Heywood BESS

Modelling report - aggregation methodology

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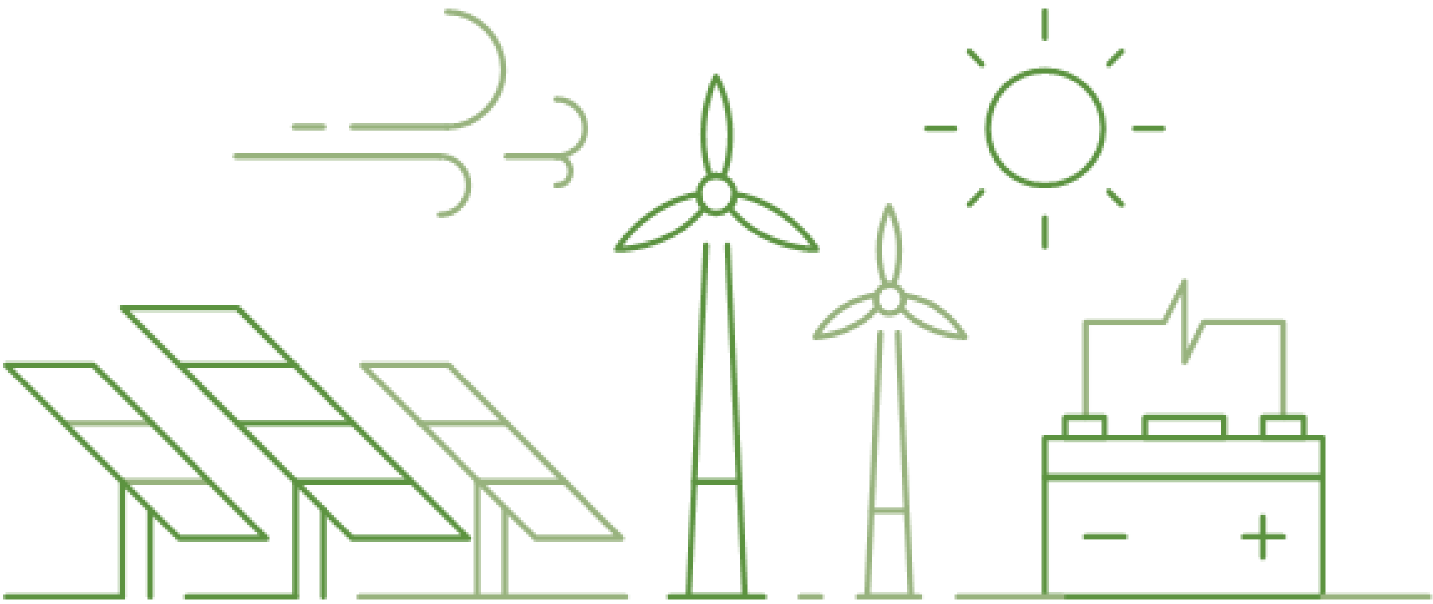

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Contents

Revision History

Table 1: Revision history

Rev.	Date	Prepared By	Reviewed By	Description
1-0-0	24/07/2025	Justin Nieuwhof	Luke Hyett	First release

This document uses *Semantic Versioning for Documents* for revision numbering.

Given a version number *MAJOR-MINOR-FIX*, the

- *MAJOR* is incremented when the document has undergone significant changes
- *MINOR* is incremented when new information has been added to the document or information has been removed from the document, and
- *FIX* is incremented when minor changes are made (e.g. fixing typos)

Where appropriate, several revisions may be represented in one table entry with all notable changes described in the *Description* column.

1. Introduction

This report is intended to summarise the work completed as part of the development of SMIB models for Heywood BESS R0 in PSCAD and PSSE. As such, this report will:

- Describe the input data used to model the BESS.
- Describe the methodology used to create an aggregated or lumped model.
- Assess the variation between the lumped models (PSCAD and PSSE) and the disaggregated model (PowerFactory) with respect to the losses in individual elements in each model.

2. Project overview

The Heywood Battery Energy Storage System (HEYWOODBESS) is a $\pm 285MW/1140MWh$ Battery Energy Storage Project, is located 5 km from the town of Heywood and 300 km west of Melbourne in Victoria as shown in Figure 2.1. The project is expected to connect directly to the existing 275 kV Heywood terminal station via a single high voltage cable.

HEYWOODBESS will include 92 SMA Sunny Central 4.6 MVA (SCS 4600 UP-S) converters which will be connected to two 275/33/33kV, 160MVA three winding transformers through a 33kV reticulation system. Each converter will have a dedicated 33/0.69kV, 4.6 MVA step up transformer.

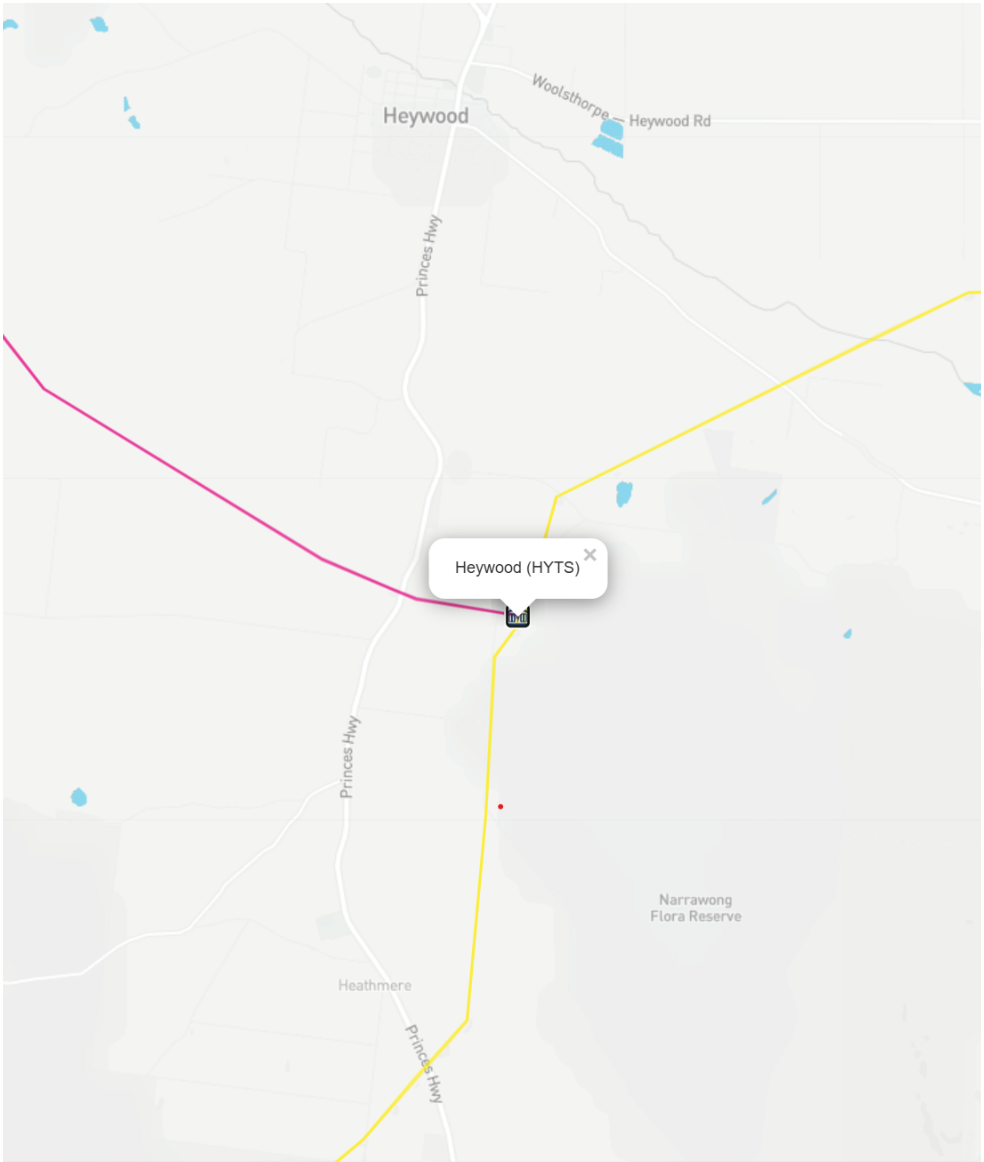

Figure 2.1: Project location

3. Input data

3.1 Grid transformers

This project is at R0 stage, and therefore design parameters for equipment are not yet final. Early stage design works have been used to derive parameters for use in power system models. The two 275/33/33 kV grid transformers have been modelled in all power system models used, with no aggregation. The following parameters, as entered into the PSCAD model in Table 3.1, apply to the main grid transformers.

Table 3.1: Grid transformer parameters

Parameter	Value
3 Phase Transformer MVA	160/80/80 [MVA]
Positive Sequence Leakage Reactance (#1-#2)	0.25 [pu] on 160 MVA rating
Positive Sequence Leakage Reactance (#1-#3)	0.5 [pu] on 160 MVA rating
Positive Sequence Leakage Reactance (#2-#3)	0.25 [pu] on 160 MVA rating
Copper Losses (#1-#2)	0.0055436 [pu]
Copper Losses (#1-#3)	0.0110872 [pu]
Copper Losses (#2-#3)	0.0055436 [pu]
Winding 1 Line to Line Voltage (RMS) (V1)	33.0 [kV]
Winding 2 Line to Line Voltage (RMS) (V2)	275.0 [kV]
Winding 3 Line to Line Voltage (RMS) (V3)	33.0 [kV]

3.2 Medium voltage transformers

Preliminary input parameters for the 4.6 MVA medium voltage converter transformers were provided by BEE as part of their initial design. These parameters align with the range of allowed impedances specified in SMA's Grid Modelling Guidelines for converter transformers. Parameters for an individual transformer, as entered into PSCAD, before scaling was applied, is shown in Table 3.2.

Scaling in PSCAD was applied via a current scaling element, with 4 groups of 23 transformers modelled. In PSSE, scaling was applied manually to the MVA base of the transformer for aggregation purposes, and to non per unit parameters, such as copper losses.

Table 3.2: Converter transformer parameters

Parameter	Value
Transformer Name (Name)	Unit TX
3 Phase Transformer MVA (Tmva)	4.6
Winding #1 Type	Wye
Winding #2 Type	Delta
Delta Lags or Leads Y (Lead)	Lags
Positive sequence leakage reactance (Xl)	0.0756 [pu]
No load losses (NLL)	0.0016 [pu]
Copper losses (CuL)	0.0075 [pu]
Tap changer on winding (Tap)	1
Winding 1 Line to Line voltage (RMS) (V1)	0.69
Winding 2 Line to Line voltage (RMS) (V2)	33

3.3 MV reticulation

The cable lengths and cable types for the BESS medium voltage reticulation network were aggregated from the input cable schedule.[1] The cable schedule was directly replicated in the BESS PowerFactory model also provided as an input to the grid studies by the electrical design consultant.

A visual representation of the preliminary electrical arrangement of the BESS has been provided in Figure 3.1 below, which shows the layout of 33 kV switchboards 1 and 2, which connect to the two 33 kV windings of one of the grid transformers. Switchboards 3 and 4, not shown here, have a similar configuration.

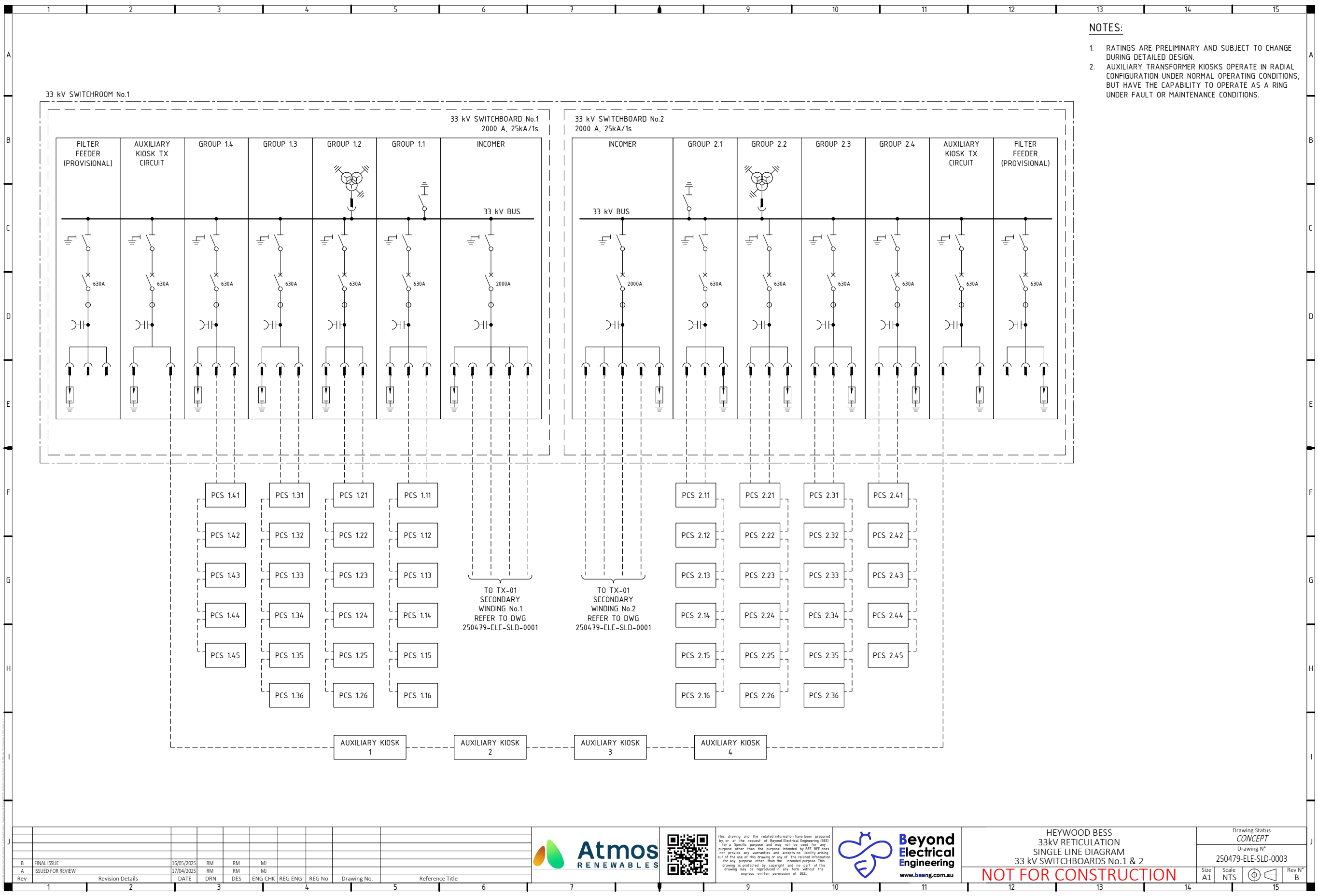

Figure 3.1: MV single line diagram - switchboard 1 and 2

4. Aggregation methodology

4.1 Aggregation of each feeder

The lumped model of the BESS was developed with the inputs provided in section 3 and in conjunction with the methodology outlined in the NREL paper ”Equivalencing the Collector System of a Large Wind Power Plant”.[2].

This technical paper outlines that each daisy-chained feeder (a) has an equivalent representation as pictured in (b).

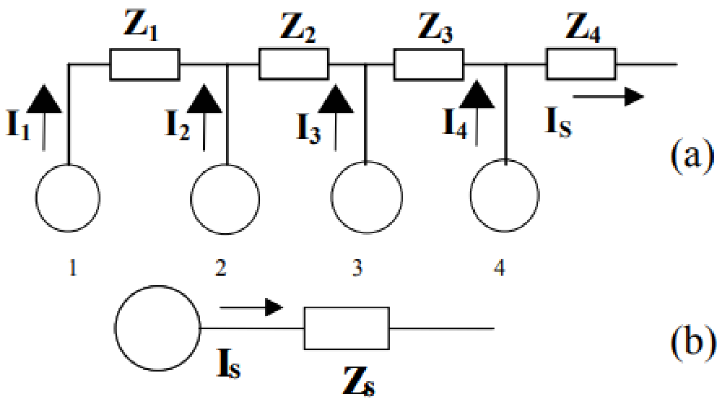

Figure 4.1: Feeder equivalent circuit

Defining this equivalent circuit allows the total impedance for the feeder to be written as follows.

$$Z_s = \frac{\sum_{m=1}^{n} m^2 Z_m}{n^2} \tag{4.1}$$

where Z_m represents the individual series impedances.

This method of impedance aggregation was applied in calculating equivalent positive and zero sequence resistance, reactance and susceptance parameters for each feeder.

4.2 Aggregation up to the 33kV bus

After calculating the aggregated impedance for each feeder, an equivalent circuit of each 33kV bus can be represented as per the below Figure 4.2.

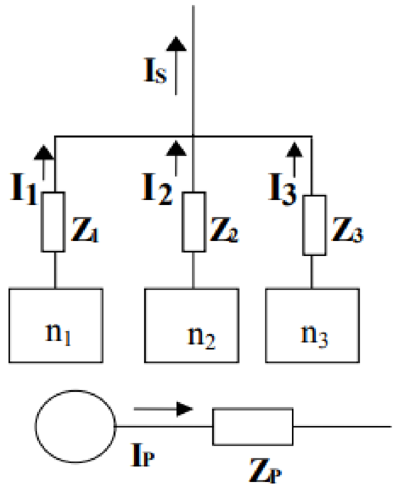

Figure 4.2: 33kV bus equivalent circuit

Defining this equivalent circuit allows the total impedance of each 33kV bus to be written as follows

$$Z_p = \frac{\sum_{m=1}^{n} n_m^2 Z_m}{[\sum_{m=1}^{n} n_m]^2} \tag{4.2}$$

where Zm represents the equivalent impedance of the individual parallel groups.

4.3 Aggregation up to each main transformer

Once reticulation impedances were aggregated up to each 33kV bus (as per Section 4.2), these were applied to two impedance elements in PSCAD and PSSE models. This results in the formulation of the aggregated or lumped impedance between the MV windings of the 3 winding grid transformer and the aggregated unit transformers.

This impedance was then utilised in preparing the plants PSCAD and PSSE Single Machine, Infinite Bus (SMIB) models.

5. Model benchmarking

5.1 Powerfactory model

The PowerFactory model for Heywood BESS is shown in Figures 5.1 and 5.2 below.

The PowerFactory model was initially developed by BEE based on their preliminary design. It was modified by Grid-Link to incorporate AusNet's estimated parameters for the 1.4 km, 275 kV high-voltage cable between the Heywood terminal station and the substation.

Figure 5.2 shows 33 kV switchboard 1 - which connects to feeders 1.1-1.4. Each feeder has either five or six 4.6 MVA power conversion stations, with 23x 4.6 MVA power conversion stations in total.

Similarly, 33 kV switchboards 2-4 each have 23x 4.6 MVA power conversion stations connected via four feeders.

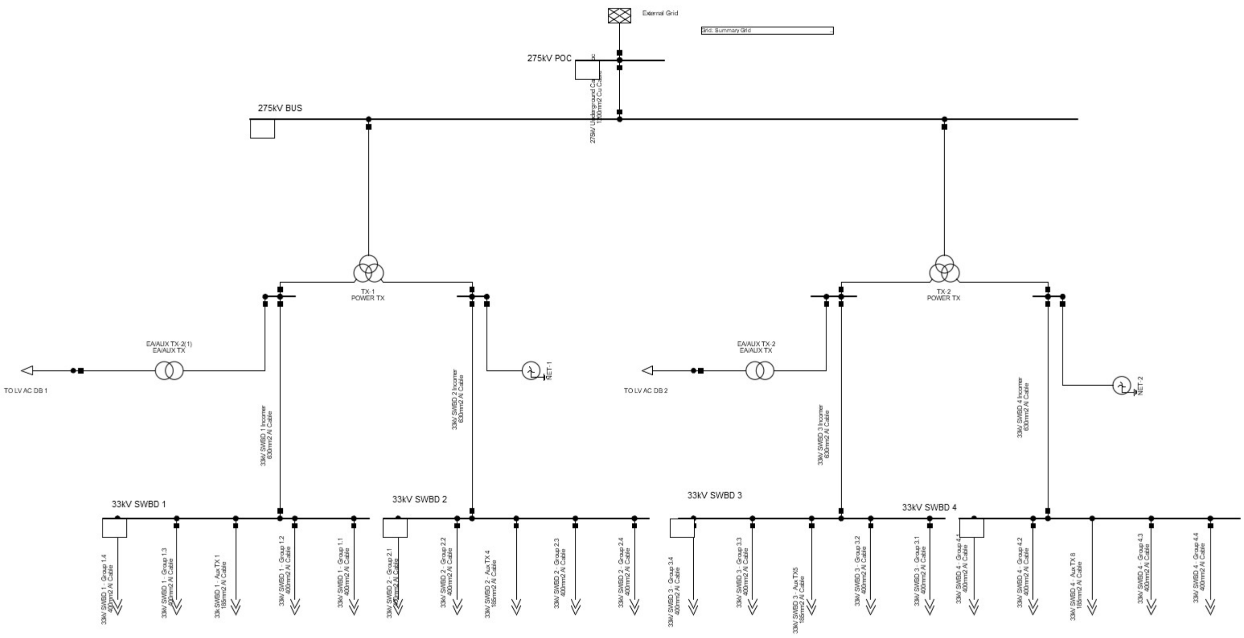

Figure 5.1: Powerfactory Model Grid Connection

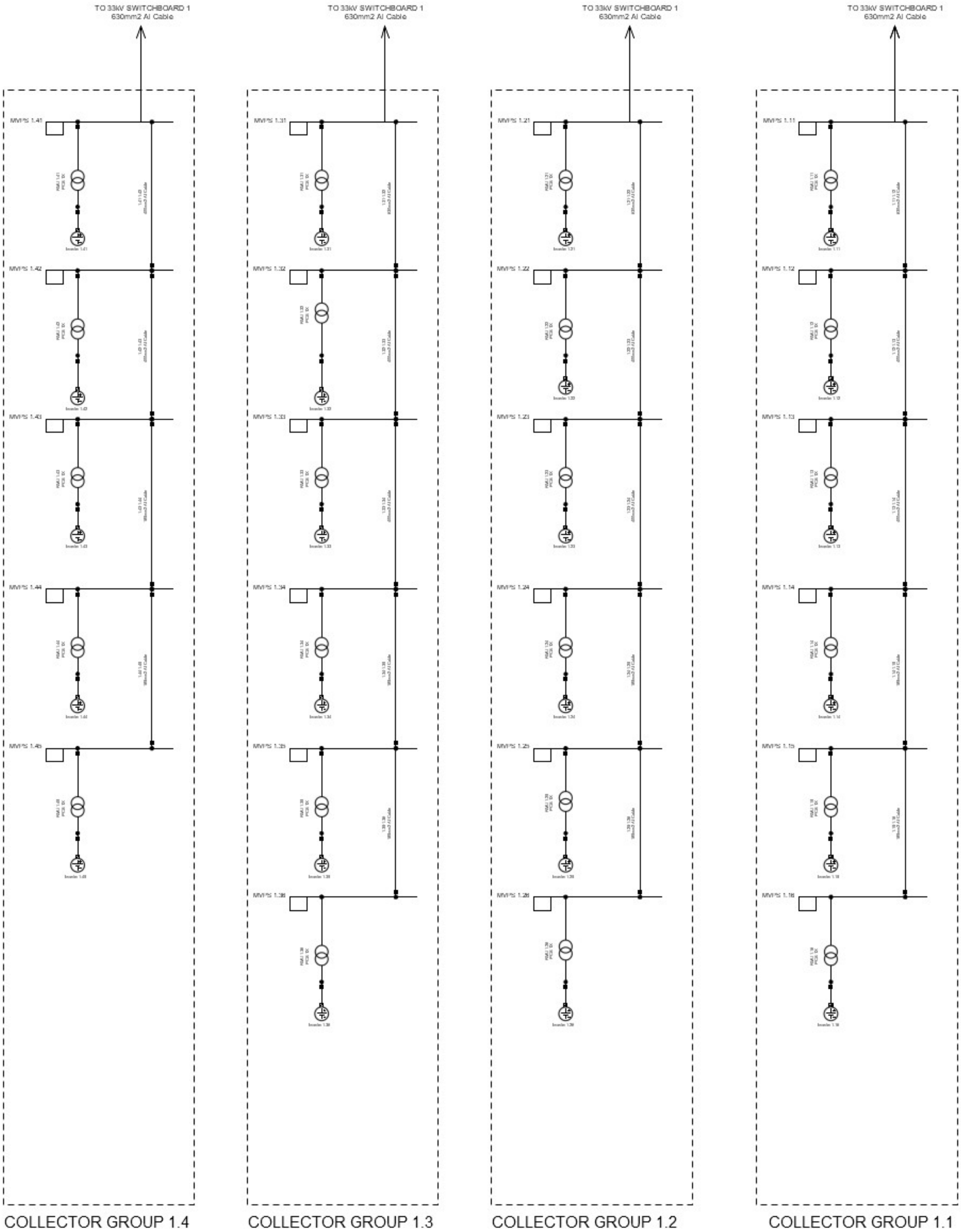

Figure 5.2: Powerfactory Model 33 kV Switchboard 1

5.2 PSCAD model

The aggregated PSCAD model for Heywood BESS is shown in Figure 5.3.

Each branch to the left of the grid transformers is composed of 23 equivalent SCS 4600 UP-S converters - each complete with its own 4.6 MVA medium voltage transformer.

The PI sections to the right of each main unit transformer incorporate the associated aggregated medium voltage impedance of the cable reticulation network. Each feeder is represented by two lumped impedance elements, which represent the daisy chained feeders, and the impedance between the 33 kV bus and the grid transformer respectively.

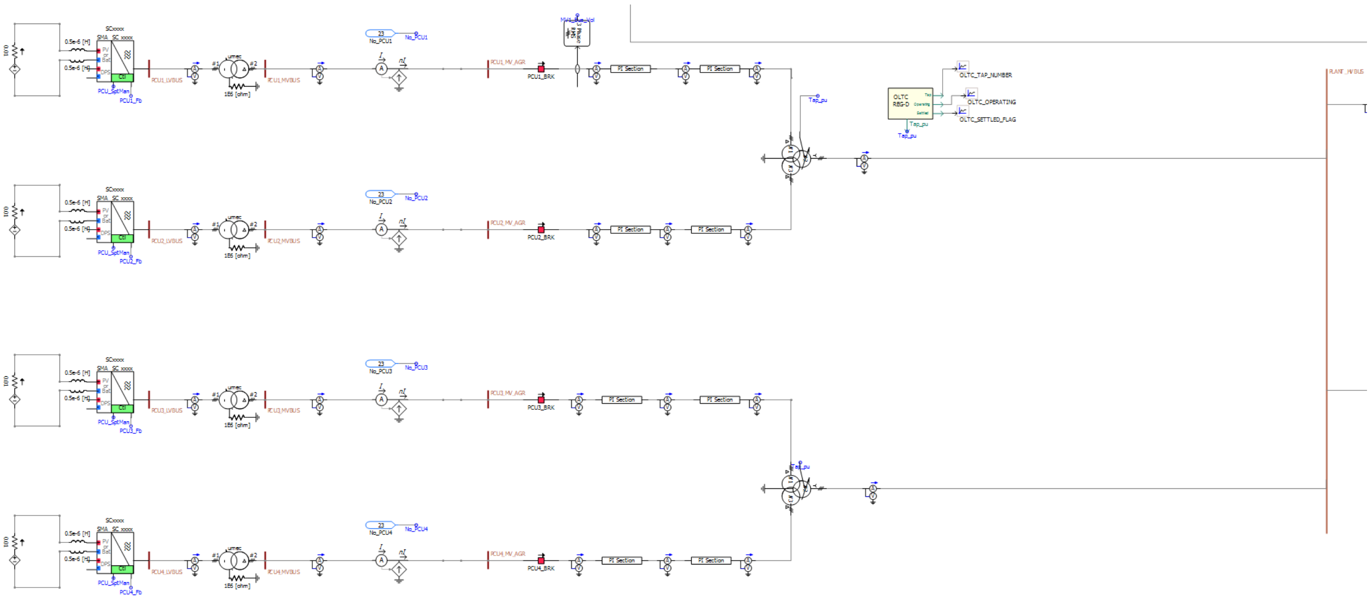

Figure 5.3: Aggregated PSCAD Model

5.3 PSSE model

The aggregated PSSE model for Heywood BESS is shown in Figure 5.4.

Each branch to the left of the grid transformers is composed of 23 equivalent SCS 4600 UP-S converters - each complete with its own 4.6 MVA medium voltage transformer, scaled up by a factor of 23.

The line sections to the right of each main unit transformer incorporate the associated aggregated medium voltage impedance of the cable reticulation network. As per PSCAD, each feeder is represented by two lumped impedance elements, which represent the daisy chained feeders, and the impedance between the 33 kV bus and the grid transformer respectively.

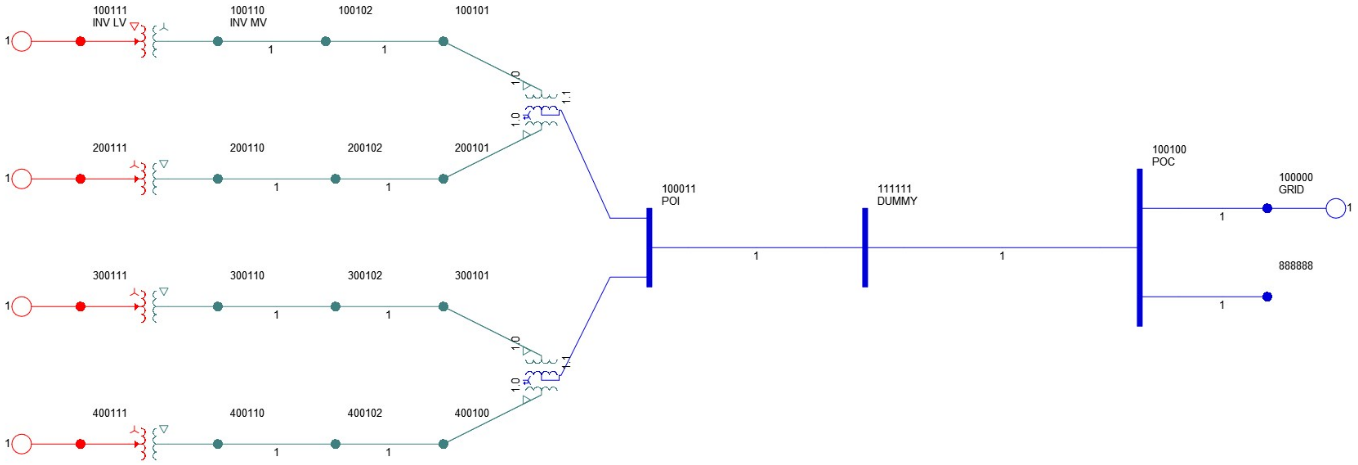

Figure 5.4: Aggregated PSSE Model

5.4 Analysis and results

To determine the validity of the aggregated model, the variation between each lumped model and the disaggregated PowerFactory model was compared. Specifically, the variation between active and reactive power losses across the 220/33/33kV transformers, the 33kV reticulation network and the 33/0.69kV transformers was compared between both models for the below operating points. These operating points represent the 'corner points' of the plant capability under steady state conditions and Vpoc is the expected normal operating voltage at the point of connection.

1. P_{poc} = 285 MW, Q_{poc} = 112.575 MVAr, V_{poc} = 1.06 pu
2. P_{poc} = 285 MW, Q_{poc} = -112.575 MVAr, V_{poc} = 1.06 pu
3. P_{poc} = 285 MW, Q_{poc} = 0.0MVAr, V_{poc} = 1.06 pu
4. P_{poc} = 0 MW, Q_{poc} = 112.575 MVAr, V_{poc} = 1.06 pu
5. P_{poc} = 0 MW, Q_{poc} = -112.575 MVAr, V_{poc} = 1.06 pu
6. P_{poc} = 0 MW, Q_{poc} = 0.0MVAr, V_{poc} = 1.06 pu
7. P_{poc} = -285 MW, Q_{poc} = 112.575 MVAr, V_{poc} = 1.06 pu
8. P_{poc} = -285 MW, Q_{poc} = -112.575 MVAr, V_{poc} = 1.06 pu
9. P_{poc} = -285 MW, Q_{poc} = 0.0MVAr, V_{poc} = 1.06 pu

A load flow was performed on the PowerFactory model platform at the above operating points to collect losses data for each component. The voltage, active power and reactive power at the point of connection was compared across all platforms to ensure the models were aligned. The PSCAD model was initialised as close as practicably possible to these setpoints and data was collected for a flat run to compare the two models. A load flow was also performed on the PSSE model at the setpoints described, to collect losses data.

Reticulation Losses

For each model, the difference between the aggregate active and reactive power leaving the High Voltage (HV) winding(s) of the converter transformers and the power flowing into the Low Voltage (LV) winding(s) of the grid transformers was determined to establish losses in the reticulation network.

1. Using the PowerFactory model the total active and reactive consumption across each cable segment in the 33kV reticulation network was extracted from the flexible data table and summated.

2. To get the same quantities in PSCAD, the active and reactive power flows were monitored on either side of the two lumped PI sections representing the 33kV reticulation network, which were then compared to derive the losses across all 33kV cables.

3. The losses were extracted from the PSSE model by subtracting the measured flow into the grid transformer from the flow out of the converter transformer. The values for each lumped section were then compared to derive the losses across all 33kV cables.

Losses in each model were then compared. The difference or delta between each models losses has been used as a point of comparison to establish that the aggregation methodology used for the MV reticulation network is fit for purpose.

The mismatch in active and reactive power through the Medium Voltage (MV) reticulation was compared between both models and summarised in 5.1 and 5.2.

- The largest absolute mismatch in active power was 0.009 MW across all scenarios.
- The largest absolute mismatch in reactive power was 0.058 MVAr across all scenarios.

Table 5.1: Reticulation results - Powerfactory vs PSCAD

			Powerfactory		PSCAD		Delta	
Test Number	P_POC (MW)	Q_POC (MVAr)	dP (MW)	dQ (MVAr)	dP (MW)	dQ (MVAr)	dP (MW)	dQ (MVAr)
1	285	112.575	0.076	-0.562	0.067	-0.532	0.009	-0.03
2	285	-112.575	0.067	-0.562	0.06	-0.519	0.006	-0.043
3	285	0	0.063	-0.56	0.055	-0.532	0.007	-0.028
4	0	112.575	0.009	-0.625	0.008	-0.595	0.001	-0.03
5	0	-112.575	0.01	-0.632	0.009	-0.589	0.001	-0.043
6	0	0	0	-0.649	0	-0.591	0	-0.058
7	-285	112.575	0.076	-0.555	0.067	-0.526	0.009	-0.03
8	-285	-112.575	0.067	-0.555	0.06	-0.512	0.006	-0.043
9	-285	0	0.061	-0.57	0.055	-0.526	0.006	-0.044

Table 5.2: Reticulation results - Powerfactory vs PSSE

			Powerfactory		PSSE		Delta	
Test Number	P_POC (MW)	Q_POC (MVAr)	dP (MW)	dQ (MVAr)	dP (MW)	dQ (MVAr)	dP (MW)	dQ (MVAr)
1	285	112.575	0.076	-0.562	0.069	-0.515	0.007	-0.047
2	285	-112.575	0.067	-0.562	0.06	-0.521	0.007	-0.041
3	285	0	0.063	-0.56	0.056	-0.525	0.007	-0.035
4	0	112.575	0.009	-0.625	0.008	-0.591	0.001	-0.034
5	0	-112.575	0.01	-0.632	0.009	-0.59	0.001	-0.042
6	0	0	0	-0.649	0	-0.597	0	-0.052
7	-285	112.575	0.076	-0.555	0.069	-0.508	0.007	-0.047
8	-285	-112.575	0.067	-0.555	0.06	-0.515	0.007	-0.04
9	-285	0	0.061	-0.57	0.056	-0.518	0.005	-0.052

To review the full output of results please refer to appendix A.

Transformer mismatch

The power flow entering the LV winding(s) of any given transformer was compared with the power flow leaving its HV winding.

1. Using the PowerFactory model the total active and reactive consumption across each transformer was extracted from the flexible data table and a summation was made for the main transformers and for the converter transformers independently.

2. To get the same quantities in PSCAD and PSSE, the active and reactive power flows were monitored on either side of the four aggregated medium voltage transformers as well as for the two main transformers.

Losses in each model were then compared. The difference or delta between each models losses has been used as a point of comparison to establish that the aggregation methodology used for the converter transformers is fit for purpose, and that the grid transformer parameters have been accurately translated between models.

These model discrepancies were then averaged across all transformers to represent the mismatch per transformer.

From the table below we make the following observations

- For the converter transformers we see that the largest total active power mismatch between models was 0.038 MW, while the largest total reactive power mismatch was 0.767 MVAr.
- For the grid transformers we see that the largest total active power mismatch between models was 0.023 MW, while the largest total reactive power mismatch between models was 0.965 MVAr.

Table 5.3: Converter transformer results - Powerfactory vs PSCAD

			Powerfactory		PSCAD		Delta	
Test Number	**P_POC (MW)**	**Q_POC (MVAr)**	**dP (MW)**	**dQ (MVAr)**	**dP (MW)**	**dQ (MVAr)**	**dP (MW)**	**dQ (MVAr)**
1	285	112.575	2.497	20.402	2.47	19.635	0.027	0.767
2	285	-112.575	2.227	17.944	2.229	17.616	-0.002	0.329
3	285	0	2.138	16.996	2.123	16.36	0.014	0.636
4	0	112.575	0.89	4.293	0.911	3.911	-0.021	0.382
5	0	-112.575	0.872	4.255	0.889	3.947	-0.016	0.308
6	0	0	0.667	2.044	0.667	1.677	0	0.367
7	-285	112.575	2.473	20.262	2.472	19.529	0.001	0.733
8	-285	-112.575	2.203	17.804	2.231	17.51	-0.028	0.293
9	-285	0	2.095	16.555	2.117	16.247	-0.022	0.308

Table 5.4: Unit transformer results - Powerfactory vs PSSE

			Powerfactory		PSSE		Delta	
Test Number	**P_POC (MW)**	**Q_POC (MVAr)**	**dP (MW)**	**dQ (MVAr)**	**dP (MW)**	**dQ (MVAr)**	**dP (MW)**	**dQ (MVAr)**
1	285	112.575	2.497	20.402	2.483	20.43	0.014	-0.028
2	285	-112.575	2.227	17.944	2.188	17.853	0.038	0.091
3	285	0	2.138	16.996	2.102	16.824	0.036	0.172
4	0	112.575	0.89	4.293	0.874	4.278	0.015	0.015
5	0	-112.575	0.872	4.255	0.836	4.242	0.037	0.013
6	0	0	0.667	2.044	0.63	2.022	0.037	0.021
7	-285	112.575	2.473	20.262	2.466	20.398	0.007	-0.136
8	-285	-112.575	2.203	17.804	2.169	17.79	0.035	0.014
9	-285	0	2.095	16.555	2.084	16.777	0.011	-0.222

Table 5.5: Grid transformer results - Powerfactory vs PSCAD

			Powerfactory		PSCAD		Delta	
Test Number	**P_POC (MW)**	**Q_POC (MVAr)**	**dP (MW)**	**dQ (MVAr)**	**dP (MW)**	**dQ (MVAr)**	**dP (MW)**	**dQ (MVAr)**
1	285	112.575	0.883	39.834	0.868	38.869	0.015	0.965
2	285	-112.575	0.772	34.787	0.774	34.794	-0.003	-0.007
3	285	0	0.724	32.638	0.712	31.895	0.012	0.743
4	0	112.575	0.108	4.893	0.102	4.708	0.006	0.185
5	0	-112.575	0.111	5.003	0.111	5.005	0	-0.002

Table 5.5: Grid transformer results - Powerfactory vs PSCAD

			Powerfactory		PSCAD		Delta	
Test Number	P_POC (MW)	Q_POC (MVAr)	dP (MW)	dQ (MVAr)	dP (MW)	dQ (MVAr)	dP (MW)	dQ (MVAr)
6	0	0	0	0.014	0	0.018	0	-0.005
7	-285	112.575	0.884	39.834	0.86	38.88	0.023	0.953
8	-285	-112.575	0.772	34.787	0.767	34.797	0.005	-0.009
9	-285	0	0.707	31.884	0.703	31.898	0.004	-0.014

Table 5.6: Grid transformer results - Powerfactory vs PSSE

			Powerfactory		PSSE		Delta	
Test Number	P_POC (MW)	Q_POC (MVAr)	dP (MW)	dQ (MVAr)	dP (MW)	dQ (MVAr)	dP (MW)	dQ (MVAr)
1	285	112.575	0.883	39.834	0.886	39.902	-0.003	-0.069
2	285	-112.575	0.772	34.787	0.768	34.576	0.003	0.211
3	285	0	0.724	32.638	0.716	32.225	0.008	0.413
4	0	112.575	0.108	4.893	0.106	4.767	0.003	0.126
5	0	-112.575	0.111	5.003	0.11	4.942	0.001	0.061
6	0	0	0	0.014	0	0.013	0	0
7	-285	112.575	0.884	39.834	0.888	39.97	-0.005	-0.136
8	-285	-112.575	0.772	34.787	0.768	34.577	0.003	0.21
9	-285	0	0.707	31.884	0.717	32.26	-0.01	-0.376

HV cable mismatch

No aggregation was required for the HV cable modelled at 275 kV between the plant and the point of connection at Heywood Terminal station. Differences in losses have been compared in the appendices of this report, but are not material and therefore have not been discussed in detail in this report.

To review the full output of results please refer to the appendix A.

5.5 Discussion

As outlined in section 5.4, the active and reactive power mismatch models for various operating points was not material. An extremely low mismatch was achieved for all elements, with the difference in losses between models equivalent to less than 0.5% of plant rating.

This suggests that the lumped models (PSCAD and PSSE) are good representations of the disaggregated model (PowerFactory), and that the aggregation methodology used is appropriate for accurate SMIB modelling.

Acronyms

References

[1] 250479-ELE-LST-0001_A - 33 kV Cable Schedule_Atmos

[2] Equivalencing the Collector System of a Large Wind Power Plant (2006)

6. Appendix A - PowerFactory vs PSCAD model benchmark results

All tabled PLOSS and PPOC values are in MWs, and all QLOSS and QPOC values are in MVArs.

Table 6.1: P_POC, Q_POC results pscad

Test Number	PPOC_PF	PPOC_-PSCAD	PPOC_DIFF	QPOC_PF	QPOC_-PSCAD	QPOC_DIFF
1	285	284.999	0.001	112.575	111.615	0.96
2	285	284.996	0.004	-112.575	-112.591	0.016
3	285	284.993	0.007	0	-0.969	0.969
4	0	-0.005	0.005	112.575	111.666	0.909
5	0	-0.007	0.007	-112.575	-112.599	0.024
6	0	-0.006	0.006	0	-0.898	0.898
7	-285	-285.012	0.012	112.575	111.743	0.832
8	-285	-285.007	0.007	-112.575	-112.595	0.02
9	-285	-285.004	0.005	0	-0.841	0.841

Table 6.2: V_POC results pscad (pu)

Test Number	VPOC_PF	VPOC_-PSCAD	VPOC_DIFF
1	1.06	1.06	0
2	1.06	1.06	0
3	1.06	1.06	0
4	1.06	1.06	0
5	1.06	1.06	0
6	1.06	1.06	0
7	1.06	1.06	0
8	1.06	1.06	0
9	1.06	1.06	0

Table 6.3: Grid TX results pscad

Test Number	GRID_TX_-PLOSS_PF	GRID_TX_-PLOSS_-PSCAD	GRID_TX_-PLOSS_-DIFF	GRID_TX_-QLOSS_PF	GRID_TX_-QLOSS_-PSCAD	GRID_TX_-QLOSS_-DIFF
1	0.883	0.868	0.015	39.834	38.869	0.965
2	0.772	0.774	-0.003	34.787	34.794	-0.007
3	0.724	0.712	0.012	32.638	31.895	0.743
4	0.108	0.102	0.006	4.893	4.708	0.185
5	0.111	0.111	0	5.003	5.005	-0.002
6	0	0	0	0.014	0.018	-0.005

Table 6.3: Grid TX results pscad

Test Number	GRID_TX_-PLOSS_PF	GRID_TX_-PLOSS_-PSCAD	GRID_TX_-PLOSS_-DIFF	GRID_TX_-QLOSS_PF	GRID_TX_-QLOSS_-PSCAD	GRID_TX_-QLOSS_-DIFF
7	0.884	0.86	0.023	39.834	38.88	0.953
8	0.772	0.767	0.005	34.787	34.797	-0.009
9	0.707	0.703	0.004	31.884	31.898	-0.014

Table 6.4: HV Cable results pscad

Test Number	HV_-CABLE_-PLOSS_PF	HV_-CABLE_-PLOSS_-PSCAD	HV_-CABLE_-PLOSS_-DIFF	HV_-CABLE_-QLOSS_PF	HV_-CABLE_-QLOSS_-PSCAD	HV_-CABLE_-QLOSS_-DIFF
1	0.048	0.042	0.006	-5.722	-5.725	0.002
2	0.049	0.042	0.007	-5.717	-5.719	0.002
3	0.042	0.036	0.006	-5.747	-5.748	0.002
4	0.006	0.005	0.001	-5.895	-5.898	0.002
5	0.007	0.006	0.001	-5.89	-5.891	0.002
6	0	0	0	-5.92	-5.921	0.002
7	0.048	0.041	0.007	-5.721	-5.723	0.002
8	0.049	0.042	0.007	-5.715	-5.717	0.002
9	0.042	0.036	0.006	-5.745	-5.746	0.002

Table 6.5: Aux TX results pscad

Test Number	AUX_TX_-PLOSS_PF	AUX_TX_-PLOSS_-PSCAD	AUX_TX_-PLOSS_-DIFF	AUX_TX_-QLOSS_PF	AUX_TX_-QLOSS_-PSCAD	AUX_TX_-QLOSS_-DIFF
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

Table 6.6: Inverter TX results pscad

Test Number	INV_TX_-PLOSS_PF	INV_TX_-PLOSS_-PSCAD	INV_TX_-PLOSS_-DIFF	INV_TX_-QLOSS_PF	INV_TX_-QLOSS_-PSCAD	INV_TX_-QLOSS_-DIFF
1	2.497	2.47	0.027	20.402	19.635	0.767
2	2.227	2.229	-0.002	17.944	17.616	0.329

Table 6.6: Inverter TX results pscad

Test Number	INV_TX_-PLOSS_PF	INV_TX_-PLOSS_-PSCAD	INV_TX_-PLOSS_-DIFF	INV_TX_-QLOSS_PF	INV_TX_-QLOSS_-PSCAD	INV_TX_-QLOSS_-DIFF
3	2.138	2.123	0.014	16.996	16.36	0.636
4	0.89	0.911	-0.021	4.293	3.911	0.382
5	0.872	0.889	-0.016	4.255	3.947	0.308
6	0.667	0.667	0	2.044	1.677	0.367
7	2.473	2.472	0.001	20.262	19.529	0.733
8	2.203	2.231	-0.028	17.804	17.51	0.293
9	2.095	2.117	-0.022	16.555	16.247	0.308

Table 6.7: Cable results pscad

Test Number	CABLE_-PLOSS_PF	CABLE_-PLOSS_-PSCAD	CABLE_-PLOSS_-DIFF	CABLE_-QLOSS_PF	CABLE_-QLOSS_-PSCAD	CABLE_-QLOSS_-DIFF
1	0.076	0.067	0.009	-0.562	-0.532	-0.03
2	0.067	0.06	0.006	-0.562	-0.519	-0.043
3	0.063	0.055	0.007	-0.56	-0.532	-0.028
4	0.009	0.008	0.001	-0.625	-0.595	-0.03
5	0.01	0.009	0.001	-0.632	-0.589	-0.043
6	0	0	0	-0.649	-0.591	-0.058
7	0.076	0.067	0.009	-0.555	-0.526	-0.03
8	0.067	0.06	0.006	-0.555	-0.512	-0.043
9	0.061	0.055	0.006	-0.57	-0.526	-0.044

Table 6.8: Shunt absorb results pscad

Test Number	SHUNT_-ABSORB_-PLOSS_PF	SHUNT_-ABSORB_-PLOSS_-PSCAD	SHUNT_-ABSORB_-PLOSS_-DIFF	SHUNT_-ABSORBE_-QLOSS_PF	SHUNT_-ABSORB_-QLOSS_-PSCAD	SHUNT_-ABSORB_-QLOSS_-DIFF
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

7. Appendix B - PowerFactory vs PSSE Model Benchmark Results

All tabled PLOSS and PPOC values are in MWs, and all QLOSS and QPOC values are in MVArs.

Table 7.1: P_POC, Q_POC results psse

Test Number	PPOC_PF	PPOC_-PSCAD	PPOC_DIFF	QPOC_PF	QPOC_-PSCAD	QPOC_DIFF
1	285	285.022	-0.022	112.575	112.09	0.485
2	285	284.967	0.033	-112.575	-112.333	-0.242
3	285	284.997	0.003	0	-0.196	0.196
4	0	0.014	-0.014	112.575	112.128	0.447
5	0	0.013	-0.013	-112.575	-112.039	-0.536
6	0	-0.007	0.007	0	0.119	-0.119
7	-285	-285.049	0.049	112.575	112.526	0.049
8	-285	-285.072	0.072	-112.575	-111.893	-0.682
9	-285	-285.087	0.087	0	0.263	-0.263

Table 7.2: V_POC results psse (pu)

Test Number	VPOC_PF	VPOC_-PSCAD	VPOC_DIFF
1	1.06	1.06	0
2	1.06	1.06	0
3	1.06	1.06	0
4	1.06	1.06	0
5	1.06	1.06	0
6	1.06	1.06	0
7	1.06	1.06	0
8	1.06	1.06	0
9	1.06	1.06	0

Table 7.3: Grid TX results psse

Test Number	GRID_TX_-PLOSS_PF	GRID_TX_-PLOSS_-PSCAD	GRID_TX_-PLOSS_-DIFF	GRID_TX_-QLOSS_PF	GRID_TX_-QLOSS_-PSCAD	GRID_TX_-QLOSS_-DIFF
1	0.883	0.886	-0.003	39.834	39.902	-0.069
2	0.772	0.768	0.003	34.787	34.576	0.211
3	0.724	0.716	0.008	32.638	32.225	0.413
4	0.108	0.106	0.003	4.893	4.767	0.126
5	0.111	0.11	0.001	5.003	4.942	0.061
6	0	0	0	0.014	0.013	0

Table 7.3: Grid TX results psse

Test Number	GRID_TX_-PLOSS_PF	GRID_TX_-PLOSS_-PSCAD	GRID_TX_-PLOSS_-DIFF	GRID_TX_-QLOSS_PF	GRID_TX_-QLOSS_-PSCAD	GRID_TX_-QLOSS_-DIFF
7	0.884	0.888	-0.005	39.834	39.97	-0.136
8	0.772	0.768	0.003	34.787	34.577	0.21
9	0.707	0.717	-0.01	31.884	32.26	-0.376

Table 7.4: HV Cable results psse

Test Number	HV_-CABLE_-PLOSS_PF	HV_-CABLE_-PLOSS_-PSCAD	HV_-CABLE_-PLOSS_-DIFF	HV_-CABLE_-QLOSS_PF	HV_-CABLE_-QLOSS_-PSCAD	HV_-CABLE_-QLOSS_-DIFF
1	0.048	0.041	0.006	-5.722	-5.729	0.006
2	0.049	0.042	0.007	-5.717	-5.717	0.001
3	0.042	0.036	0.006	-5.747	-5.75	0.003
4	0.006	0.005	0.001	-5.895	-5.9	0.005
5	0.007	0.006	0.001	-5.89	-5.889	-0.001
6	0	0	0	-5.92	-5.921	0.002
7	0.048	0.042	0.006	-5.721	-5.724	0.003
8	0.049	0.042	0.007	-5.715	-5.713	-0.002
9	0.042	0.036	0.006	-5.745	-5.745	0

Table 7.5: Aux TX results psse

Test Number	AUX_TX_-PLOSS_PF	AUX_TX_-PLOSS_-PSCAD	AUX_TX_-PLOSS_-DIFF	AUX_TX_-QLOSS_PF	AUX_TX_-QLOSS_-PSCAD	AUX_TX_-QLOSS_-DIFF
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

Table 7.6: Inverter TX results psse

Test Number	INV_TX_-PLOSS_PF	INV_TX_-PLOSS_-PSCAD	INV_TX_-PLOSS_-DIFF	INV_TX_-QLOSS_PF	INV_TX_-QLOSS_-PSCAD	INV_TX_-QLOSS_-DIFF
1	2.497	2.483	0.014	20.402	20.43	-0.028
2	2.227	2.188	0.038	17.944	17.853	0.091

Table 7.6: Inverter TX results psse

Test Number	INV_TX_-PLOSS_PF	INV_TX_-PLOSS_-PSCAD	INV_TX_-PLOSS_-DIFF	INV_TX_-QLOSS_PF	INV_TX_-QLOSS_-PSCAD	INV_TX_-QLOSS_-DIFF
3	2.138	2.102	0.036	16.996	16.824	0.172
4	0.89	0.874	0.015	4.293	4.278	0.015
5	0.872	0.836	0.037	4.255	4.242	0.013
6	0.667	0.63	0.037	2.044	2.022	0.021
7	2.473	2.466	0.007	20.262	20.398	-0.136
8	2.203	2.169	0.035	17.804	17.79	0.014
9	2.095	2.084	0.011	16.555	16.777	-0.222

Table 7.7: Cable results psse

Test Number	CABLE_-PLOSS_PF	CABLE_-PLOSS_-PSCAD	CABLE_-PLOSS_-DIFF	CABLE_-QLOSS_PF	CABLE_-QLOSS_-PSCAD	CABLE_-QLOSS_-DIFF
1	0.076	0.069	0.007	-0.562	-0.515	-0.047
2	0.067	0.06	0.007	-0.562	-0.521	-0.041
3	0.063	0.056	0.007	-0.56	-0.525	-0.035
4	0.009	0.008	0.001	-0.625	-0.591	-0.034
5	0.01	0.009	0.001	-0.632	-0.59	-0.042
6	0	0	0	-0.649	-0.597	-0.052
7	0.076	0.069	0.007	-0.555	-0.508	-0.047
8	0.067	0.06	0.007	-0.555	-0.515	-0.04
9	0.061	0.056	0.005	-0.57	-0.518	-0.052

Table 7.8: Shunt absorb results psse

Test Number	SHUNT_-ABSORB_-PLOSS_PF	SHUNT_-ABSORB_-PLOSS_-PSCAD	SHUNT_-ABSORB_-PLOSS_-DIFF	SHUNT_-ABSORBE_-QLOSS_PF	SHUNT_-ABSORB_-QLOSS_-PSCAD	SHUNT_-ABSORB_-QLOSS_-DIFF
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

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