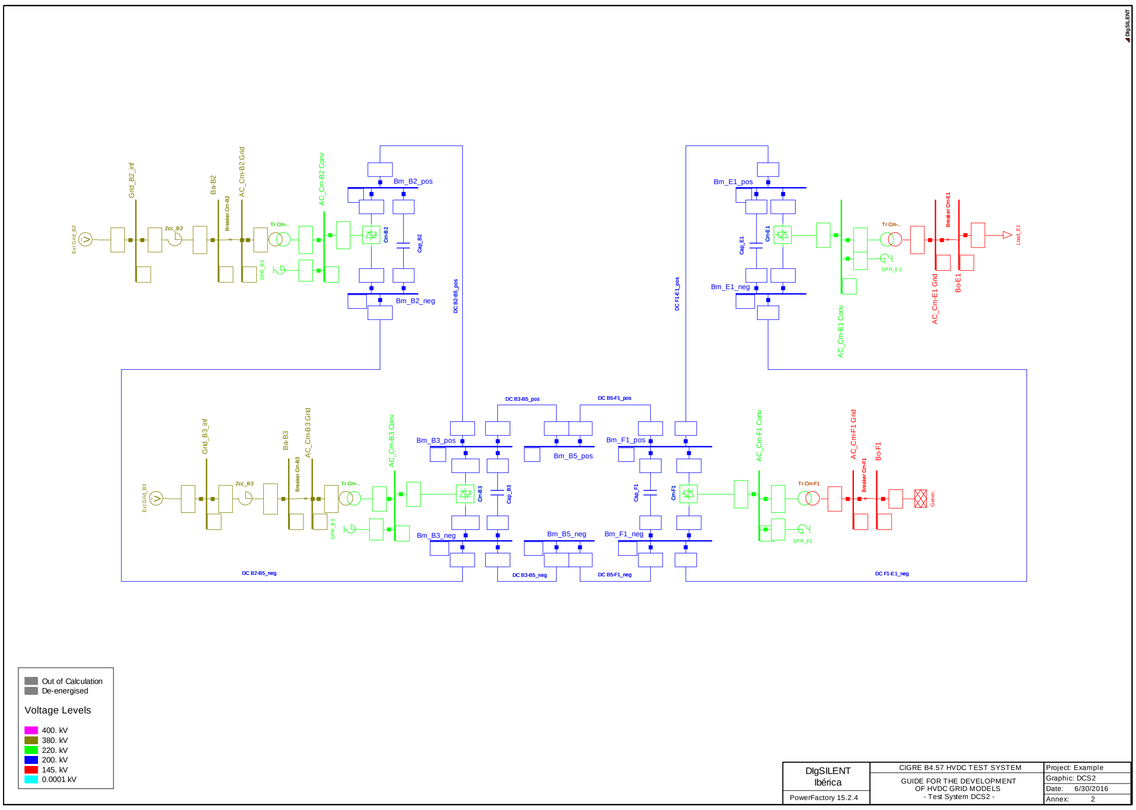

Figure 2: Single Line Diagram of "DCS2" in DIgSILENT PowerFactory

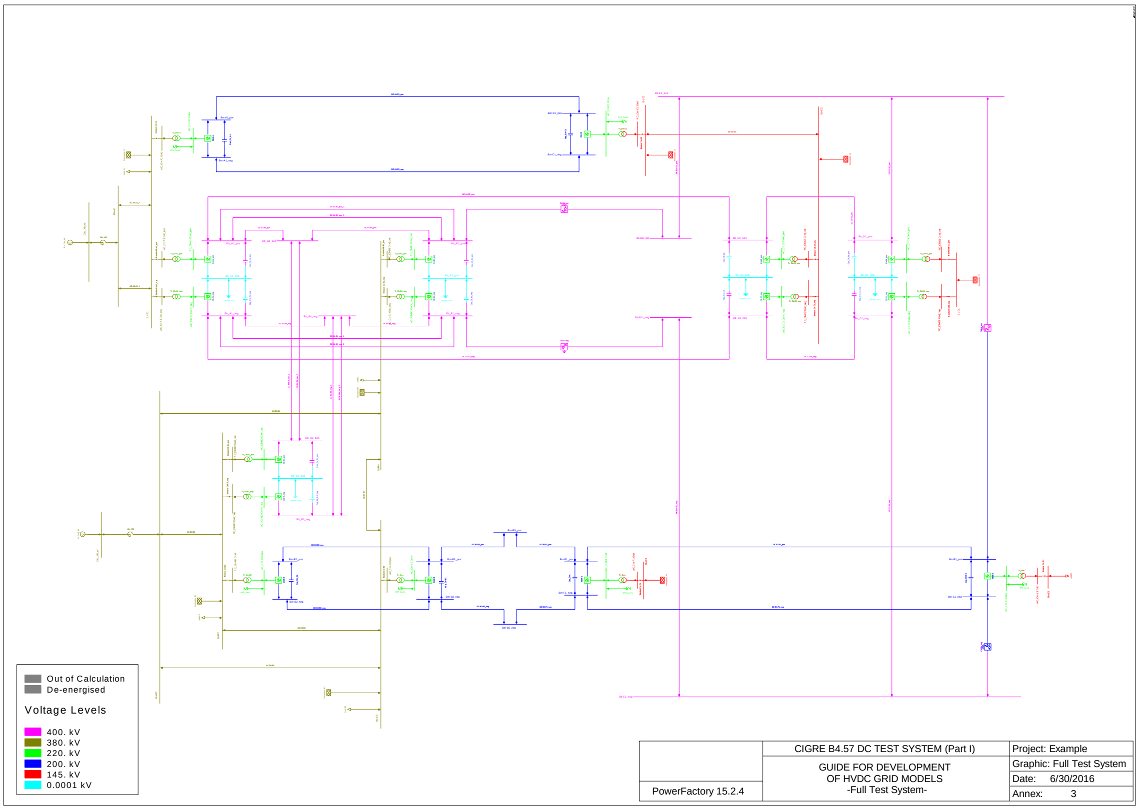

Figure 3: Single Line Diagram of the "Full Test System" in DIgSILENT PowerFactory

2 Model Parameters

The following subsections describe the network data used to set up the load flow model in DIgSILENT PowerFactory, extracted from [2]. Parameters are included in Appendix A.

2.1 Loads

System loads do not depend on voltage, the active and reactive power demand is constant. Please note that this is achieved by *disabling* the load option "Consider Voltage Dependency of Loads" in the DIgSILENT *PowerFactory* load flow calculation command.

The load flow data used to configure the load elements in DIgSILENT (active power P and reactive power Q) listed in Table 1.

2.2 Generation and external AC systems

The complete CIGRE DC Grid Test System include both offshore and onshore generation. Both types of generation are modelled as constant active and reactive power generation sources.

Constant active and reactive power generation has been modelled by the DIgSILENT *PowerFactory* element "External Grid".

The interconnection between the represented AC systems and external AC systems has been modelled by Thevenin Voltage Source equivalents.

In each study case, the Thevenin Voltage Source equivalents are in charge of the slack function in the corresponding busbars where they are connected. In the "DCS2" and "Full

Test System", the slack function in the offshore AC systems is performed by the AC/DC converters.

Parameters to set up the generation are given in [2] and listed in Table 2, 3 and 4. Active and reactive power dispatch values are entered for PQ generator type. Voltage magnitude and angle in the controlled terminals are provided for Thevenin Voltage Sources (slack type).

2.3 AC/DC Converter Stations

AC/DC converter stations are composed by an external transformer and a converter based on VSC-MMC technology. Two different topologies have been defined in the CIGRE DC Grid Test System:

- Symmetrical monopole configuration.
- Bipolar configuration.

Both topologies are modelled as shown in Figure 4 and Figure 5.

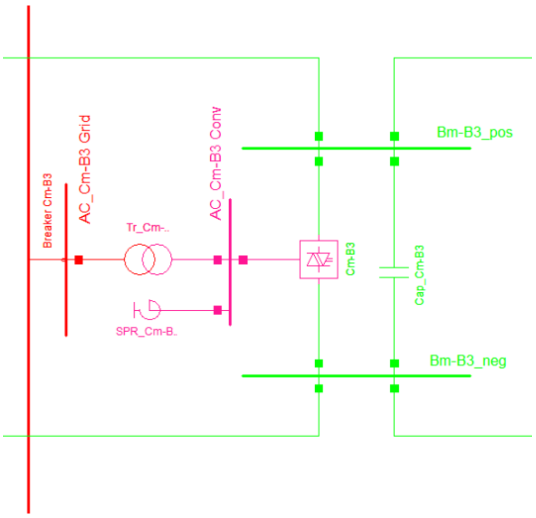

Figure 4. Symmetrical monopole configuration

Please note that bipolar configuration requires a ground reference in the common busbar between the positive and negative busbars. This is achieved in DIgSILENT *PowerFactory* version 15.2 by using a DC voltage source configured with a voltage set point of 0 p.u.

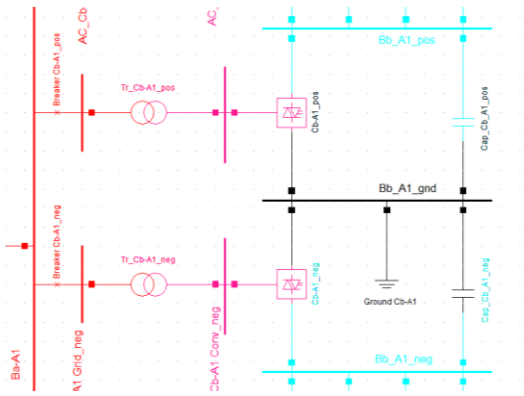

Figure 5. Bipolar configuration

Load losses in transformers and converters are included in the system implemented in DIgSILENT *PowerFactory*. No-load losses, switching losses and auxiliary losses are not included in the model, but they can be added by the user. Transformer parameters used in each AC/DC station converter are provided in Table 8. AC/DC converter parameters are gathered in Table 9.

AC/DC converter stations can be configured to control different parameters of the system such as power flows, voltages magnitudes and angles. The parameters controlled by each converter have been assigned according to [2] for each study case. Control modes of each AC/DC converter as well as their respective set points are given for each one of the three study cases in Tables 10, 11 and 12. Additional details about the configuration of AC/DC controllers in slack or droop mode are included in the next subsections.

Voltage and angle control

The configuration of the AC/DC converters with slack function requires to take into account some details. Although AC/DC converters are able to control the voltage magnitude and angle in any AC busbar, this control is not always possible when in an AC system there are other elements which can perform this function, such as the DIgSILENT *PowerFactory* elements "External Grid" or "AC Voltage Source".

The element "External Grid" can be configured as slack, PQ or PV type. To set AC/DC converters as slack controlling a remote busbar, an "External Station Controller" has to be defined. The "External Station Converter" allows to control the voltage magnitude in any AC busbar, avoiding the eventual conflict when an "External Grid" is connected to the same remote busbar.

Under these circumstances, AC/DC converters cannot control directly the voltage angle in other AC busbar, except in their own AC terminal. As a result, every angle in the corresponding AC system will be shifted. This phase shift is not important since the same increment or decrement in the voltage angle is produced in every busbar of the AC system.

In any case, the voltage angle value in the desired AC busbar can be achieved by shifting the reference angle in the own converter AC terminal with the opposite shifted angle.

Voltage droop control

The voltage droop control must be configured taking into account the branch where the power flow is controlled and the sign convention in DIgSILENT *PowerFactory*.

In generator elements or AC/DC converters, the power flow is positive when it flows out of these elements and vice versa. However, in branch elements such as transformers or lines, the power flow is considered positive when it flows into the branch element at both ends and negative when it goes out from it at both ends.

It is important to set the reference power flow used in the AC/DC converter according to the sign convention at the point where the power flow is controlled.

2.4 DC/DC Converter Stations

DC/DC converter stations increase or reduce the voltage level in an ideal way, since losses are not included in the model. The DC/DC converter model in DIgSILENT *PowerFactory* behaves like a closed circuit in the diode flowing direction. In the opposite direction the model behaves as an open circuit. For this reason, it is necessary to take care during the connection of terminals so that the power flow circulates in both branches.

DC/DC converters parameter values are given by [2] and listed in Table 7.

2.5 Transmission Lines

Line parameters are presented in [2] and listed in Table 5 and Table 6. The line model used to represent the transmission lines is a lumped parameter pi-section model.

3 Model for steady-state operation

The model is built in DIgSILENT PowerFactory version 15.2 and it is contained in the file "CIGRE B4.57 DC TEST SYSTEM (Part I).pfd".

Three grids are provided in the project corresponding to the three test systems. To access every system, the user can activate each study case. Three operation scenarios are defined and will be activated with every study case.

The steady-state load flow is examined by executing the load flow calculation (). Both balanced and unbalanced calculations can be carried out for the study cases "DCS1" and "DCS2", but only unbalanced calculation is available for the study case "Full Test System".

The three study cases contain pre-defined bar diagrams, to display the busbar voltage magnitudes. The bar diagrams are presented in Figures 6, 7 and 8.

The voltage magnitude of negative DC busbars is not included since they have the same voltage magnitude as their respective positive DC busbars, with opposite sign.

The results of the DIgSILENT *PowerFactory* load flow calculation in each one of the three study cases are given in Appendix B.

5. References

[1] T. K. Vrana, Y. T. Yang, and D. Jovcic, “The CIGRE B4 DC grid test system,” Electra, vol. 270, pp. 10–19, Oct. 2013.

[2] Cigré Working Group B4.57, Guide for the Development of Models for HVDC Converters in a HVDC Grid, vol. 604, no. December. 2014.

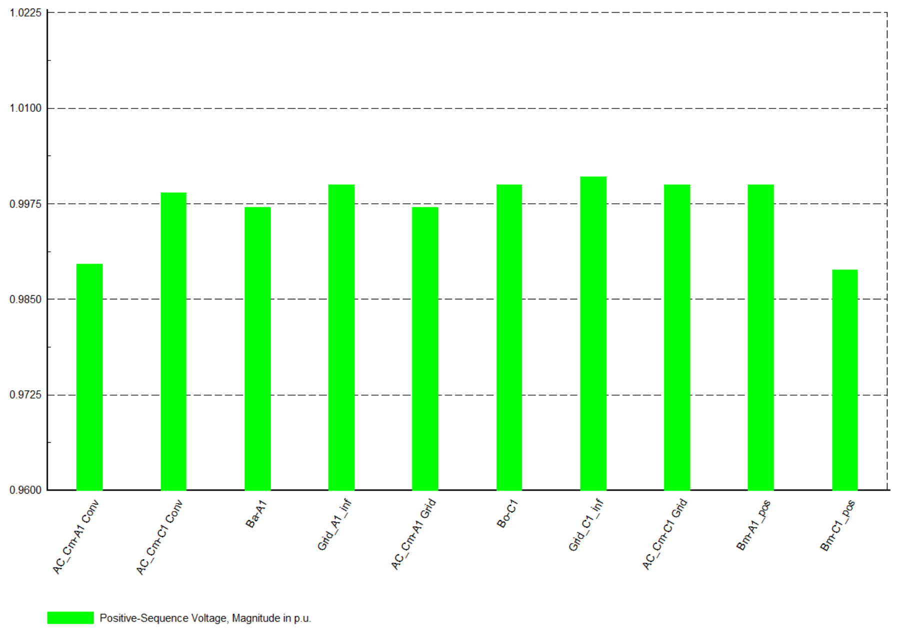

Figure 6: Load flow solution “DCS1” – Voltage magnitudes

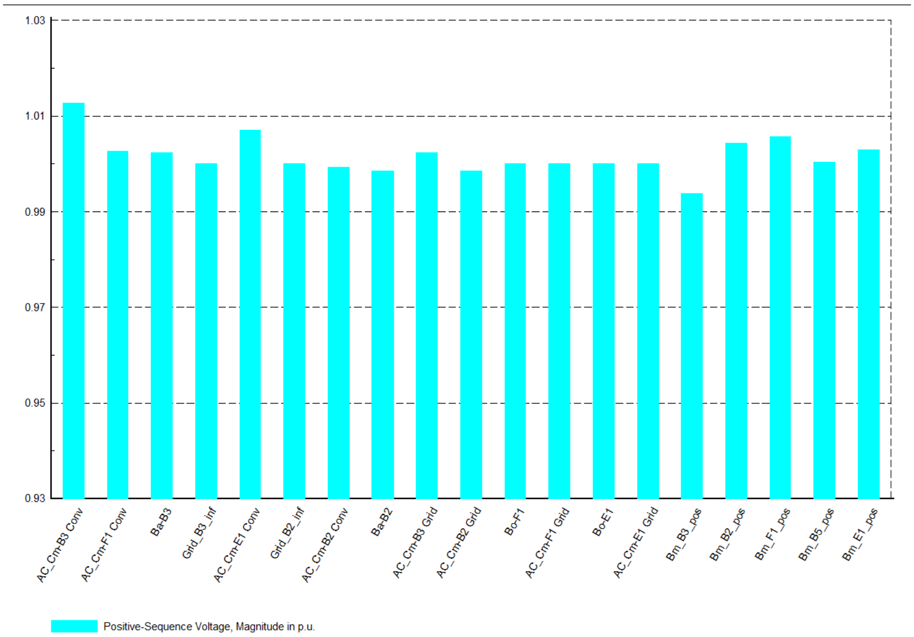

Figure 7: Load flow solution “DCS2” – Voltage magnitudes

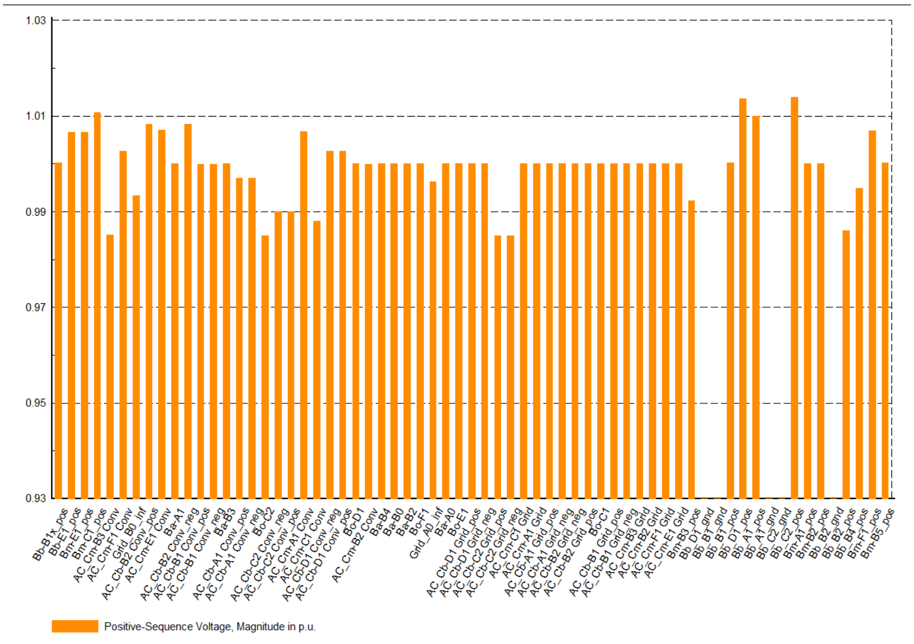

Figure 8: Load flow solution “Full Test System” – Voltage magnitudes

Appendix A: Model parameters

Table 1: Load demand

Load	Busbar	P in MW	Q in Mvar
Load_A1	Ba-A1	1000	0
Load_B1	Ba-B1	2200	0
Load_B2	Ba-B2	2300	0
Load_B3	Ba-B3	1900	0
Load_E1	Bo-E1	100	0

Table 2. Generation configuration. Study Case “DCS1”

Generation	Busbar	Nominal Voltage in KV	Short Circuit Power in GVA	R/X Ratio	Type	Control	Set points
Ext_Grid_A1	Ba-A1	380	30	0.1	Voltage source	V	1.00 p.u.
						φ	0.00 º
Ext_Grid_C1	Bo-C1	145	8	0.1	Voltage source	V	1.00 p.u.
						φ	0.00 º

Table 3. Generation configuration. Study Case “DCS2”

Generation	Busbar	Nominal Voltage in KV	Short Circuit Power in GVA	R/X Ratio	Type	Control	Set points
Ext_Grid_B2	Ba-B2	380	30	0.1	Voltage source	V	1.00 p.u.
						φ	0.00 º
Ext_Grid_B3	Ba-B3	380	30	0.1	Voltage source	V	1.00 p.u.
						φ	0.00 º
G-F1	Bo-F1	145	8	0.1	Voltage source	V	1.00 p.u.
						φ	0.00 º

Table 4. Generation configuration. Study Case "Full Test System"

Generation	Busbar	Nominal Voltage in KV	Short Circuit Power in GVA	R/X Ratio	Type	Control	Set points
Ext_Grid_A0	Ba-A0	380	30	0.1	Voltage source	V	1.00 p.u.
						φ	0.00 º
G-A1	Bo-A1	380	30	0.1	Power source	P	2000 MW
						Q	0 Mvar
Ext_Grid_B0	Bo-B0	380	30	0.1	Voltage source	V	1.00 p.u.
						φ	0.00 º
G-B1	Bo-B1	380	30	0.1	Power source	P	1000 MW
						Q	0 Mvar
G-B2	Bo-B2	380	30	0.1	Power source	P	1000 MW
						Q	0 Mvar
G-B3	Bo-B3	380	30	0.1	Power source	P	1000 MW
						Q	0 Mvar
G-C1	Bo-C1	145	8	0.1	Power source	P	500 MW
						Q	0 Mvar
G-C2	Bo-C2	145	8	0.1	Power source	P	500 MW
						Q	0 Mvar
G-D1	Bo-D1	145	8	0.1	Power source	P	1000 MW
						Q	0 Mvar
G-F1	Bo-F1	145	8	0.1	Power source	P	500 MW
						Q	0 Mvar

Table 5. Transmission lines

Line	From Busbar	To Busbar	Line type	Length	Nominal Voltage
AC A0-A1_1	Ba-A0	Ba-A1	AC OHL 380kV	200 km	380 kV
AC A0-A1_2	Ba-A0	Ba-A1	AC OHL 380kV	200 km	380 kV
AC B0-B1	Ba-B0	Ba-B1	AC OHL 380kV	200 km	380 kV
AC B0-B2	Ba-B0	Ba-B2	AC OHL 380kV	200 km	380 kV
AC B0-B3	Ba-B0	Ba-B3	AC OHL 380kV	200 km	380 kV
AC B1-B3	Ba-B1	Ba-B3	AC OHL 380kV	200 km	380 kV
AC B2-B3	Ba-B2	Ba-B3	AC OHL 380kV	200 km	380 kV
AC C1-C2	Bo-C1	Bo-C2	AC cable 145kV	50 km	145 kV
DC A1-C1_neg	Bm-A1	Bm-C1	DC cable +/- 200kV	200 km	200 kV
DC A1-C1_pos	Bm-A1	Bm-C1	DC cable +/- 200kV	200 km	200 kV
DC A1-B1_neg_1	Bb-A1	Bb-B1	DC OHL +/- 400kV	400 km	400 kV
DC A1-B1_pos_1	Bb-A1	Bb-B1	DC OHL +/- 400kV	400 km	400 kV
DC A1-B1_neg_2	Bb-A1	Bb-B1	DC OHL +/- 400kV	400 km	400 kV
DC A1-B1_pos_2	Bb-A1	Bb-B1	DC OHL +/- 400kV	400 km	400 kV
DC A1-B4_neg	Bb-A1	Bb-B4	DC OHL +/- 400kV	500 km	400 kV
DC A1-B4_pos	Bb-A1	Bb-B4	DC OHL +/- 400kV	500 km	400 kV
DC A1-C2_neg	Bb-A1	Bb-C2	DC cable +/- 400kV	200 km	400 kV
DC A1-C2_pos	Bb-A1	Bb-C2	DC cable +/- 400kV	200 km	400 kV
DC B1-B4_neg	Bb-B1	Bb-B4	DC OHL +/- 400kV	200 km	400 kV
DC B1-B4_pos	Bb-B1	Bb-B4	DC OHL +/- 400kV	200 km	400 kV
DC B1x-E1_neg	Bb-B1x	Bb-E1	DC cable +/- 400kV	200 km	400 kV
DC B1x-E1_pos	Bb-B1x	Bb-E1	DC cable +/- 400kV	200 km	400 kV
DC B2-B3_neg	Bm-B2	Bm-B3	DC cable +/- 200kV	200 km	200 kV
DC B2-B3_pos	Bm-B2	Bm-B3	DC cable +/- 200kV	200 km	200 kV
DC B2-B4_neg_1	Bb-B2	Bb-B4	DC OHL +/- 400kV	300 km	400 kV
DC B2-B4_pos_1	Bb-B2	Bb-B4	DC OHL +/- 400kV	300 km	400 kV
DC B2-B4_neg_2	Bb-B2	Bb-B4	DC OHL +/- 400kV	300 km	400 kV
DC B2-B4_pos_2	Bb-B2	Bb-B4	DC OHL +/- 400kV	300 km	400 kV
DC B3-B5_neg	Bm-B3	Bm-B5	DC OHL +/- 200kV	100 km	200 kV
DC B3-B5_pos	Bm-B3	Bm-B5	DC OHL +/- 200kV	100 km	200 kV
DC B5-F1_neg	Bm-B5	Bm-F1	DC cable +/- 200kV	100 km	200 kV
DC B5-F1_pos	Bm-B5	Bm-F1	DC cable +/- 200kV	100 km	200 kV
DC C2-D1_neg	Bb-C2	Bb-D1	DC cable +/- 400kV	300 km	400 kV
DC C2-D1_pos	Bb-C2	Bb-D1	DC cable +/- 400kV	300 km	400 kV
DC D1-E1_neg	Bb-D1	Bb-E1	DC cable +/- 400kV	200 km	400 kV
DC D1-E1_pos	Bb-D1	Bb-E1	DC cable +/- 400kV	200 km	400 kV
DC E1-F1_neg	Bm-E1	Bm-F1	DC cable +/- 200kV	200 km	200 kV
DC E1-F1_pos	Bm-E1	Bm-F1	DC cable +/- 200kV	200 km	200 kV

Table 6. Line types

Line type	R [Ω/km]	L [mH/km]	C [µF/km]	G [µS/km]	Max. current [A]
DC OHL +/- 400kV	0.0114	0.9356	0.0123	-	3500
DC OHL +/- 200kV	0.0133	0.8273	0.0139	-	3000
DC cable +/- 400kV	0.011	2.615	0.1908	0.048	2265
DC cable +/- 200kV	0.011	2.615	0.2185	0.055	1962
AC cable 145kV	0.0843	0.2526	0.1837	0.041	715
AC OHL 380kV	0.0200	0.8532	0.0135	-	3555

Table 7: DC/DC converters

DC/DC Converter	From Busbar	To Busbar	Alpha U2/U1	Rated Current in A
Cd-B1_pos	Bb-B1x_pos	Bb-B1_pos	1	5000
Cd-B1_neg	Bb-B1_neg	Bb-B1x_neg	1	5000
Cd-E1_pos	Bb-E1_pos	Bm-E1_pos	0.5	5000
Cd-E1_neg	Bm-E1_neg	Bb-E1_neg	2	5000

Table 8: Transformers

Transformer	From Busbar	To Busbar	Ur HV in KV	Ur LV in kV	Rated Power in MVA	X in p.u.	R in p.u.	Connection Type
Tr_Cm-A1	AC_Cm-A1 Grid	AC_Cm-A1 Conv	380 kV	220 kV	800	0.18	0.006	YNd0
Tr_Cb-A1_pos	AC_Cb-A1 Grid_pos	AC_Cb-A1 Conv_pos	380 kV	220 kV	1200	0.18	0.006	YNd0
Tr_Cb-A1_neg	AC_Cb-A1 Grid_neg	AC_Cb-A1 Conv_neg	380 kV	220 kV	1200	0.18	0.006	YNd0
Tr_Cb-B1_pos	AC_Cb-B1 Grid_pos	AC_Cb-B1 Conv_pos	380 kV	220 kV	1200	0.18	0.006	YNd0
Tr_Cb-B1_neg	AC_Cb-B1 Grid_neg	AC_Cb-B1 Conv_neg	380 kV	220 kV	1200	0.18	0.006	YNd0
Tr_Cm-B2	AC_Cm-B2 Grid	AC_Cm-B2 Conv	380 kV	220 kV	800	0.18	0.006	YNd0
Tr_Cb-B2_pos	AC_Cb-B2 Grid_pos	AC_Cb-B2 Conv_pos	380 kV	220 kV	800	0.18	0.006	YNd0
Tr_Cb-B2_neg	AC_Cb-B2 Grid_neg	AC_Cb-B2 Conv_neg	380 kV	220 kV	800	0.18	0.006	YNd0
Tr_Cm-B3	AC_Cm-B3 Grid	AC Cm-B3 Conv	380 kV	220 kV	1200	0.18	0.006	YNd0
Tr_Cm-C1	AC_Cm-C1 Grid	AC_Cm-C1 Conv	220 kV	145 kV	800	0.18	0.006	YNd0
Tr_Cb-C2_pos	AC_Cb-C2 Grid_pos	AC_Cb-C2 Conv_pos	220 kV	145 kV	400	0.18	0.006	YNd0
Tr_Cb-C2_neg	AC_Cb-C2 Grid_neg	AC_Cb-C2 Conv_neg	220 kV	145 kV	400	0.18	0.006	YNd0
Tr_Cb-D1_pos	AC_Cb-D2 Grid_pos	AC_Cb-D2 Conv_pos	220 kV	145 kV	800	0.18	0.006	YNd0
Tr_Cb-D1_neg	AC_Cb-D1 Grid_neg	AC_Cb-D1 Conv_neg	220 kV	145 kV	800	0.18	0.006	YNd0
Tr_Cm-E1	AC_Cm-E1 Grid	AC_Cm-E1 Conv	220 kV	145 kV	200	0.18	0.006	YNd0
Tr_Cm-F1	AC_Cm-F1 Grid	AC_Cm-F1 Conv	220 kV	145 kV	800	0.18	0.006	YNd0

Table 9: AC/DC converters

AC/DC Converter	DC Busbar+ DC Busbar -	AC Busbar	Ur AC in KV	Ur DC in kV	Rated Power in MVA	Short Circuit Impedance in %	Copper Losses in kW	Resistive Loss Factor in mΩ
Cm-A1	Bm-A1_pos Bm-A1_neg	AC_Cm-A1 Conv	220	400	800	15	2400	242
Cb-A1_pos	Bb-A1_pos Bb-A1_gnd	AC_Cb-A1 Conv_pos	220	400	1200	15	3600	161.3333
Cb-A1_neg	Bb-A1_gnd Bb-A1_neg	AC_Cb-A1 Conv_neg	220	400	1200	15	3600	161.3333
Cb-B1_pos	Bb-B1_pos Bb-B1_gnd	AC_Cb-B1 Conv_pos	220	400	1200	15	3600	161.3333
Cb-B1_neg	Bb-B1_gnd Bb-B1_neg	AC_Cb-B1 Conv_neg	220	400	1200	15	3600	161.3333
Cm-B2	Bm-B2_pos Bm-B2_neg	AC_Cm-B2 Conv	220	400	800	15	2400	242
Cb-B2_pos	Bb-B2_pos Bb-B2_gnd	AC_Cb-B2 Conv_pos	220	400	800	15	2400	242
Cb-B2_neg	Bb-B2_gnd Bb-B2_neg	AC_Cb-B2 Conv_neg	220	400	800	15	2400	242

AC/DC Converter	DC Busbar+ DC Busbar -	AC Busbar	Ur AC in KV	Ur DC in kV	Rated Power in MVA	Short Circuit Impedance in %	Copper Losses in kW	Resistive Loss Factor in mΩ
Cm-B3	Bm-B3_pos Bm_B3_neg	AC Cm-B3 Conv	220	400	1200	15	3600	161.3333
Cm-C1	Bm-C1_pos Bm-C1_neg	AC_Cm-C1 Conv	220	400	800	15	2400	242
Cb-C2_pos	Bb-C2_pos Bb-C2_gnd	AC_Cb-C2 Conv_pos	220	400	400	15	1200	484
Cb-C2_neg	Bb-C2_gnd Bb-C2_neg	AC_Cb-C2 Conv_neg	220	400	400	15	1200	484
Cb-D1_pos	Bb-D1_pos Bb-D1_gnd	AC_Cb-D2 Conv_pos	220	400	800	15	2400	242
Cb-D1_neg	Bb-D1_gnd Bb-D1_neg	AC_Cb-D1 Conv_neg	220	400	800	15	2400	242
Cm-E1	Bm-E1_pos Bm-E1_neg	AC_Cm-E1 Conv	220	400	200	15	600	968
Cm-F1	Bm-F1_pos Bm-F1_neg	AC_Cm-F1 Conv	220	400	800	15	2400	242

Table 10: AC/DC converters control modes in Study Case "DCS1"

AC/DC Converter	Control	Set points	Voltage and angle control	Power flow control	
			Controlled Busbars	Busbar From	Busbar To
Cm-A1	V_{DC}	1.00 p.u.	Bm-A1_pos/Bm-A1_neg	-	-
	Q	0 Mvar	-	AC_Cm-A1 Grid	AC_Cm-A1 Conv
Cb-A1_pos	P	400 MW	-	AC_Cm-C1 Grid	AC_Cm-C1 Conv
	Q	0 Mvar	-	AC_Cm-C1 Grid	AC_Cm-C1 Conv

Table 11: AC/DC converters control modes in Study Case "DCS2"

AC/DC Converter	Control	Set points	Voltage and angle control	Power flow control	
			Controlled Busbars	Busbar From	Busbar To
Cm-B2	Voltage droop control	K:0.00025 p.u./MW Pref: 400 MW V_{DC}_ref: 1.00 p.u.	Bm-B2_pos/Bm-B2_neg	AC_Cm-B2 Grid	Ba-B2
	Q	0 Mvar	-	AC_Cm-B2 Grid	AC_Cm-B2 Conv
Cm-B3	Voltage droop control	K:0.00016666 p.u./MW Pref: 800 MW V_{DC}_ref: 1.00 p.u.	Bm-B3_pos/Bm-B3_neg	AC_Cm-B3 Grid	Ba-B3
	V_{AC}	1 p.u.	Ba-B3	-	-
Cm-E1	V_{AC}	1.00 p.u.	Co-E1	-	-
	φ	0.00 º	Co-E1	-	-
Cm-F1	V_{AC}	1.00 p.u.	Co-F1	-	-
	φ	0.00 º	Co-F1	-	-

Table 12: AC/DC converters control modes in Study Case “Full Test System”

AC/DC Converter	Control	Set points	Voltage and angle control	Power flow control	
			Controlled Busbars	Busbar From	Busbar To
Cm-A1	V_{DC}	1.00 p.u.	Bm-A1_pos/Bm-A1_neg	-	-
	Q	0 Mvar	-	AC_Cm-A1 Grid	AC_Cm-A1 Conv
Cb-A1_pos	V_{DC}	1.01 p.u.	Bb-A1_pos	-	-
	V_{AC}	1.00 p.u.	Ba-A1	-	-
Cb-A1_neg	V_{DC}	1.01 p.u.	Bb-A1_neg	-	-
	V_{AC}	1.00 p.u.	Ba-A1	-	-
Cb-B1_pos	Voltage droop control	K: 0.00016666 p.u./MW Pref: 750 MW V_{DC}_ref: 1.00 p.u.	Bb-B1_pos	AC_Cb-B1 Grid_pos	Ba-B1
	V_{AC}	1 p.u.	Ba-B1	-	-
Cb-B1_neg	Voltage droop control	K: 0.00016666 p.u./MW Pref: 750 MW V_{DC}_ref: 1.00 p.u.	Bb-B1_neg	AC_Cb-B1 Grid_neg	Ba-B1
	V_{AC}	1.00 p.u.	Ba-B1	-	-
Cm-B2	V_{DC}	1.00 p.u,	Bm-B2_pos/Bm-B2_neg	-	-
	Q	0 Mvar	-	AC_Cm-B2 Grid	AC_Cm-B2 Conv
Cb-B2_pos	Voltage droop control	K:0.00016666 p.u./MW Pref: 850 MW V_{DC}_ref: 1.00 p.u.	Bb-B2_pos	AC_Cb-B2 Grid_pos	Ba-B2
	V_{AC}	1.00 p.u.	Ba-B2	-	-
Cb-B2_neg	Voltage droop control	K:0.00016666 p.u./MW Pref: 850 MW V_{DC}_ref: 1.00 p.u.	Bb-B2_neg	AC_Cb-B2 Grid_neg	Ba-B2
	V_{AC}	1 p.u.	Ba-B2	-	-
Cm-B3	Voltage droop control	K:0.00016666 Pref: V_{DC}_ref:	Bm-B3_pos/Bm-B3_neg	AC_Cm-B3 Grid	Ba-B3
	V_{AC}	1 p.u.	Ba-B3	-	-
Cm-C1	V_{AC}	1 p.u.	Co-C1	-	-
	φ	0.00 º	Co-C1	-	-
Cb-C2_pos	P	300 MW	-	AC_Cb-C2 Grid_pos	AC_Cb-C2 Conv_pos
	Q	0 Mvar	-	AC_Cb-C2 Grid_pos	AC_Cb-C2 Conv_pos
Cb-C2_neg	P	300 MW	-	AC_Cb-C2 Grid_neg	AC_Cb-C2 Conv_neg
	Q	0 Mvar	-	AC_Cb-C2 Grid_neg	AC_Cb-C2 Conv_neg
Cb-D1_pos	V_{AC}	1 p.u.	Co-D1	-	-
	φ	0.00 º	Co-D1	-	-
Cb-D1_neg	V_{AC}	1 p.u.	Co-D1	-	-
	φ	0.00 º	Co-D1	-	-
Cm-E1	V_{AC}	1.00 p.u.	Co-E1	-	-
	φ	0.00 º	Co-E1	-	-
Cm-F1	V_{AC}	1 p.u.	Co-F1	-	-
	φ	0.00 º	Co-F1	-	-

Appendix B Load Flow Results

Table 13: “DCS1” – Busbars

Busbar	Nominal Voltage [KV]	Voltage Magnitude [p.u.]	Voltage Angle [º]
AC_Cm-A1 Conv	220	1,0068	5,01
AC_Cm-A1 Grid	380	1,0000	0,00
AC_Cm-C1 Conv	220	1,0011	-5,16
AC_Cm-C1 Grid	145	1,0000	0,00
Ba-A1	380	1,0000	0,00
Bm-A1_neg	200	-1,0000	0,00
Bm-A1_pos	200	1,0000	0,00
Bm-C1_neg	200	-1,0108	0,00
Bm-C1_pos	200	1,0108	0,00
Bo-C1	145	1,0000	0,00
Grid_A1_inf	380	0,9987	-0,82
Grid_C1_inf	145	1,0070	3,12

Table 14: “DCS1” – Lines

Line	Losses [kW]	Capacitive Losses [MVAr]	Current [kA]	Max. Current [kA]	Loading [%]
DC A1-C1_neg	2571,302	-	0,982	1,962	50,17
DC A1-C1_pos	2571,302	-	-0,982	1,962	50,17

Table 15: “DCS2” – Busbars

Busbar	Nominal Voltage [KV]	Voltage Magnitude [p.u.]	Voltage Angle [º]
AC_Cm-B2 Conv	220	0,9994	-5,77
AC_Cm-B2 Grid	380	0,9985	-0,80
AC_Cm-B3 Conv	220	1,0126	8,05
AC_Cm-B3 Grid	380	1,0024	1,59
AC_Cm-E1 Conv	220	1,0070	5,13
AC_Cm-E1 Grid	145	1,0000	0,00
AC_Cm-F1 Conv	220	1,0026	-6,44
AC_Cm-F1 Grid	145	1,0000	0,00
Ba-B2	380	0,9985	-0,80
Ba-B3	380	1,0024	1,59
Bm_B2_neg	200	-1,0041	0,00
Bm_B2_pos	200	1,0041	0,00
Bm_B3_neg	200	-0,9937	0,00
Bm_B3_pos	200	0,9937	0,00
Bm_B5_neg	200	-1,0002	0,00
Bm_B5_pos	200	1,0002	0,00
Bm_E1_neg	200	-1,0028	0,00
Bm_E1_pos	200	1,0028	0,00
Bm_F1_neg	200	-1,0056	0,00
Bm_F1_pos	200	1,0056	0,00
Bo-E1	145	1,0000	0,00
Bo-F1	145	1,0000	0,00
Grid_B2_inf	380	1,0000	0,00
Grid_B3_inf	380	1,0000	0,00

Table 16. “DCS2” - Lines

Line	Losses [kW]	Capacitive Losses [MVAr]	Current [kA]	Max. Current [kA]	Loading [%]
DC F1-E1_pos	583,053	-	0,253	1,962	12,88
DC F1-E1_neg	583,053	-	-0,253	1,962	12,88
DC B5-F1_pos	1281,628	-	-0,981	1,962	50,07
DC B5-F1_neg	1281,628	-	0,981	1,962	50,07
DC B3-B5_pos	1280,629	-	-0,981	3,000	32,71
DC B3-B5_neg	1280,629	-	0,981	3,000	32,71
DC B2-B5_pos	2421,540	-	0,950	1,962	48,44
DC B2-B5_neg	2421,540	-	-0,950	1,962	48,44

Table 17. “Full Test System” – Busbars

Busbar	Nominal Voltage [KV]	Voltage Magnitude [p.u.]	Voltage Angle [º]
Grid_B0_inf	380	0,9933	-0,30
Grid_A0_inf	380	0,9962	0,69
Bo-F1	145	1,0000	-0,00
Bo-E1	145	1,0000	0,00
Bo-D1	145	1,0000	-0,00
Bo-C2	145	0,9850	-1,44
Bo-C1	145	1,0000	0,00
Bm-F1_pos	200	1,0068	0,00
Bm-F1_neg	200	-1,0068	0,00
Bm-E1_pos	200	1,0065	0,00
Bm-E1_neg	200	-1,0065	0,00
Bm-C1_pos	200	1,0108	0,00
Bm-C1_neg	200	-1,0108	0,00
Bm-B5_pos	200	1,0002	0,00
Bm-B5_neg	200	-1,0002	0,00
Bm-B3_pos	200	0,9922	0,00
Bm-B3_neg	200	-0,9922	0,00
Bm-B2_pos	200	1,0000	0,00
Bm-B2_neg	200	-1,0000	0,00
Bm-A1_pos	200	1,0000	0,00
Bm-A1_neg	200	-1,0000	0,00
Bb_D1_pos	400	1,0135	0,00
Bb_D1_neg	400	-1,0135	0,00
Bb_D1_gnd	0,0001	0,0000	0,00
Bb_C2_pos	400	1,0138	0,00
Bb_C2_neg	400	-1,0138	0,00
Bb_C2_gnd	0,0001	0,0000	0,00
Bb_B4_pos	400	0,9947	0,00
Bb_B4_neg	400	-0,9947	0,00
Bb_B2_pos	400	0,9861	0,00
Bb_B2_neg	400	-0,9861	0,00
Bb_B2_gnd	0,0001	0,0000	0,00
Bb_B1_pos	400	1,0002	0,00
Bb_B1_neg	400	-1,0002	0,00
Bb_B1_gnd	0,0001	0,0000	0,00
Bb_A1_pos	400	1,0100	0,00
Bb_A1_neg	400	-1,0100	0,00
Bb_A1_gnd	0,0001	0,0000	0,00
Bb-E1_pos	400	1,0065	0,00
Bb-E1_neg	400	-1,0065	0,00
Bb-B1x_pos	400	1,0002	0,00
Bb-B1x_neg	400	-1,0002	0,00
Ba-B4	380	1,0000	3,27

Busbar	Nominal Voltage [KV]	Voltage Magnitude [p.u.]	Voltage Angle [º]
Ba-B3	380	1,0000	0,06
Ba-B2	380	1,0000	0,07
Ba-B0	380	1,0000	0,00
Ba-A1	380	1,0000	-3,38
Ba-A0	380	1,0000	-0,00
AC_Cm-F1 Grid	145	1,0000	-0,00
AC_Cm-F1 Conv	220	1,0026	-6,44
AC_Cm-E1 Grid	145	1,0000	0,00
AC_Cm-E1 Conv	220	1,0070	5,13
AC_Cm-C1 Grid	145	1,0000	0,00
AC_Cm-C1 Conv	220	0,9881	-5,17
AC_Cm-B3 Grid	380	1,0000	0,06
AC_Cm-B3 Conv	220	0,9851	6,70
AC_Cm-B2 Grid	380	1,0000	0,07
AC_Cm-B2 Conv	220	0,9999	-3,60
AC_Cm-A1 Grid	380	1,0000	-3,38
AC_Cm-A1 Conv	220	1,0067	1,60
AC_Cb-D1 Grid_pos	145	1,0000	-0,00
AC_Cb-D1 Grid_neg	145	1,0000	-0,00
AC_Cb-D1 Conv_pos	220	1,0026	-6,44
AC_Cb-D1 Conv_neg	220	1,0026	-6,44
AC_Cb-C2 Grid_pos	145	0,9850	-1,44
AC_Cb-C2 Grid_neg	145	0,9850	-1,44
AC_Cb-C2 Conv_pos	220	0,9899	-9,40
AC_Cb-C2 Conv_neg	220	0,9899	-9,40
AC_Cb-B2 Grid_pos	380	1,0000	0,07
AC_Cb-B2 Grid_neg	380	1,0000	0,07
AC_Cb-B2 Conv_pos	220	1,0082	10,31
AC_Cb-B2 Conv_neg	220	1,0082	10,31
AC_Cb-B1 Grid_pos	380	1,0000	3,27
AC_Cb-B1 Grid_neg	380	1,0000	3,27
AC_Cb-B1 Conv_pos	220	0,9999	9,76
AC_Cb-B1 Conv_neg	220	0,9999	9,76
AC_Cb-A1 Grid_pos	380	1,0000	-3,38
AC_Cb-A1 Grid_neg	380	1,0000	-3,38
AC_Cb-A1 Conv_pos	220	0,9972	-10,73
AC_Cb-A1 Conv_neg	220	0,9972	-10,73

Table 18: “Full Test System” - Lines

Line	Losses [kW]	Capacitive Losses [MVAr]	Current [kA]	Max. Current [kA]	Loading [%]
AC A0-A1_1	697,175	122,484	0,262	3,555	7,38
AC A0-A1_2	697,175	122,484	0,262	3,555	7,38
AC B0-B1	649,521	122,484	0,242	3,555	7,16
AC B0-B2	0,319	122,484	0,094	3,555	2,63
AC B0-B3	0,250	122,484	0,093	3,555	2,63
AC B1-B3	624,288	122,484	0,250	3,555	7,04
AC B2-B3	0,004	122,484	0,093	3,555	2,62
AC C1-C2	2288,718	59,763	0,404	0,715	65,39
DC A1-B1_pos_2	3339,716	-	0,856	3,500	24,45
DC A1-B1_neg_1	3339,908	-	-0,856	3,500	24,45
DC A1-B1_neg_2	3339,908	-	-0,856	3,500	24,45
DC A1-B1_pos_1	3339,716	-	0,856	3,500	24,45
DC A1-B4_neg	6529,053	-	-1,070	3,500	30,58
DC A1-B4_pos	6528,960	-	1,070	3,500	30,58
DC A1-C1_neg	2546,964	-	0,976	1,962	49,88
DC A1-C1_pos	2546,964	-	-0,976	1,962	49,88

Line	Losses [kW]	Capacitive Losses [MVAr]	Current [kA]	Max. Current [kA]	Loading [%]
DC A1-C2_neg	2619,535	-	0,688	2,265	30,54
DC A1-C2_pos	2620,298	-	-0,688	2,265	30,55
DC B1x-E1_neg	4428,585	-	1,143	2,265	50,62
DC B1x-E1_pos	4428,933	-	-1,143	2,265	50,62
DC B2-B3_neg	1539,228	-	-0,709	1,962	36,14
DC B2-B3_pos	1539,228	-	0,709	1,962	36,14
DC B2-B4_neg_1	3538,126	-	1,017	3,500	29,06
DC B2-B4_neg_2	3538,126	-	1,017	3,500	29,06
DC B2-B4_pos_1	3538,205	-	-1,017	3,500	29,06
DC B2-B4_pos_2	3538,205	-	-1,017	3,500	29,06
DC B3-B5_neg	1927,487	-	1,204	3,000	40,13
DC B3-B5_pos	1927,487	-	-1,204	3,000	40,13
DC B4-B1_neg	2118,754	-	0,964	3,500	27,54
DC B4-B1_pos	2118,887	-	-0,964	3,500	27,54
DC B5-F1_neg	1817,178	-	1,204	1,962	61,41
DC B5-F1_pos	1817,178	-	-1,204	1,962	61,41
DC D1-C2_neg	2372,354	-	-0,042	2,265	1,87
DC D1-C2_pos	2372,375	-	-0,037	2,265	1,87
DC E1-D1_neg	5059,862	-	1,258	2,265	55,72
DC E1-D1_pos	5060,247	-	-1,258	2,265	55,72
DC F1-E1_neg	447,578	-	-0,029	1,962	1,46
DC F1-E1_pos	447,578	-	0,029	1,962	1,46