APD ENGINEERING

NHILL RENEWABLE ENERGY FACILITY STEADY STATE CONNECTION STUDIES

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REVISION HISTORY

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EXECUTIVE SUMMARY

Vibe Energy Pty Ltd (Vibe Energy) has engaged APD Engineering (APD) to perform steady state studies of the Nhill Renewable Energy Facility (NREF) which is connecting into the Powercor Australia Ltd (Powercor) network from the 22kV Nhill substation. The NREF will contain two 2.475MVA SMA SC2500-EV inverters, with a rated capacity of 4.7MW. The NREF will supply a 2MW of load (hydrogen electrolyser), with 300kVA auxiliary supply.

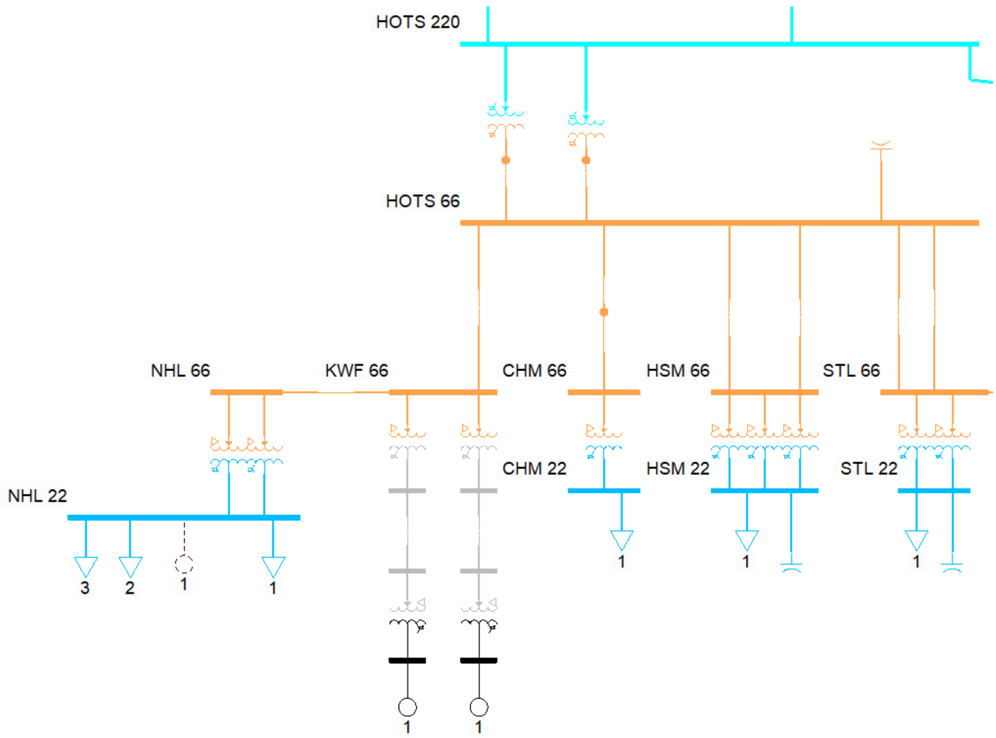

Figure 1 Nhill Renewable Energy Facility (NREF) and surrounding substations

From the network studies, the NREF will not breach any thermal or fault level limits in the network.

The nearby Kiata Wind Farm (KWF) provides important voltage support to the network around the NHL substation. While the KWF is out of service and the load at the NHL substation is high, the voltage and thermal requirements are still met, with the steady state voltages being lower in the high load case and higher in the low load case.

The studies show that no further network augmentation is required in order to satisfy any thermal or voltage limitations in the network.

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF FIGURES

ABBREVIATIONS

ABBREVIATION	DESCRIPTION
APD	Alliance Power and Data PTY. LTD. T/A APD Engineering
ASCC	Automatic Sequencing Fault Calculation
KWF	Kiata Wind Farm
NREF	Nhill Renewable Energy Facility
PSS/E	Power System Simulator for Engineering

1. INTRODUCTION

Vibe Energy Pty Ltd (Vibe Energy) has engaged APD Engineering (APD) to perform steady state studies of the Nhill Renewable Energy Facility (NREF) which is connecting into the Powercor Australia Ltd (Powercor) network from the 22kV Nhill substation. The NREF contains two SMA SC-2500-EV inverter (rated at 4.95MVA), a hydrogen electrolyser (2MW) and 300kVA auxiliary load. Figure 2 displays the NREF (contained within the box) and the surrounding network.

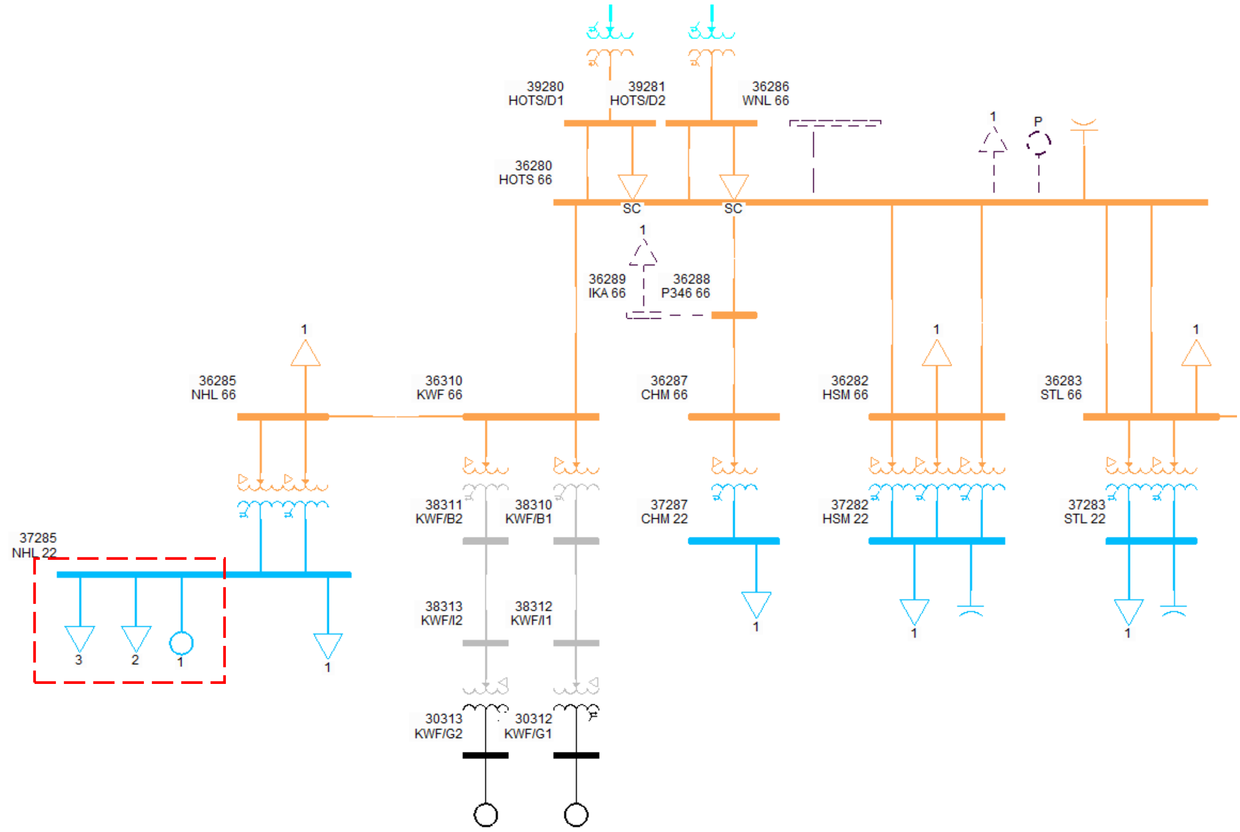

Figure 2: SLD of the network around Nhill Renewable Energy Facility

The Nhill substation connects to the Horsham Terminal Station via a 93km 66kV powerline. The Kiata Wind Farm (KWF) taps into this line and provides voltage support for the Nhill substation. The Horsham substation connects into the 220kV network, as well as many other 66/22kV substations.

2. MODELLING

2.1. SIMULATION TOOLS

The steady state analysis was performed in Siemens PTI PSS/E V34.2.0 power system analysis software.

2.2. NETWORK MODEL AND STUDY SCENARIOS

Powercor supplied the following case for the purposes of these steady state studies. All study base cases were created from this base case.

- R0-CP PAL 2018 (Proponent model).sav

2.2.1. BASE CASES SETUP

The steady state studies were conducted on network scenarios advised by Powercor [1]. The following changes were applied to Powercor's base case to create the various scenarios:

- Loads and capacitor banks at the NHL, HSM, CHM, STL, ART and BAN 22kV substations were modified to create high and low base cases
  - In the high load case, the NREF was set to maximum load (2MW hydrogen electrolyser + 300kVA auxiliary load), with no generation
  - In the low load case, the NREF was set to minimum load (0MW hydrogen electrolyser + 0kVA auxiliary load), with the PV generating at the maximum level (4.7MW)
- The Kiata WF and Challicum Hills WF were enabled in both cases, with the VCS set according to the RUGs
- For the high and low load cases, the following KWF configurations were considered:
  - KWF in service at maximum output
  - KWF in service, only providing reactive support
  - KWF out of service

The six scenarios considered for the studies are summarised in Table 1, with the single line diagrams of the network configurations shown in APPENDIX B.

Table 1 Thermal overload and voltage level study cases

Scenario	NHL Zone Substation Load	NREF Load	NREF Generation	KWF Generation
1	Maximum Load	Maximum Load	No Gen	Full Gen
2	Maximum Load	Maximum Load	No Gen	In Service, No Gen
3	Maximum Load	Maximum Load	No Gen	Disconnected
4	Minimum Load	Minimum Load	Maximum Gen	Full Gen
5	Minimum Load	Minimum Load	Maximum Gen	In Service, No Gen
6	Minimum Load	Minimum Load	Maximum Gen	Disconnected

2.2.2. NHILL RENEWABLE ENERGY FACILITY PARAMETERS

The NREF contains as a range of equipment that has been implemented within the model. The hydrogen electrolyser and auxiliary supply load parameters are displayed in Table 2.

Table 2 NREF loads

Parameter	Hydrogen Electrolyser	Auxiliary Supply	Unit
Power Rating	2.0	0.3	MW/MVA
Pload	2.0	0.27	MW
Qload	0.0	0.1308	Mvar
Power factor	1.0	0.9 absorbing	-

The SMA inverters used for the NREF will be custom built and based on the SMA SC2500-EV units. The nameplate capacity of these inverters will be 2475kVA per unit. The full dynamic parameters and settings will be included in with a future SMIB package.

For the steady state studies the SMA PV Inverters are modelled as a generator in PSS/E, with parameters given in Table 3 and Table 4.

Table 3 SMA inverter [2]

Parameter	PV Inverter	Unit
Inverter Type and Number of Inverters	2 x SC2500-EV	-
Nominal AC voltage connection	22	kV
Power Rating (on MV side)	4.95	MVA
Power Rating (on MV side)	4.70	MW
Power Factor	0.95 absorbing	-

Table 4 NCSFCC function values [3]

Parameter	PV Inverter	Unit
Ik”	1.35 x I_N	-
Active Fault Current Contribution	0	pu
Reactive Fault Current Contribution	1.35	pu
Positive Sequence R	0.0	pu
Subtransient X	0.740741	pu

As the NREF is connected to the NHL 22kV bus for the steady state studies, the VRR target required recalculation based on the new load levels. The VRR settings were calculated for the high load cases (scenarios 1 – 3) and low load cases (scenarios 4 – 6) separately, as given in Table 5.

Table 5 VRR target for NHL substation

Case	P (mw)	Q (Mvar)	VRR (pu)	Vmax (pu)	Vmin (pu)	NHL taps
High Load	13.74	1.36	1.031	1.036	1.026	68
Low Load	-3.21	-0.08	0.993	0.998	0.988	68

2.3. POWERCOR LIMITS

Powercor have outlined several ratings and limits which must not be exceeded during the steady state studies. The required limits for the fault levels, thermal line ratings, power station ratings, and voltage fluctuation levels are given in Table 6 to Table 9.

Table 6 Fault level limits at relevant buses

Bus	Fault Level Limits (MVA)	Fault Level Limits (kA)
HOTS 66kV	2500	21.9
NHL 66kV	2500	21.9
NHL 22kV	250	13.1

Table 7 Thermal line ratings

66kV Line	Rating (A)
HOTS-KWF-NHL	380

Table 8 Station power ratings

Terminal Station	Nameplate & Reverse Power Rating (system normal), MVA	Nameplate & Reverse Power Rating (N-1), MVA
HOTS	200	100
NHL	20	10

Table 9 Voltage fluctuation limits

Bus Voltage (kV)	Fluctuation Limit
66	3%
22	5%

3. STEADY STATE ASSESSMENT

3.1. VOLTAGE LEVELS AND THERMAL OVERLOADS

A range of test scenarios were used for investigating voltage levels and thermals overloads in the network surrounding NREF, as described in Table 1 of Section 2.2.1. During these tests, bus voltages were recorded at the 22kV and 66kV NHL substation buses as well as the 66kV KWF bus. The voltages measured during the different scenarios are shown in Table 10. Based on the VRR/LDC settings, the target voltage for the 66/22kV transformers used during the tests was 1.031pu for the high load case, and 0.993pu for the low load case.

Further measurements of current, real power and reactive power were recorded at the HOTS-KWF and KWF-NHL lines for each scenario, as shown in Table 11. Measurements of apparent, real and reactive power were also taken at the NHL and HOTS transformers, as provided in Table 11.

Table 10 Bus voltages observed for various scenarios

Scenario	NHL 22kV Bus Voltage (pu)	NHL 66kV Bus Voltage (pu)	KWF 66kV Bus Voltage (pu)
1	1.034	1.012	1.030
2	1.031	1.005	1.022
3	1.029	0.901	0.920
4	1.004	1.053	1.050
5	0.994	1.033	1.030
6	1.003	1.052	1.049

Table 10 shows that the voltages at the NHL 22kV bus remained within ±1.8% of the transformer target voltage for all scenarios tested. In scenario 3, the KWF was disconnected from the network, with minimum generation and maximum load from the NREF. This resulted in lower voltage at the NHL and KWF 66kV buses (0.901pu and 0.920pu respectively), although the NHL transformers were able to set the voltage at the 22kV bus without reaching their limits.

The voltage at the KWF bus must be maintained below 1.053pu, else the KWF generation will be run back. The voltage at this bus is maintained at or below 1.05pu in all cases.

Table 11 Line and transformer loading

Units	Amps		MW		Mvar		MVA		MW		Mvar	
Scenario	HOTS-KWF	KWF-NHL	HOTS-KWF	KWF-NHL	HOTS-KWF	KWF-NHL	NHL TX	HOTS TX	NHL TX	HOTS TX	NHL TX	HOTS TX
1	159.9	120.7	-14.6	14.0	11.6	2.3	7.0	18.7	6.9	-14.6	1.1	11.6
2	165.4	121.4	16.1	14.0	-10.8	2.3	7.0	19.4	6.9	16.1	1.1	-10.8
3	133.1	135.3	15.4	14.0	2.5	2.4	7.0	15.6	6.9	15.4	1.1	2.5
4	304.6	26.6	-26.7	-3.2	23.5	-0.2	1.6	35.6	-1.6	-26.7	0.0	23.5
5	27.5	27.2	-3.1	-3.2	0.7	-0.2	1.6	3.2	-1.6	-3.1	0.0	0.7
6	31.3	26.6	-3.1	-3.2	-1.9	-0.2	1.6	3.6	-1.6	-3.1	0.0	-1.9

Table 11 shows the thermal loading throughout the network for the various scenarios. As the HOTS and NHL transformers are in parallel with identical loading, only one of each transformer pair is shown in the table. For all scenarios considered, the monitored branches and transformers remain within the specified limits. No thermal overloads are seen during these studies.

3.2. VOLTAGE LEVELS AND THERMAL OVERLOADS AFTER NREF TRIP

The studies conducted in Section 3.1 were repeated for a trip of the inverters or loads at the NREF, as shown in Figure 3. After the contingency was applied, the bus voltages observed were compared with those shown in Table 10 of Section 3.1, with the difference in voltage levels pre and post contingent shown in Table 12. Additional data from these tests (including current and power) is presented in APPENDIX A.

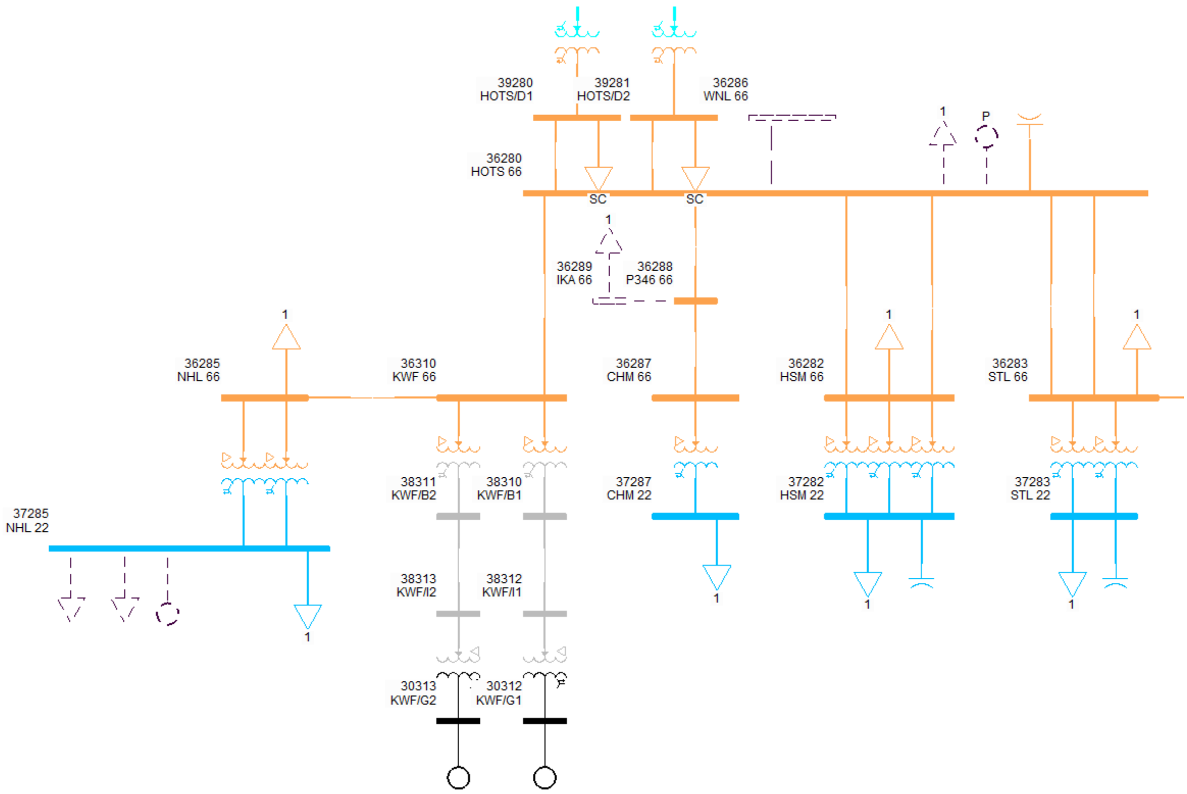

Figure 3 NREF trip for load flow studies

Table 12 Change in bus voltage when NREF has been tripped

Scenario	NHL 22kV Bus Voltage (pu)			NHL 66kV Bus Voltage (pu)			KWF 66kV Bus Voltage (pu)		
	Pre-trip (pu)	Post-trip (pu)	Diff (pu)	Pre-trip (pu)	Post-trip (pu)	Diff (pu)	Pre-trip (pu)	Post-trip (pu)	Diff (pu)
1	1.034	1.039	0.005	1.012	1.015	0.003	1.030	1.030	0.000
2	1.031	1.044	0.013	1.005	1.015	0.011	1.022	1.030	0.008
3	1.029	1.061	0.032	0.901	0.927	0.026	0.920	0.943	0.023
4	1.004	1.011	0.007	1.053	1.054	0.001	1.050	1.053	0.004
5	0.994	0.998	0.004	1.033	1.031	-0.003	1.030	1.030	0.000
6	1.003	0.994	-0.009	1.052	1.035	-0.017	1.049	1.035	-0.014

It can be observed that for all the voltage fluctuations remained within Powercor's specified ranges of 0.03pu and 0.05pu, for the 66kV and 22kV networks respectively.

3.3. FAULT LEVEL CURRENT

To assess the contribution to fault current on the connecting network, the three phase and phase to ground fault currents at specified network buses were calculated with and without the NREF in service. For the fault level studies, a 5MVA 22/0.6kV transformer with 5% impedance was modelled between the inverter generator and the NHL 22kV substation.

The maximum fault levels were calculated in PSS/E using the high load case, with all NREF generators online. The NREF inverters were modelled using the Non-Conventional Sources Fault Current Contribution (NCSFCC), with the ASCC method used to calculate the maximum fault levels at considered buses. The results from these studies are listed in Table 13 and Table 14.

Table 13 Maximum fault current summary

System Fault Location	Fault Levels without NHL		Fault Levels with NHL		NHL Contribution to System Faults	
	3ph (kA)	1ph-G (kA)	3ph (kA)	1ph-G (kA)	3ph (kA)	1ph-G (kA)
HOTS 66kV	6.21	7.81	6.23	7.83	0.02	0.02
KWF 66kV	1.20	0.61	1.26	0.62	0.06	0.01
NHL 66kV	0.99	0.51	1.04	0.52	0.05	0.01
NHL 22kV	2.04	2.78	2.21	2.97	0.17	0.19

Table 14 Maximum fault MVA summary

System Fault Location	Fault Levels without NHL		Fault Levels with NHL		NHL Contribution to System Faults	
	3ph (MVA)	1ph-G (MVA)	3ph (MVA)	1ph-G (MVA)	3ph (MVA)	1ph-G (MVA)
HOTS 66kV	710.1	892.6	712.7	894.9	2.6	2.3
KWF 66kV	137.2	69.6	143.7	71.1	6.5	1.5
NHL 66kV	112.7	57.7	119.4	59.3	6.7	1.6
NHL 22kV	77.5	105.8	84.2	113.1	6.7	7.3

Comparison of the results with and without the NREF in service shows that the maximum fault current contribution from the NREF when the lines are connected is 0.19kA (1-phase to ground fault at the NHL 22kV bus). The current limits from the Victorian Electricity Distribution Code are 21.9kA at 66kV and 13.1kA at 22kV, as shown in Table 6 of Section 2.3. As such, these limits were not reached or exceeded with the addition of the NREF.

The results also show that the maximum contribution of the NREF in MVA is 7.3MVA (1-phase to ground fault at the NHL 22kV bus). Considering the MVA fault level limits provided by Powercor [1] in Table 6 of Section 2.3, NREF will not cause these limits to be exceeded.

4. SUMMARY AND CONCLUSIONS

The studies show that the NREF does not breach any thermal or fault level limits in the network.

The nearby Kiata Wind Farm (KWF) provides important voltage support to the network around the NHL substation. While the KWF is out of service the voltage and thermal requirements are still met, with the steady state voltages being lower in the high load case and higher in the low load case.

The studies show that no further network augmentation is required in order to satisfy any thermal or voltage limitations in the network.

5. REFERENCES

[1] "System Data for Steady State Studies", System Data Pack, Powercor, 12 April 2019.

[2] "MVPS-S-AU Power Skid Australia Brochure 20180706", SMA, 2018

[3] "Short-circuit behaviour of SMA Sunny Central", SC 2750-EV, SMA, 2018.

APPENDIX A. CHANGE IN THERMAL LOADING FOR LOSS OF NREF

Table 15 Bus current differences after NREF generation has been tripped

Case	HOTS-KWF Current			KWF-NHL Current		
	Pre-trip (A)	Post-trip (A)	Diff (A)	Pre-trip (A)	Post-trip (A)	Diff (A)
1	159.9	180.9	21.0	120.7	100.8	-19.9
2	165.4	143.5	-21.9	121.4	101.1	-20.2
3	133.1	110.6	-22.5	135.3	112.4	-22.9
4	304.6	262.6	-42.1	26.6	19.8	-6.8
5	27.5	25.2	-2.3	27.2	19.9	-7.2
6	31.3	32.2	0.9	26.6	19.8	-6.8

Table 16 Bus real power differences after NREF generation has been tripped

Case	HOTS-KWF Real Power			KWF-NHL Real Power		
	Pre-trip (MW)	Post-trip (MW)	Diff (MW)	Pre-trip (MW)	Post-trip (MW)	Diff (MW)
1	-14.6	-16.4	-1.7	14.0	11.7	-2.3
2	16.1	13.3	-2.8	14.0	11.8	-2.2
3	15.4	12.9	-2.5	14.0	12.0	-2.1
4	-26.7	-23.8	2.9	-3.2	1.5	4.7
5	-3.1	1.5	4.7	-3.2	1.5	4.7
6	-3.1	1.6	4.7	-3.2	1.5	4.7

Table 17 Bus reactive power differences after NREF generation has been tripped

Case	HOTS-KWF Reactive Power			KWF-NHL Reactive Power		
	Pre-trip (Mvar)	Post-trip (Mvar)	Diff (Mvar)	Pre-trip (Mvar)	Post-trip (Mvar)	Diff (Mvar)
1	11.6	13.2	1.7	2.3	1.8	-0.5
2	-10.8	-10.2	0.6	2.3	1.8	-0.5
3	2.5	1.5	-1.1	2.4	1.9	-0.5
4	23.5	19.6	-4.0	-0.2	-1.8	-1.6
5	0.7	-2.5	-3.2	-0.2	-1.8	-1.6
6	-1.9	-3.4	-1.5	-0.2	-1.8	-1.6

The following tables represent flows through the NHL and HOTS transformers. For both substations, there are identical transformers in parallel. Only one transformer for each substation is listed in these tables, as both transformers had identical flows.

Table 18 transformer apparent power differences after NREF generation has been tripped

Case	NHL TX Apparent Power			HOTS TX Apparent Power		
	Pre-trip (MVA)	Post-trip (MVA)	Diff (MVA)	Pre-trip (MVA)	Post-trip (MVA)	Diff (MVA)
1	7.0	5.9	-1.1	18.7	21.1	2.4
2	7.0	5.9	-1.1	19.4	16.8	-2.6
3	7.0	6.0	-1.0	15.6	13.0	-2.6
4	1.6	1.1	-0.5	35.6	30.8	-4.8
5	1.6	1.1	-0.5	3.2	2.9	-0.3
6	1.6	1.1	-0.5	3.6	3.8	0.1

Table 19 Transformer real power differences after NREF generation has been tripped

Case	NHL TX Real Power			HOTS TX Real Power		
	Pre-trip (MW)	Post-trip (MW)	Diff (MW)	Pre-trip (MW)	Post-trip (MW)	Diff (MW)
1	6.9	5.8	-1.1	-14.6	-16.4	-1.7
2	6.9	5.8	-1.1	16.1	13.3	-2.8
3	6.9	5.9	-1.0	15.4	12.9	-2.5
4	-1.6	0.8	2.4	-26.7	-23.8	2.9
5	-1.6	0.7	2.4	-3.1	1.5	4.7
6	-1.6	0.7	2.3	-3.1	1.6	4.7

Table 20 Transformer power differences after NREF generation has been tripped

Case	NHL TX Reactive Power			HOTS TX Reactive Power		
	Pre-trip (Mvar)	Post-trip (Mvar)	Diff (Mvar)	Pre-trip (Mvar)	Post-trip (Mvar)	Diff (Mvar)
1	1.1	0.9	-0.2	11.6	13.2	1.7
2	1.1	0.9	-0.2	-10.8	-10.2	0.6
3	1.1	0.9	-0.2	2.5	1.5	-1.1
4	0.0	-0.8	-0.8	23.5	19.6	-4.0
5	0.0	-0.8	-0.8	0.7	-2.5	-3.2
6	0.0	-0.8	-0.8	-1.9	-3.4	-1.5

APPENDIX B. SINGLE LINE DIAGRAMS OF SCENARIOS

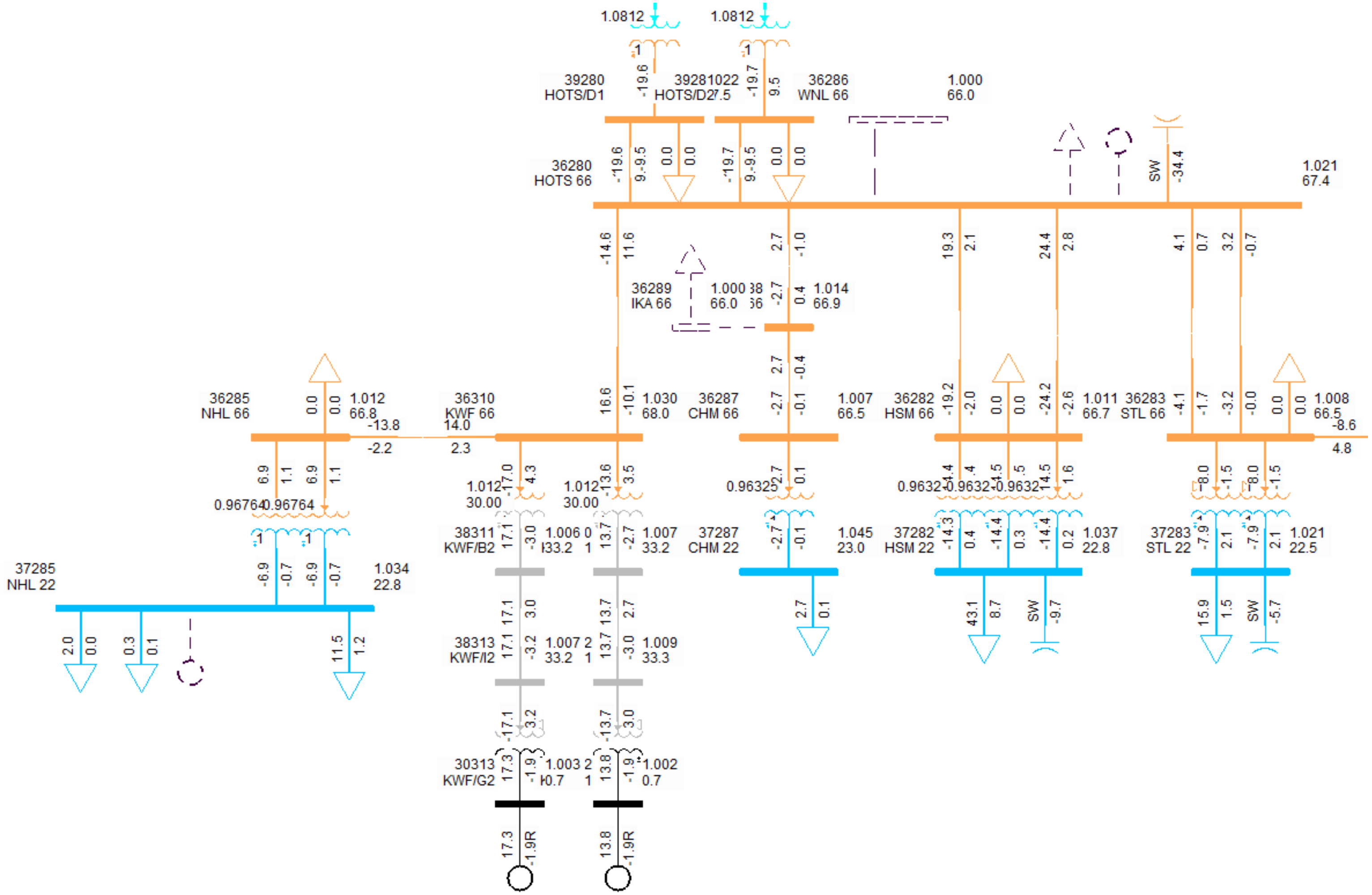

Figure 4 Scenario 1 – High network load, KWF maximum output, minimum NREF generation, maximum NREF load

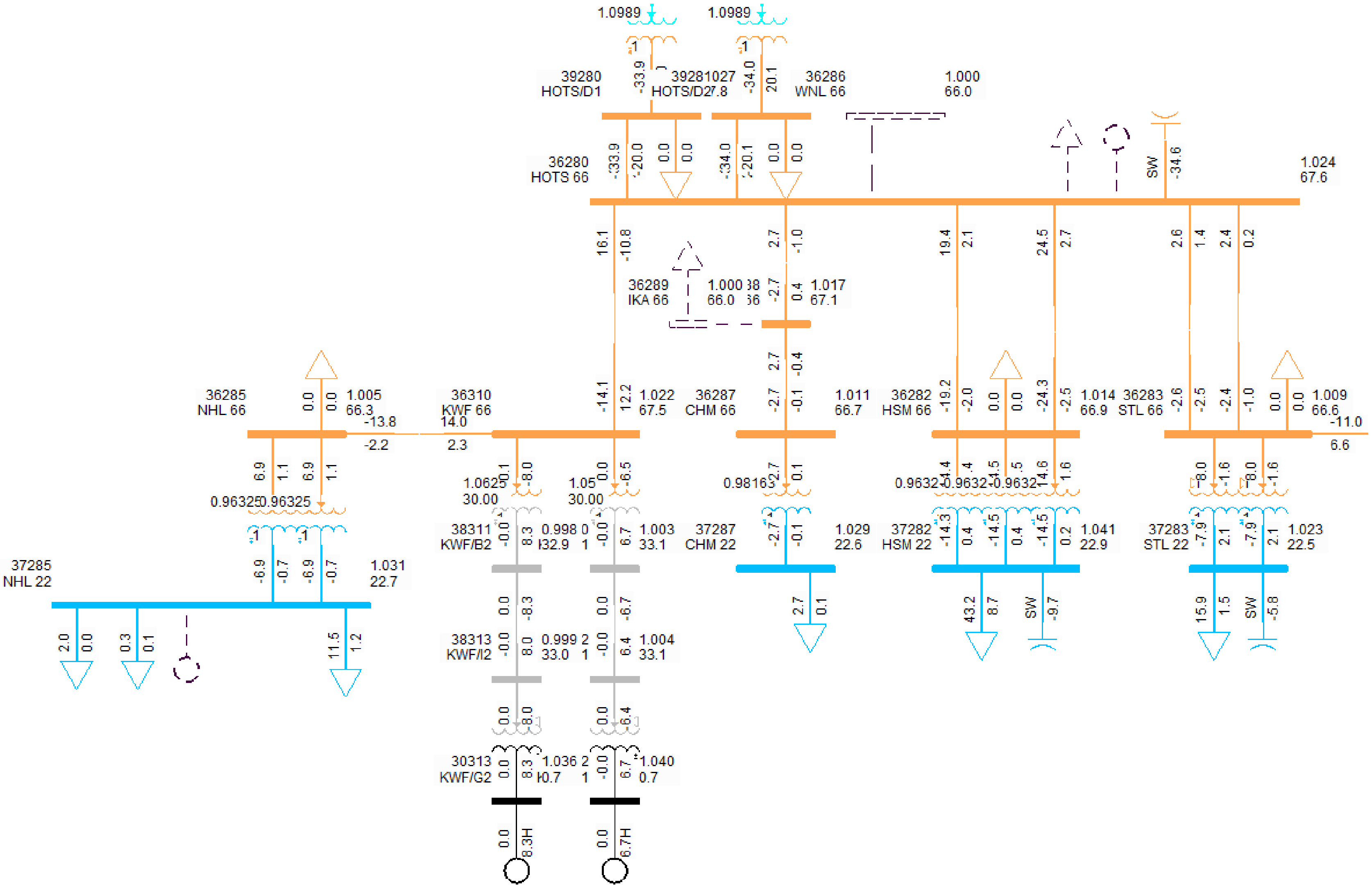

Figure 5 Scenario 2 – High network load, KWF reactive support only, minimum NREF generation, maximum NREF load

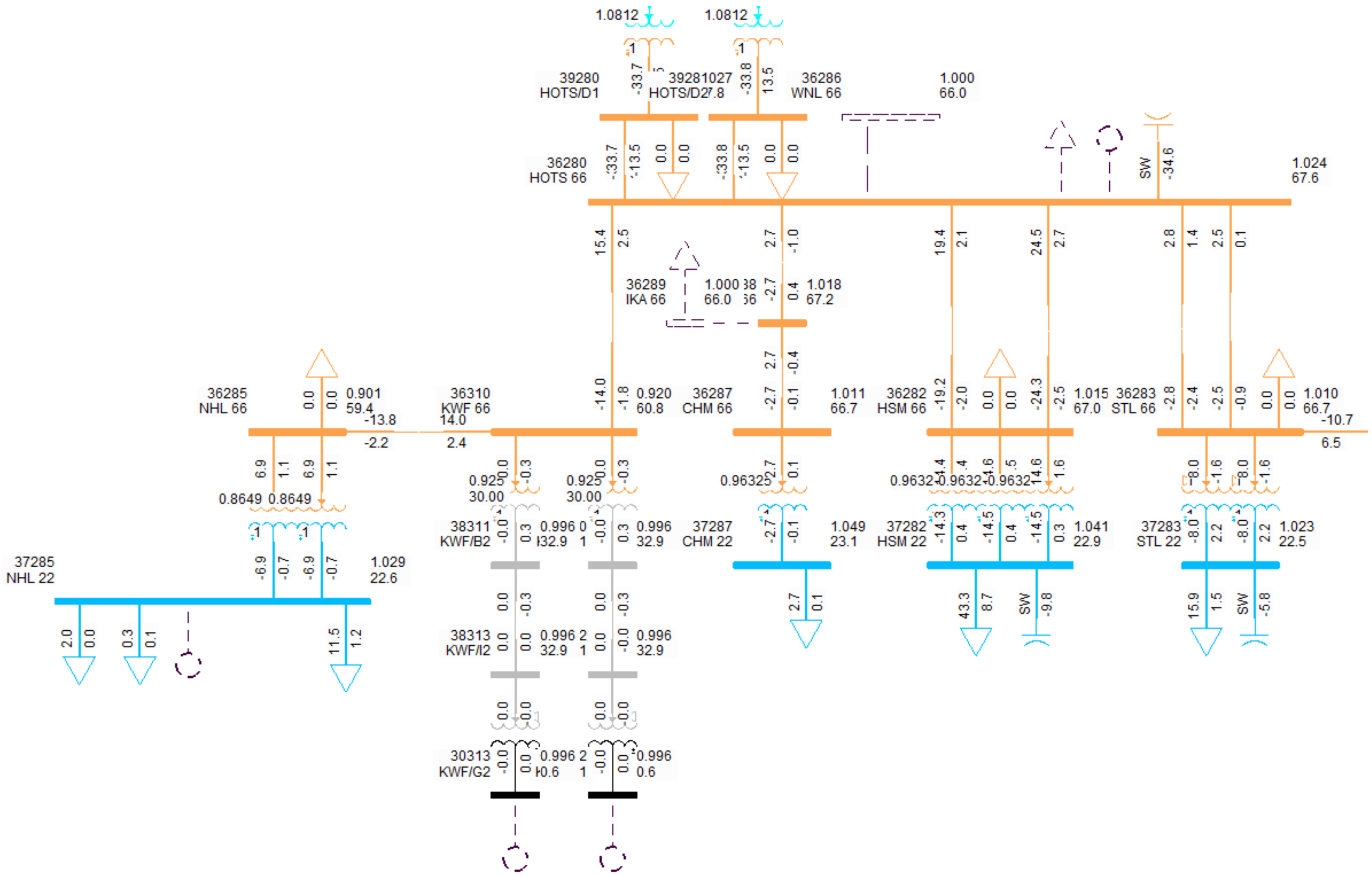

Figure 6 Scenario 3 – High network load, KWF offline, minimum NREF generation, maximum NREF load

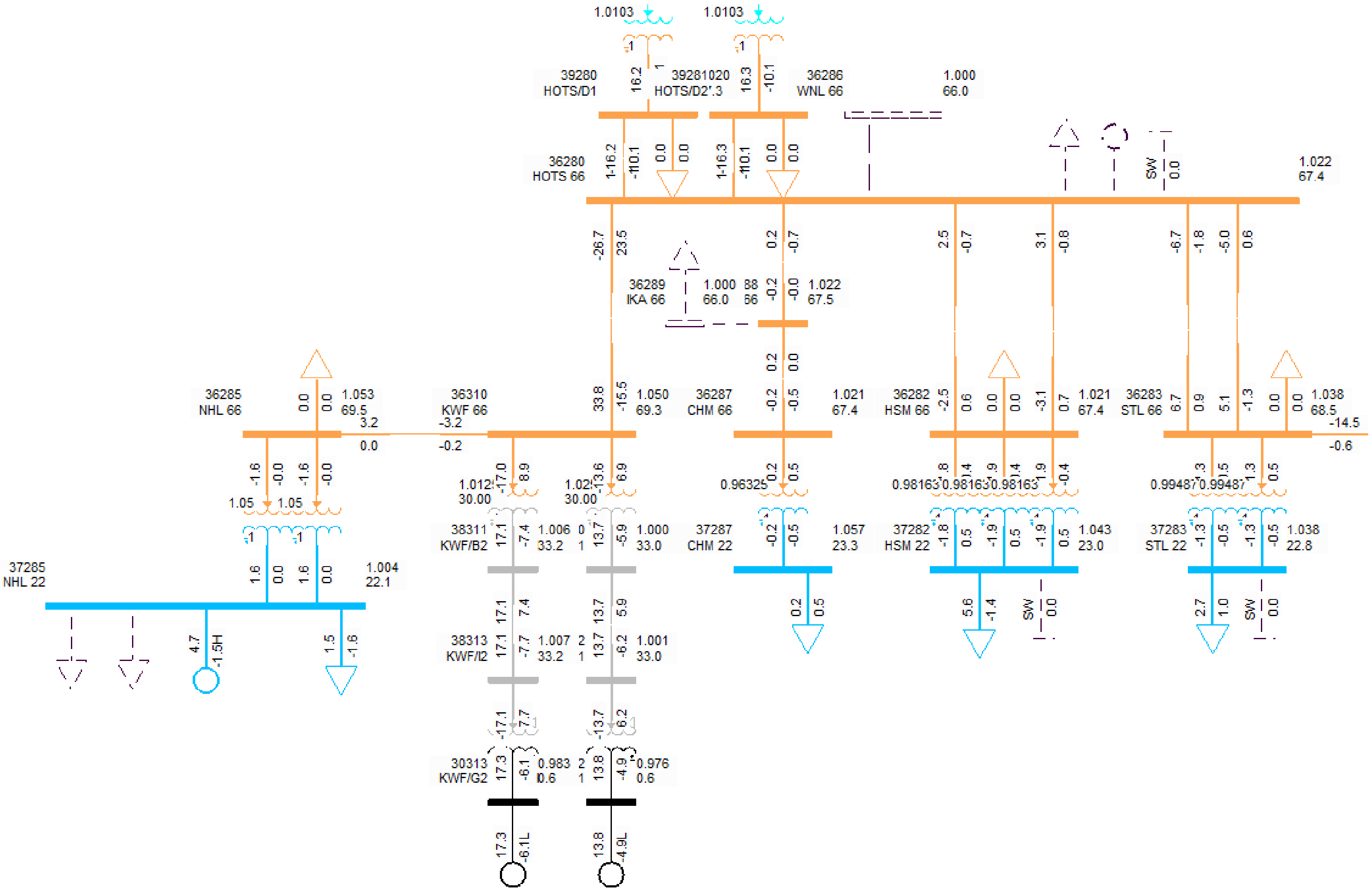

Figure 7 Scenario 4 – Low network load, KWF maximum output, maximum NREF generation, minimum NREF load

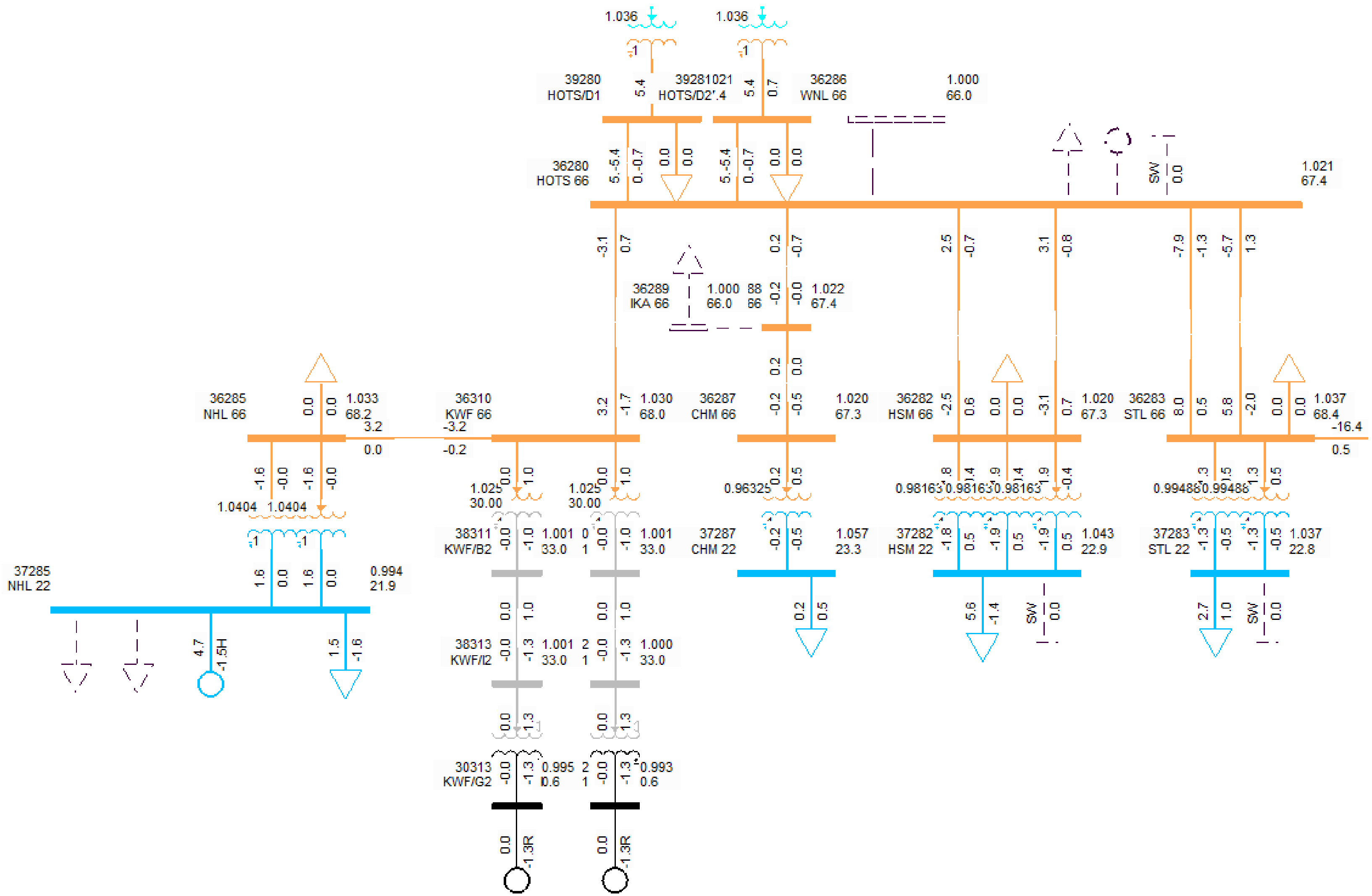

Figure 8 Scenario 5 – Low network load, KWF reactive support only, maximum NREF generation, minimum NREF load

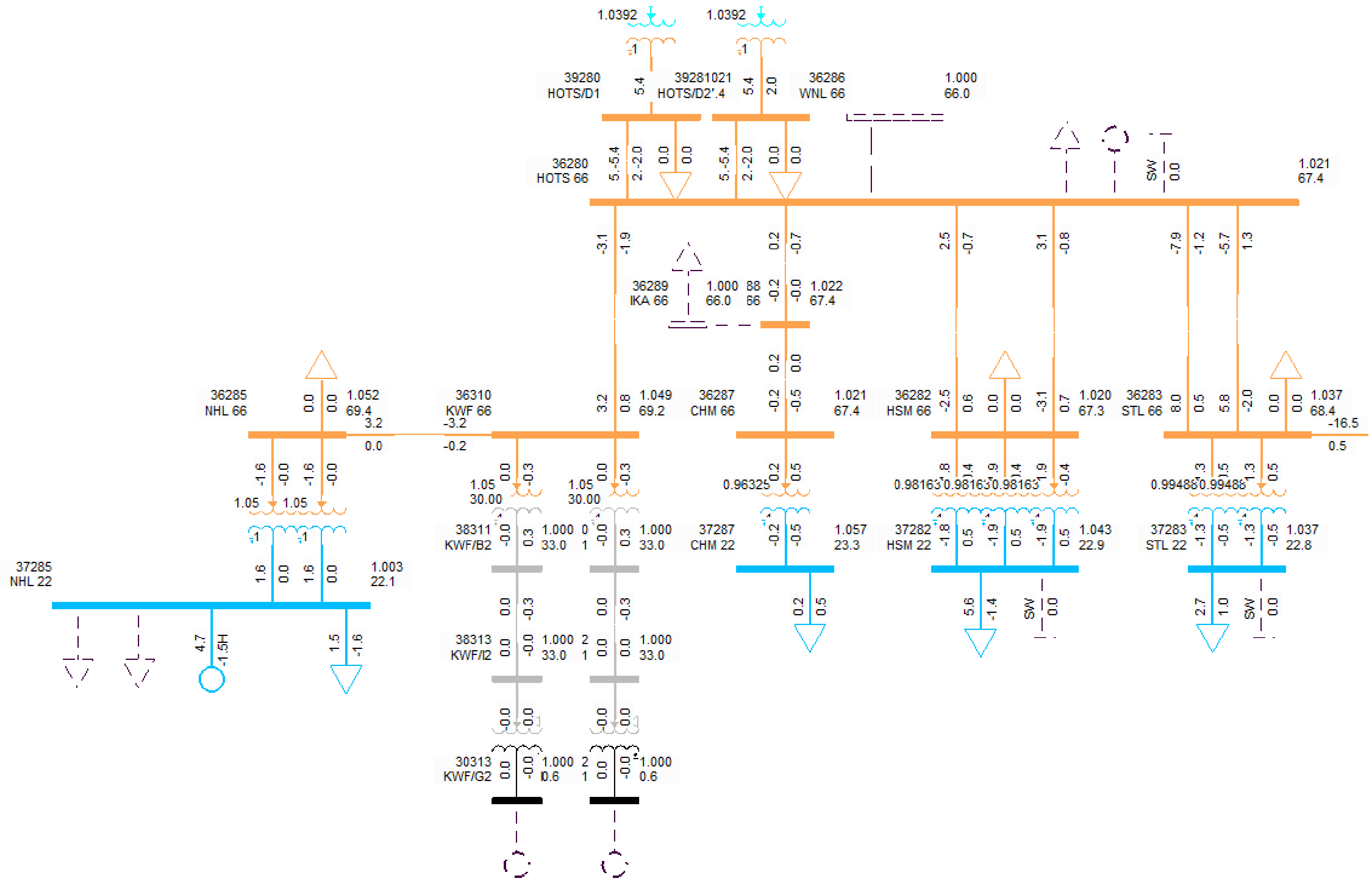

Figure 9 Scenario 6 – Low network load, KWF offline, maximum NREF generation, minimum NREF load