PROTECTION CO-ORDINATION STUDY FOR MIDDLE BALBEGGIE SOLAR FARM

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Middle Balbeggie Solar Park

Protection Co-ordination Study

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- The suitability of the Dynamic Voltage Support method for representing the Redhouse BESS should be reviewed by SP Energy Networks.
- Revised protection settings are proposed for the Redhouse trial where generation is provided by a BESS and diesel generators. Main protection is provided using overcurrent and earth fault protection and back-up is provided by undervoltage relays.
- It is proposed to change the overcurrent settings at the following locations: -
    - 11 kV Middle Balbeggie Solar Park Incomer
    - 33 kV Circuit 11 (Redhouse Primary) at Redhouse GSP
    - 33 kV Circuit 16 (Redhouse BESS/Aggreko Diesel) at Redhouse GSP
    - 33 kV Circuit Breaker 1C0 at the Redhouse BESS/Aggreko Diesel Busbar

  Proposed overcurrent settings are detailed in Appendix C.
- It is proposed to change the undervoltage settings at the following locations: -
    - 33 kV Circuit Breaker 1L5 at the Redhouse BESS/Aggreko Diesel Busbar
    - 33 kV Circuit Breaker 2L5 at the Redhouse BESS/Aggreko Diesel Busbar

  Proposed undervoltage settings are detailed in Appendix C.

  Revised settings have been implemented using Stage 1 undervoltage. As an alternative, consideration could be given to implementing the revised settings using Stage 2.
- Overcurrent settings have been selected on the assumption that the Redhouse Primary 24 MVA transformer will be energised using point-on-wave switching.
- Overcurrent settings have been chosen to ride through energisation of the Middle Balbeggie Solar Park PV 1.95 MVA transformers.
- The proposed undervoltage settings should be reviewed to ensure that they do not interfere with the BESS or diesel energisation sequence. If the BESS voltage were to be ramped up sensitive undervoltage settings could be detrimental.
- The maximum power output from the PV generation is no different from normal operation.
- It would be prudent for the tripping on breaker 2L5 (Aggreko Diesel) to intertrip 1L5 (BESS) since loss of 2L5 means loss of the 33 kV system earth.

- All auxiliary transformer LV faults will be cleared by the 10 A fuse on the transformer HV winding. No other protection is sensitive enough to detect such faults. This statement is true for the existing system and is not introduced by the Redhouse trial.
- PV transformer LV earth faults will not be detectable on the 33 kV or 11 kV systems since the transformer winding configuration is Dy11. An alternative method such as insulation monitoring will be required. This statement is true for the existing system and is not introduced by the Redhouse trial.
- Revised settings are tabulated in Appendix C and illustrated in Appendix D using yellow highlighting.

Recommendations

- Setting philosophy using overcurrent and undervoltage protection should be reviewed to ensure there is not technical conflict with the energising/testing philosophy to be used during the Redhouse trial. A quick reference to the protection philosophy can be made with reference to Appendix D.
- Settings detailed in Appendix C should be implemented during the Redhouse trial.

1 Introduction

Scottish Power Energy Networks (SPEN) requested Arcadis UK to undertake a series of protection assessments to identify the protection limitations and changes required for Redhouse Live Trial with respect to the connection of Middle Balbeggie Solar Park. The network will be operated in 'island mode' as part of the Distributed ReStart project live testing.

This report is divided into 10 sections. Following this introduction, section 2 details the scope of work. Section 3 contains an overview of Middle Balbeggie Solar Park and the surrounding topography. Source data for the power system model is presented in section 4. Fault levels and retained voltage are discussed in section 5. Existing protection settings are documented in section 6. Recommendations for revised protection settings are detailed in section 7. Other network issues are discussed in section 8. The conclusions and recommendations are outlined in section 9. Section 10 contains a list of report references.

This report has 4 appendices. Appendix A contains the Digsilent short-circuit diagrams while Appendix B summarises the branch fault flows at key points in the network. The protection schedule is presented in Appendix C and the revised protection is shown graphically in Appendix D.

2 Scope of Work

The scope of work is as follows [1]. The outcome will be detailed in a technical report. The studies for the Middle Balbeggie Solar Farm will be conducted using DIgSILENT PowerFactory and SKM PowerTools for Windows.

This assessment is required to allow the Middle Balbeggie network to be protected when energised from the Redhouse BESS system as part of the Redhouse live testing. The test network in question for this scope is Phase 2 Test Network – SPD. Middle Balbeggie Solar farm is rated at 3.8 MW and is fed from the Redhouse Primary 11 kV Switchboard.

The network to be energised is illustrated in Figure 2.1.

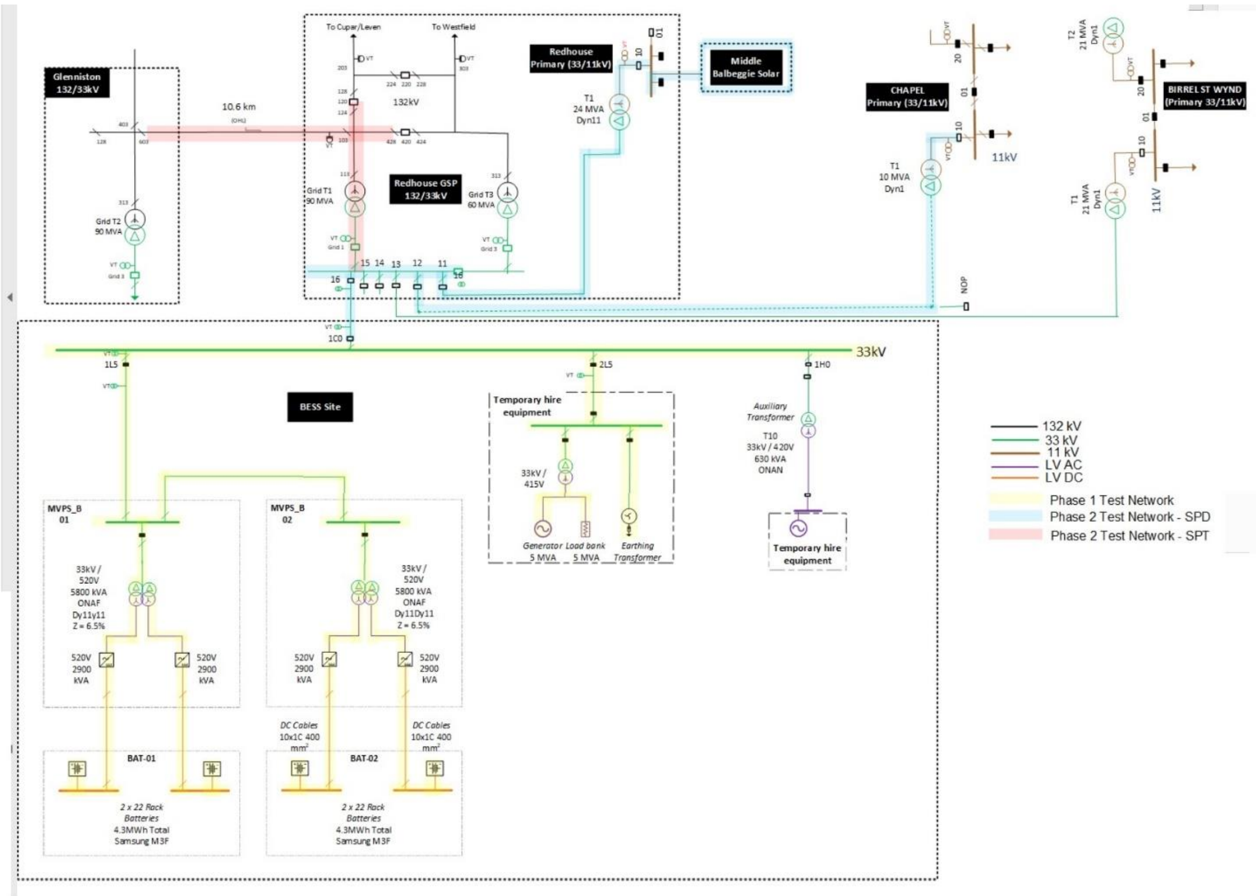


Figure 2.1 Redhouse GSP 33 kV and Middle Balbeggie 11 kV Network Topography

SPEN shall provide details on the restoration strategy. During the trials the solar farm main 11 kV busbars will be energised by the DNO. It is assumed that the solar farm is in grid-following mode and will rely on the BESS supply. Details on the solar farm fault level contribution and layout will be required.

Arcadis will:

- Consider load flows during restoration.
- Short Circuit analysis to determine fault levels during restoration.

- Identify the issues, limitations and gaps in requirements associated with the existing protections on the solar farm 11 kV and LV electrical network.
- The Redhouse BESS site protections are covered by others.
- Consideration of overcurrent, earth fault, differential, voltage protection and intertrips with SPT.
- Consideration of LLL, LL, LLG and LG faults.
- Determine protection changes required for safe energisation of the Phase 2 test SPD network e.g. revised settings required, protection changes or protections to be switched out of service.
- Identify if it is not feasible to protect any of the test network utilising the existing protection.
- Identify the generation/loading limitations associated with the proposed protection alterations.

Time current discrimination curves will be produced using the Captor software package which is part of SKM Power*Tools; protection schedules will be produced in Excel format. The level of protection relay setting details that will be provided in the schedules will be sufficient for the relays to achieve their required protection functionality but will not include (within the prices in this quotation) information that is dependent on switchboard wiring or information for the control and communications elements of the more modern protection relays. Setting files for the relays will not be provided.

Where required Arcadis will review the existing protection scheme and recommended equipment change which would improve the performance of the electrical protection system. Any equipment changes will be generic only and will not be limited to specific manufacturers or relay types, e.g. “this feeder should also be fitted with directional overcurrent protection”.

3 Overview of Balbeggie Solar Park and the Upstream Network

Details of the trial network are summarised below: -

- The source of power for the trial network will be the battery energy storage system/Aggreko diesel generation at Redhouse that comprises: -
    - 4 OFF 2.9407 MVA 0.8 PF BESS batteries,
    - 2 OFF 5.8 MVA 3-winding Dy11y11 BESS transformers,
    - 1 OFF 33 kV neutral earthing transformer with X0 = 74 Ohms,
    - 3 OFF 1.25 MVA diesel generators with a fault contribution of 3 x FLC for 10s,
    - 1 OFF 6 MVA, 2-winding Dy11 diesel generator step-up transformer.
- For the purposes of this protection study the Aggreko diesel generation will be considered as being both in-service and out-of-service.
- The BESS/Aggreko network will energise one side of the Redhouse GSP 33 kV switchboard.
- A single Redhouse Primary 33/11 kV 12/24/ MVA ONAN/ONAF transformer will be energised.
- Middle Balbeggie Solar Park will be energised from Redhouse Primary 11 kV.
- Middle Balbeggie Solar Park comprises the following components: -
    - 2 OFF 1.950 MVA, 2-winding Dy11 transformers,
    - 2 OFF 2.5 MW solar arrays,
    - 1 OFF 50 kVA, 2-winding Dyn11 auxiliary transformer.
- The electrical topography to be energised during the trial is shown in Figure 3.1.

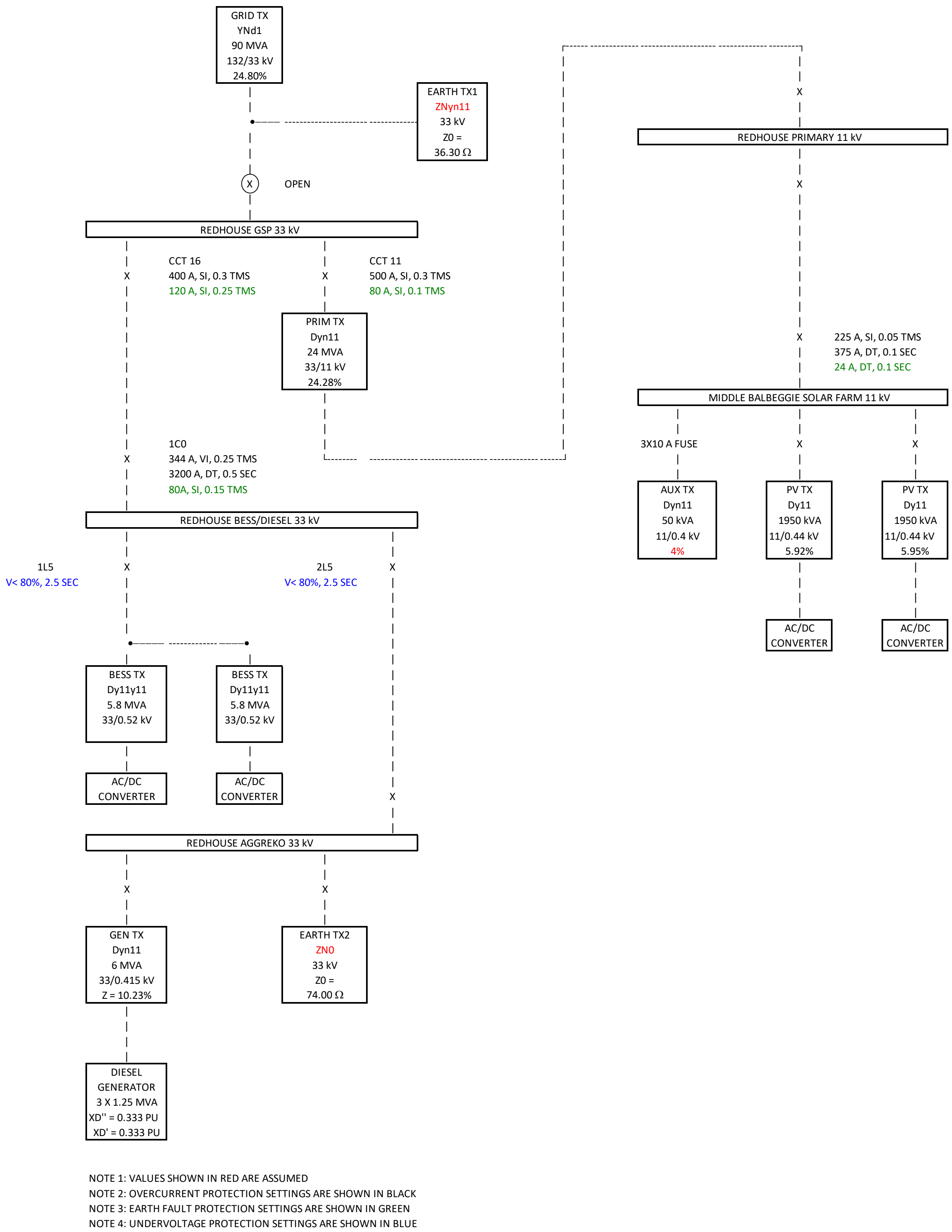


Figure 3.1 Redhouse Trial Network Topography

4 Software and Power System Model Source Data

4.1 Software

Short-circuit studies were conducted in Digsilent PowerFactory 2022 SP3 using the Complete method. . A model of the SPEN network was provided to Arcadis [2]. The model was extended to include a more detailed representation of Middle Balbeggie Solar Park.

4.2 Redhouse Battery Energy Storage System

Battery details were provided in the Digslient Model from SPEN [2]. Batteries were modelled with the following parameters: -

- Rated Voltage 0.52 kV
- Rated Apparent Power 2.9407 MVA
- Rated Power Factor 0.8
- Short-Circuit Model Dynamic Voltage Support
- Subtransient Short-Circuit Level 4.7051 MVA
- R to X'' Ratio 0.164
- K Factor 2
- Max. Current 1 pu
- Negative Sequence Resistance, r2 0.1 pu
- Negative Sequence Reactance, x2 0.61 pu

There are four batteries in the model.

Dynamic voltage support is interpreted as meaning that the battery injects reactive current in the positive- as well as negative-sequence system due to any change of the corresponding voltage between fault and pre-fault [3].

From correspondence with the BESS developer the values for the short circuit current and voltage ride through capability are given below [13,14]

In case of the full dynamic grid support you find the values for the initial symmetrical short-circuit current I_k'', the surge current i_p and the uninterrupted short-circuit current I_k in the following tables.

I_k''	i_p	I_k
1.6 I_N	2.3 I_N	1.0 I_N

Table 1: Values for initial symmetrical short-circuit current I_k'', surge current i_p and uninterrupted short-circuit current I_k

a) Voltage Ride Through

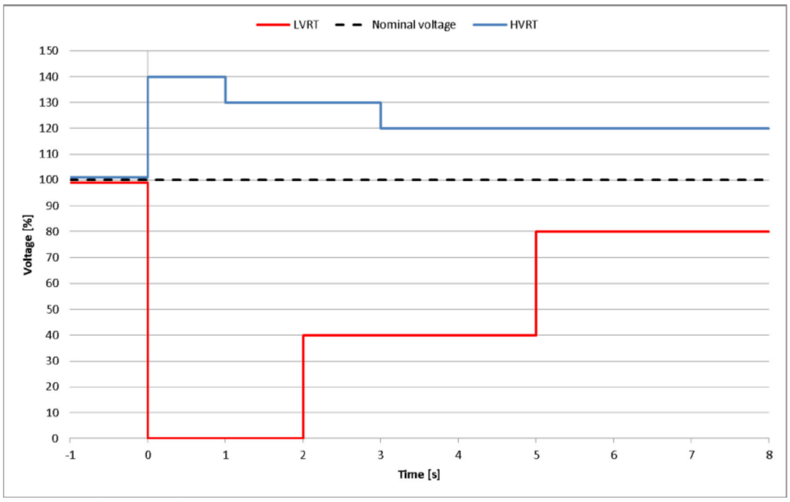


Figure 21: LVRT/HVRT capabilities

It should be noted that the particular model used to represent the battery in DigSilent will be discontinued in the future [4]: -

4.2.2 Dynamic Voltage Support

Static generators configured using the option *Dynamic Voltage Support* are similar to an *Equivalent Synchronous Machine*, but the transient contribution is modelled as a constant current injection. The subtransient contribution is considered as a rotating contribution.

Note: This model is deprecated and will be removed in future versions. A suitable alternative is the *Doubly Fed Asynchronous Generator*.

The transient contribution I'k is used in these studies as being representative of the fault contribution supplied by the battery system.

4.3 Battery Energy Storage System Transformers

The BESS 3-winding transformers are modelled with the following parameters from SPEN: -

• MVA Rating	5.8/2.9/2.9	MVA
• Voltage Rating	33/0.52/0.52	kV
• Winding Connection	Dy11y11	
• Impedance Winding 12	3.25%	X/R =30
• Impedance Winding 13	3.25%	X/R = 30
• Impedance Winding 23	99%	X/R = 60

There are two transformers in the model.

4.4 Diesel Generators

The diesel generators are modelled with the following parameters from SPEN: -

• Rated Apparent Power	1.25	MVA
• Rated Voltage	0.4	kV
• Rated Power Factor	0.8	
• Stator Resistance	0.00126	pu
• Subtransient Reactance, xd''	0.333	pu
• Transient Reactance, xd'	0.333	pu
• Negative Sequence Reactance, x2	0.2	pu
• Negative Sequence Resistance, r2	0	pu
• Zero Sequence Reactance, x0	0.1	pu
• Zero Sequence Resistance, r0	0	pu

The subtransient and transient impedances are modelled so as to give a fault contribution of three times full load current.

There are 3 parallel diesel generators in the model.

4.5 Diesel Generators Step-Up Transformer

The step-up transformer for the diesel generators is modelled with the following parameters from SPEN: -

• MVA Rating	6	MVA
• Voltage Rating	33/0.415	kV
• Winding Connection	Dy11	
• Impedance	10.23	%
• X/R Ratio	19.16	

4.6 Earthing Transformer

The earthing transformer has the following parameters from SPEN: -

• Voltage Rating	33	kV
• Winding Connection	ZN0	
• Zero Sequence Reactance	74	Ohms

4.7 Redhouse Primary Transformer

Redhouse primary transformer has the following parameters from SPEN: -

• MVA Rating	12/24	MVA ONAN/ONAF
• Voltage Rating	33/11	kV
• Winding Connection	Dyn11	
• Impedance	24.58%	on 24 MVA Base
• X/R Ratio	16.34	
• Z0 = Z1.		

The transformer has a 33 kV cable with the folllowing parameters from SPEN: -

- Rating 410 A
- R1 0.140 Ohms/km
- X1 0.201 Ohms/km
- C 0.209 uF/km
- R0 0.258 Ohms/km
- X0 0.089 Ohms/km
- Length 1 km

4.8 Middle Balbeggie Solar Park

4.8.1 Cables

The cable schedule for Middle Balbeggie Solar Park is presented in Table 4.8.1.1. The cable parameters are shown in Table 4.8.1.2.

FROM	TO	CORES PER PHASE	LENGTH (km)	CONSTRUCTION
REDHOUSE PRIMARY	MIDDLE BALEGGIE PV	2	0.225	185 mm^2 3C AL XLPE
MIDDLE BALEGGIE PV	PV TX 1	1	0.02	185 mm^2 1C AL XLPE
MIDDLE BALEGGIE PV	PV TX 2	1	0.34	185 mm^2 1C AL XLPE
MIDDLE BALEGGIE PV	AUX TX	1	0.02	185 mm^2 1C AL XLPE

Table 4.8.1.1: 11 kV Cable Schedule for Middle Balbeggie Solar Park

PARAMETER	UNIT	185AL	185AL
CORES PER CABLE	-	1	3
R1	OHMS/km	0.211	0.211
X1	OHMS/km	0.103	0.092
C1	uF/km	0.43	0.46

Table 4.8.1.2: 11 kV Cable Parameters

4.8.2 Transformers

Middle Balbeggie PV1 transformer has the following parameters: -

- MVA Rating 1.95 MVA
- Voltage Rating 11/0.44 kV
- Winding Connection Dy11
- Impedance 5.92%
- X/R Ratio 6.069

Middle Balbeggie PV2 transformer has the following parameters: -

- MVA Rating 1.9-05 MVA
- Voltage Rating 11/0.44 kV
- Winding Connection Dy11
- Impedance 5.95%
- X/R Ratio 6.13

Middle Balbeggie auxiliary transformer has the following parameters: -

- kVA Rating 50 kVA
- Voltage Rating 11/0.4 kV
- Winding Connection Dyn11
- Impedance 4% Assumed
- X/R Ratio 6 Assumed

4.8.3 PV Generation

PV generation is not in-service during these fault calculations, as a worst-case scenario.

5 Fault Levels and Retained Voltage

Fault levels were calculated at key locations for LLL, LL and LG faults for two scenarios: -

- Redhouse BESS as only source of fault contribution,
- Redhouse BESS and Aggreko diesel contributing to fault current.

The results for a LLG study can be inferred from the results of the other studies so were not specifically conducted.

The short-circuit studies conducted are listed in Table 5.1.

STUDY	FAULT TYPE	REDHOUSE BESS STATUS	AGGREKO DIESEL STATUS	NODE NAME	FAULT LOCATION
SC1	LLL	IN	OUT	REDH_BESS	REDHOUSE GSP 33 KV
SC2	LLL	IN	OUT	REDH5-	REDHOUSE PRIMARY 11 KV
SC3	LLL	IN	OUT	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC4	LLL	IN	OUT	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC5	LLL	IN	OUT	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC6	LL	IN	OUT	REDH_BESS	REDHOUSE GSP 33 KV
SC7	LL	IN	OUT	REDH5-	REDHOUSE PRIMARY 11 KV
SC8	LL	IN	OUT	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC9	LL	IN	OUT	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC10	LL	IN	OUT	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC11	LG	IN	OUT	REDH_BESS	REDHOUSE GSP 33 KV
SC12	LG	IN	OUT	REDH5-	REDHOUSE PRIMARY 11 KV
SC13	LG	IN	OUT	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC14	LG	IN	OUT	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC15	LG	IN	OUT	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC16	LLL	IN	IN	REDH_BESS	REDHOUSE GSP 33 KV
SC17	LLL	IN	IN	REDH5-	REDHOUSE PRIMARY 11 KV
SC18	LLL	IN	IN	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC19	LLL	IN	IN	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC20	LLL	IN	IN	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC21	LL	IN	IN	REDH_BESS	REDHOUSE GSP 33 KV
SC22	LL	IN	IN	REDH5-	REDHOUSE PRIMARY 11 KV
SC23	LL	IN	IN	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC24	LL	IN	IN	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC25	LL	IN	IN	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC26	LG	IN	IN	REDH_BESS	REDHOUSE GSP 33 KV
SC27	LG	IN	IN	REDH5-	REDHOUSE PRIMARY 11 KV
SC28	LG	IN	IN	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC29	LG	IN	IN	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC30	LG	IN	IN	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV

NOTE: SC14 and SC29 have not been conducted since the PV transformers are Dy11 connection (unearthed on the LV)since no fault current flows during these faults.

Table 5.1: Short-Circuit Studies

The Digsilent plots are presented in Appendix A and the fault contribution and retained voltage for each fault type are shown in Appendix B.

5.1 Fault Current

Referring to Appendices A and B, the minimum fault contribution from the BESS is calculated as 206 A at 33 kV for all fault scenarios considered. This determines the maximum overcurrent protection setting at 33 kV. A maximum pick-up of 100 A is necessary at 33 kV and a maximum pick-up of 300 A is necessary at 11 kV.

5.2 Retained Voltage

As a back-up to overcurrent and earth fault protection, undervoltage protection can be used to detect faults. The retained voltage at the Redhouse BESS/Aggreko 33 kV busbar is detailed below.

5.2.1 33 kV Faults

For a 33 kV fault, the system voltage will drop by a substantial amount in at least one phase. There is no issue detecting 33 kV faults using undervoltage protection.

5.2.2 11 kV Faults

Referring to Appendix A, the retained voltage at Redhouse BESS / Aggreko busbar in the 'worst' phase for an 11 kV fault is as follows: -

- SC3 LLL 0.381 pu
- SC8 LL 0.522 pu
- SC13 LG 0.486 pu

The abnormal voltages that develop during 11 kV faults are sufficient to be detected by undervoltage protection.

5.2.3 0.44 kV Faults (Middle Balbeggie PV Transformer LV)

Referring to Appendix A, the retained voltage at Redhouse BESS / Aggreko busbar in the 'worst' phase for a 0.44 kV fault is as follows: -

- SC4 LLL 0.712 pu
- SC9 LL 0.715 pu

SC14 (LG fault) has not been conducted since the PV transformer LV winding is unearthed. LG faults do not create abnormal current or voltage conditions at 33 kV.

The abnormal voltages that develop during a PV transformer LV fault are sufficient to be detected by undervoltage protection.

5.2.4 0.4 kV Faults (Middle Balbeggie Auxiliary Transformer LV)

- SC5 LLL 0.980 pu
- SC10 LL 0.981 pu
- SC15 LG 0.988 pu

The system voltages that develop during an auxiliary transformer LV fault are too high to be detected by undervoltage protection.

6 Existing Protection Settings

This section documents existing protection settings in key locations. The existing protection settings are also indicated in Figure 3.1.

6.1 Middle Balbeggie Solar Park 11 kV

The key protection settings are as follows [8][9]: -

- Circuit Breaker Description — Main Incomer
- Relay — Schneider Micom P341
- Protection Type — Overcurrent
- Current Transformer Rating — 300/1A
- Stage 1 Pick-Up, I> — 0.75 x Iref, 225 A
- Stage 1 Curve — Normal Inverse
- Stage 1 Time Multiplier Setting — 0.05
- Stage 2 Pick-Up, I>> — 1.25 x Iref, 375 A
- Stage 2 Curve — Definite Time
- Stage 2 Time Setting — 0.1 s

- Circuit Breaker Description — Main Incomer
- Relay — Schneider Micom P341
- Protection Type — Earth Fault
- Current Transformer Rating — 300/1A
- Stage 1 Pick-Up, I> — 0.08 x Iref, 24 A
- Stage 1 Curve — Definite Time
- Stage 1 Time Setting — 0.1 s

- Circuit Breaker Description — Main Incomer
- Relay — Schneider Micom P341
- Protection Type — Under-Voltage
- Pick-Up, UV< — 80% Un
- Operate Time — 2.5 s

The PV transformers each have a dedicated overcurrent and earth fault relay on the HV winding [9]. Details of this protection is unknown.

The auxiliary transformer is protected by a 10 A fuse on the HV winding [9].

6.2 Redhouse Grid Supply Point 33 kV Circuit 11

The key protection settings are as follows [7]: -

- Circuit Breaker ID: Circuit 11
- Circuit Breaker Description Redhouse Primary
- Relay Alstom P14N
- Current Transformer Rating 400/1 A
- Protection Type Overcurrent
- Stage 1 Pick-Up, I> 500 A
- Stage 1 Curve Standard Inverse
- Stage 1 Time Multiplier Setting 0.3

- Circuit Breaker ID: Circuit 11
- Circuit Breaker Description Redhouse Primary
- Relay Alstom P14N
- Current Transformer Rating 400/1 A
- Protection Type Earth Fault
- Stage 1 Pick-Up, Io> 80 A
- Stage 1 Curve Standard Inverse
- Stage 1 Time Multiplier Setting 0.1

6.3 Redhouse Grid Supply Point 33 kV Circuit 16

The key protection settings are as follows [7]: -

- Circuit Breaker ID: Circuit 16
- Circuit Breaker Description Redhouse BESS/Diesel
- Relay Alstom P14N
- Current Transformer Rating 800/1 A
- Protection Type Overcurrent
- Stage 1 Pick-Up, I> 400 A
- Stage 1 Curve Standard Inverse
- Stage 1 Time Multiplier Setting 0.3

- Circuit Breaker ID: Circuit 16
- Circuit Breaker Description Redhouse BESS/Diesel
- Relay Alstom P14N

- Current Transformer Rating 800/1 A
- Protection Type Earth Fault
- Stage 1 Pick-Up, Io> 120 A
- Stage 1 Curve Standard Inverse
- Stage 1 Time Multiplier Setting 0.25

6.3 Redhouse BESS/Aggreko Diesel 33 kV

The key protection settings are as follows [5][6]: -

- Circuit Breaker ID: 1L5
- Circuit Breaker Description Feeder to Battery Generation
- Relay Siprotec 5 7SJ82
- Protection Type Under-Voltage
- Pick-Up, UV< 80% Un
- Operate Time 2.5 s

- Circuit Breaker ID: 2L5
- Circuit Breaker Description Feeder to Diesel Generation and Earthing Transformer
- Relay Siprotec 5 7SJ82
- Protection Type Under-Voltage
- Pick-Up, UV< 80% Un
- Operate Time 2.5 s

- Circuit Breaker ID: 1C0
- Circuit Breaker Description Incomer to Redhouse BESS/Diesel
- Relay Siemens 7SJ82
- Protection Type Overcurrent
- Stage 1 Pick-Up, I> 344 A
- Stage 1 Curve Very Inverse
- Stage 1 Time Multiplier Setting 0.25
- Stage 2 Pick-Up, I>> 3200 A
- Stage 2 Operate Time 0.5 s

- Circuit Breaker ID: 1C0
- Circuit Breaker Description Incomer to Redhouse BESS/Diesel
- Relay Unknown

- Protection Type   Earth Fault
- Stage 1 Pick-Up, Io>   80 A
- Stage 1 Curve   Standard Inverse
- Stage 1 Time Multiplier Setting   0.15
- Stage 2 Pick-Up, Io>>   Off

7 Revised Protection Settings

It is proposed to use overcurrent protection to detect all faults with a back-up being provided by the undervoltage protection at the Redhouse BESS/Aggreko Diesel 33 kV busbar.

Revised settings are proposed in the following paragraphs.

Protection co-ordination diagrams are shown in Figures 7.1 – 7.4 at the end of this section.

7.1 Middle Balbeggie Solar Park 11 kV Overcurrent

The maximum protection setting is governed by the available fault current. A maximum pick-up of 300 A at 11 kV was determined in section 5.1. However, the overcurrent protection must be able to ride through energisation of the PV 1.950 MVA transformers. Inrush is taken as 8 times full load current. For a PV transformer, inrush equates to 8 * 102 A = 819 A. In the Micom P341 manual [10] it is stated that: -

> Due to the nature of operation of the third and fourth overcurrent stages in the P341 relays, it is possible to apply settings corresponding to 35% of the peak inrush current, whilst maintaining stability for the condition.

Therefore, the minimum setting is taken as 35% * 819 A = 287 A, using the stage 3 overcurrent. The following additional settings are proposed: -

• Circuit Breaker Description	Main Incomer
• Relay	Schneider Micom P341
• Protection Type	Overcurrent
• Current Transformer Rating	300/1A
• Stage 3 Pick-Up, I>3	300 A
• Stage 3 Curve	Definite Time
• Stage 3 Time Delay	0.1 s

It is confirmed that stage 3 of the overcurrent protection can achieve the desired setting [10]: -

I>3 Status:	Disabled, Enabled
I>3 Direction:	Non-Directional or Directional Fwd or Directional Rev
I>3 Current Set:	0.08…10.00 In
I>3 Time Delay:	0.00…100.00 s

7.2 Redhouse Grid Supply Point 33 kV Circuit 11 Overcurrent

The maximum protection setting is governed by the available fault current. A maximum pick-up of 100 A @ 33 kV was determined in section 5.1. However, the overcurrent protection must be able to ride through energisation of the PV 1.950 MVA transformers and energisation of the Redhouse Primary 24 MVA transformer.

SPEN has advised that the Redhouse Primary 24 MVA transformer will be energised using point-on-wave switching so transient inrush current is expected to be minimal for this transformer.

For a PV transformer, inrush equates to 8 * 34 A = 273 A.

In the Micom P14 manual [11] it is stated that: -

> All four overcurrent stages operate on the fourier fundamental component. Hence, for the third and fourth overcurrent stages in P140 relays, it is possible to apply settings corresponding to 35% of the peak inrush current, whilst maintaining stability for the condition.

Therefore, the minimum setting is taken as 35% * 273 A = 96 A, using the stage 3 overcurrent. The following additional settings are proposed: -

- Circuit Breaker ID: Circuit 16
- Circuit Breaker Description Redhouse BESS/Diesel
- Relay Alstom P14N
- Current Transformer Rating 400/1 A
- Protection Type Overcurrent
- Stage 3 Pick-Up, I>3 100 A
- Stage 3 Curve Definite Time
- Stage 3 Time Delay 0.3 s

It is confirmed that stage 3 of the overcurrent protection can achieve the desired setting [11]: -

Courier Text	UI	Courier		Data Type	Strings	MODBUS Address		MODBUS Database	Default Setting	Cell Type	Min	Max	Step
		Col	Row			Start	End						
I>3 Status		35	40	Indexed String	G37	41268		G37	Disabled	Setting	0	1	1
I>3 Direction		35	41	Indexed String	G44	41269		G44	Non-Directional	Setting	0	2	1
I>3 Current Set		35	44	Courier Number (current)		41270		G2	20	Setting	0.08*I1	32*I1	0.01*I1
I>3 Time Delay		35	45	Courier Number (time)		41271		G2	0	Setting	0	100	0.01

7.3 Redhouse Grid Supply Point 33 kV Circuit 16 Overcurrent

The maximum protection setting is governed by the available fault current. A maximum pick-up of 100 A at 33 kV was determined in section 5.1. The minimum setting is taken as 96 A from section 7.2, using the stage 3 overcurrent. The following additional settings are proposed: -

- Circuit Breaker ID: Circuit 16
- Circuit Breaker Description Redhouse BESS/Diesel
- Relay Alstom P14N
- Current Transformer Rating 800/1 A
- Protection Type Overcurrent
- Stage 3 Pick-Up, I>3 104 A
- Stage 3 Curve Definite Time
- Stage 3 Time Delay 0.5 s

7.4 Redhouse BESS/Aggreko Diesel 33 kV Overcurrent

The maximum protection setting is governed by the available fault current. A maximum pick-up of 100 A at 33 kV was determined in section 5.1. However, the overcurrent protection must be able to ride through energisation of the PV 1.950 MVA transformers. Inrush is taken as 273 A from section 7.2. However, the proposed settings for the overcurrent on circuit breaker 1C0 have sufficient delay on it to allow inrush decay. The following settings are therefore proposed: -

- Circuit Breaker ID: 1C0
- Circuit Breaker Description Incomer to Redhouse BESS/Diesel
- Relay Siprotec 7SJ82
- Protection Type Overcurrent
- Stage 3 Pick-Up, I>3 104 A
- Stage 3 Curve Definite Time
- Stage 3 Time Setting 0.75 s

It is confirmed that stage 3 of the overcurrent protection can achieve the desired setting [12]: -

13.5.1 Stage with Definite-Time Characteristic Curve

Setting Value for the Function Block Filter

h(0)	-100.000 to 100.000	Increments of 0.001
h(1)	-100.000 to 100.000	Increments of 0.001
h(2)	-100.000 to 100.000	Increments of 0.001
h(3)	-100.000 to 100.000	Increments of 0.001
h(4)	-100.000 to 100.000	Increments of 0.001

Setting Values for Protection Stage

Method of measurement		Fundamental component RMS value	–
Threshold value[77]	1 A @ 50 and 100 Irated	0.030 A to 35.000 A	Increments of 0.001 A
	5 A @ 50 and 100 Irated	0.15 A to 175.00 A	Increments of 0.01 A
	1 A @ 1.6 Irated	0.001 A to 1.600 A	Increments of 0.001 A
	5 A @ 1.6 Irated	0.005 A to 8.000 A	Increments of 0.001 A
Dropout ratio		0.90 to 0.99	Increments of 0.01
Operate delay		0.00 s to 100.00 s	Increments of 0.01 s
Dropout delay		0.00 s to 60.00 s	Increments of 0.01 s
Pickup delay		0.00 s to 60.00 s	Increments of 0.01 s

7.5 Redhouse BESS/Aggreko Diesel 33 kV Undervoltage

It is proposed that the undervoltage protection at the Redhouse BESS/Aggreko Diesel busbar be made more sensitive during the trial. The earthing transformer should be the last thing to disconnect to ensure the 33 kV network is always earthed while (grid forming) generation is connected. The following settings are proposed: -

- Circuit Breaker ID: 1L5
- Circuit Breaker Description Feeder to Battery Generation
- Relay Siprotec 5 7SJ82
- Protection Type Under-Voltage
- Pick-Up, UV< 90% Un
- Operate Time 1 s

- Circuit Breaker ID: 2L5
- Circuit Breaker Description Feeder to Diesel Generation and Earthing Transformer
- Relay Siprotec 5 7SJ82
- Protection Type Under-Voltage
- Pick-Up, UV< 90% Un
- Operate Time 1.25 s

There is a risk that the Middle Balbeggie PV generation remains connected to the network after 2L5 has tripped. However, it is assumed the PV generation is grid following rather than grid forming and so cannot remain operational in the absence of an alternative voltage source.

7.6 Earth Fault Protection

It is not proposed to adjust the earth fault protection during the trial. However, in this section, the operation of the earth fault protection will be assessed.

7.6.1 33 kV Earth Faults

The residual current for 33 kV earth faults is calculated as follows: -

- SC11 LG 33 kV 618 A
- SC26 LG 33 kV 632 A

The 33 kV earth fault at the Redhouse BESS/Aggreko Diesel busbar (80 A, SI, 0.15) will operate in 503 ms for a fault contribution of 618 A. This is more rapid than the overcurrent on 1C0, which is set to operate in 0.75 s.

7.6.2 11 kV Earth Faults

The residual current for 11 kV earth faults is calculated as follows: -

- SC13 LG 11 kV 1,866 A
- SC28 LG 11 kV 2,402 A

The 11 kV earth fault at the Middle Balbeggie busbar (24 A, DT, 0.1 s) will operate in 0.1 s for an 11 kV earth fault.

7.6.3 0.44 kV Earth Faults (PV Transformer LV)

The Middle Balbeggie PV transformers are unearthed on the LV winding. LV earth faults will not generate fault current or abnormal voltages on the HV network. LV earth faults must therefore be detected by an alternative means such as insulation monitoring.

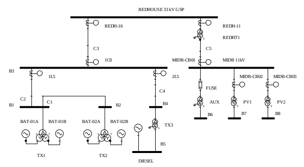
7.6.4 0.4 kV Earth Faults (Auxiliary Transformer LV)

LV faults on the auxiliary transformer LV will be detected by the 10 A fuse protection on the HV winding. The fuse protection on the HV winding is the only protection that will detect an auxiliary transformer LV fault.

7.7 Differential Protection

There is balanced earth fault protection (BEF) installed on CCT 11 (Redhouse Primary feeder) at Redhouse GSP. This protection is provided by an MFAC relay with a 75 V setting. This protection cannot be assessed without the stabilising resistor rating being known. It is not necessary to assess this protection to determine the adequacy of the protection scheme as a whole.

```
LV Breakers
Name/Type          Description          Frame/Sensor/Plug Settings          SC Ratings(kA)
LLL @ 11 kV        Fault Level Marker  0.0A                    FAULT LEVEL  Interrupting 0.0 0
Specialty Device

Relays
Name/Type          Description          CT Ratio (A)       Settings
MIDB-CB01 STAGE 3  SCHNEIDER            300 / 1               I>>> 1 (300A)
Electronic         MICOM P341                                 tI>>> 0.1 (sec)
                   50/51 OC 50N/51N EF


MIDB-CB01          SCHNEIDER            300 / 1               I> 0.75 (225A)
Electronic         MICOM P341                                 I> SI 20xDT 0.25
                   50/51 OC 50N/51N EF                        I>> 1.25 (375A)
                                                              tI>> 0.1 (sec)
```



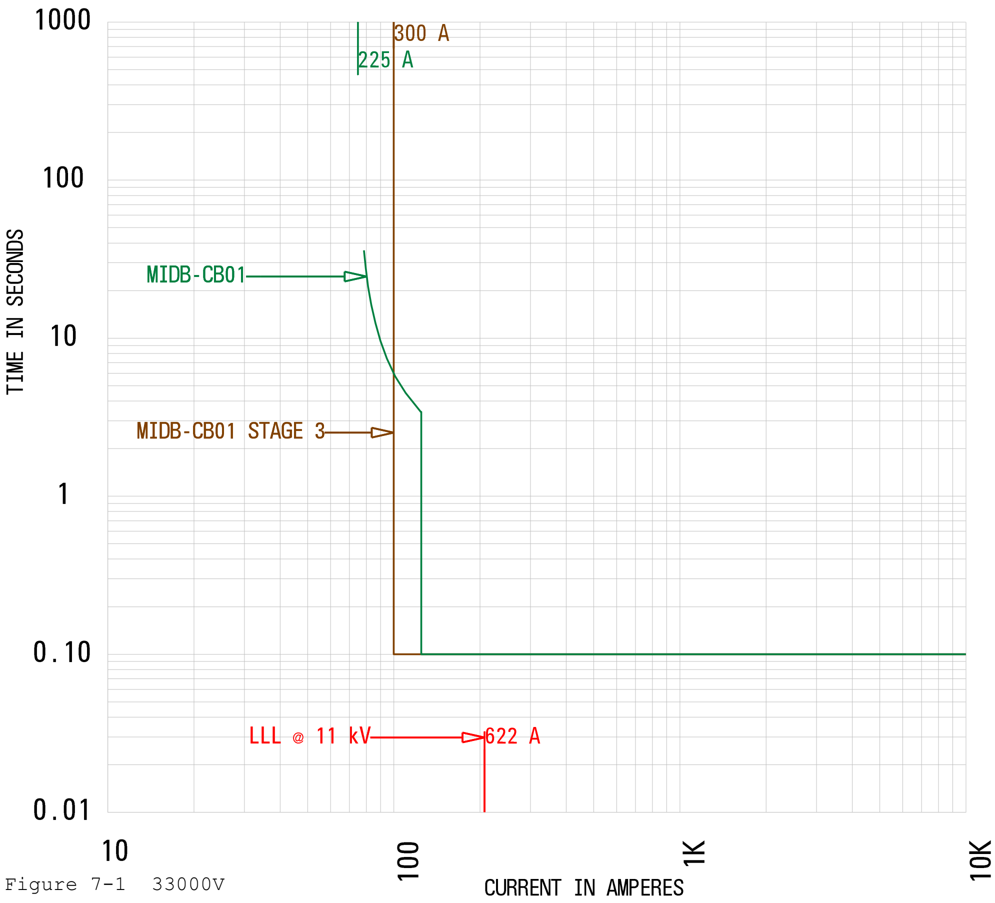
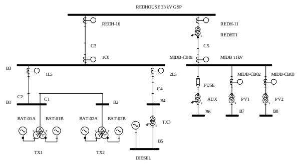


Figure 7.1: Overcurrent Protection at Middle Balbeggie 11 kV

```
LV Breakers
Name/Type         Description          Frame/Sensor/Plug Settings          SC Ratings(kA)
LLL @ 33 kV       Fault Level Marker   0.0A                 FAULT LEVEL    Interrupting 0.0 0
Specialty Device

Relays
Name/Type         Description          CT Ratio (A)     Settings
REDH-11 STAGE 3   SCHNEIDER            400 / 1             I>>> 0.25 (100A)
Electronic        MICOM P14x                               tI>>> 0.3 (sec)
                  50/51 OC 50N/51N EF


REDH-11           SCHNEIDER            400 / 1             I> 1.25 (500A)
Electronic        MICOM P14x                               I> SI 20xDT 0.3
                  50/51 OC 50N/51N EF
```



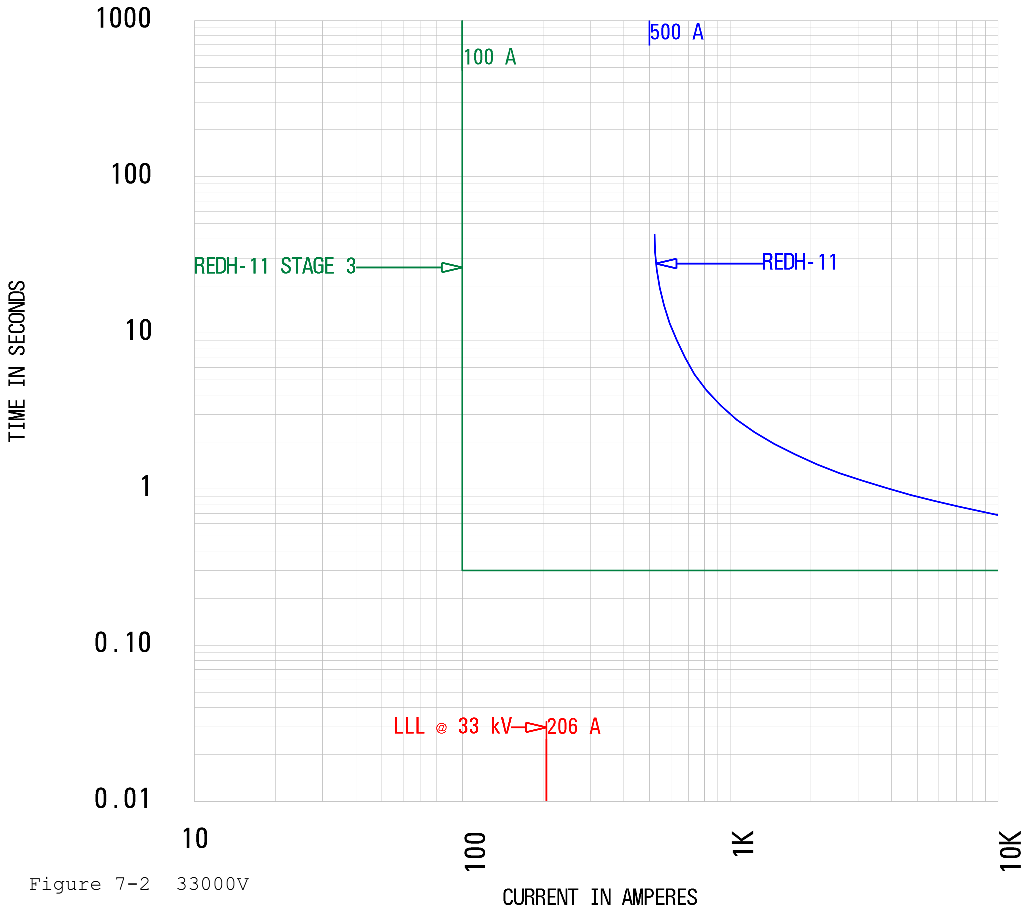
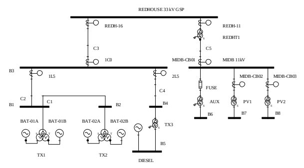


Figure 7.2: Overcurrent Protection at Redhouse GSP 33 kV – Circuit 11

```
LV Breakers
Name/Type        Description          Frame/Sensor/Plug Settings          SC Ratings(kA)
LLL @ 33 kV      Fault Level Marker   0.0A                 FAULT LEVEL    Interrupting 0.0 0
Specialty Device

Relays
Name/Type        Description          CT Ratio (A)      Settings
REDH-16          SCHNEIDER            800 / 1              I> 0.5 (400A)
Electronic       MICOM P14x                                I> SI 20xDT 0.3
                 50/51 OC 50N/51N EF

REDH-16 STAGE 3  SCHNEIDER            800 / 1              I>>> 0.13 (104A)
Electronic       MICOM P14x                                tI>>> 0.5 (sec)
                 50/51 OC 50N/51N EF
```



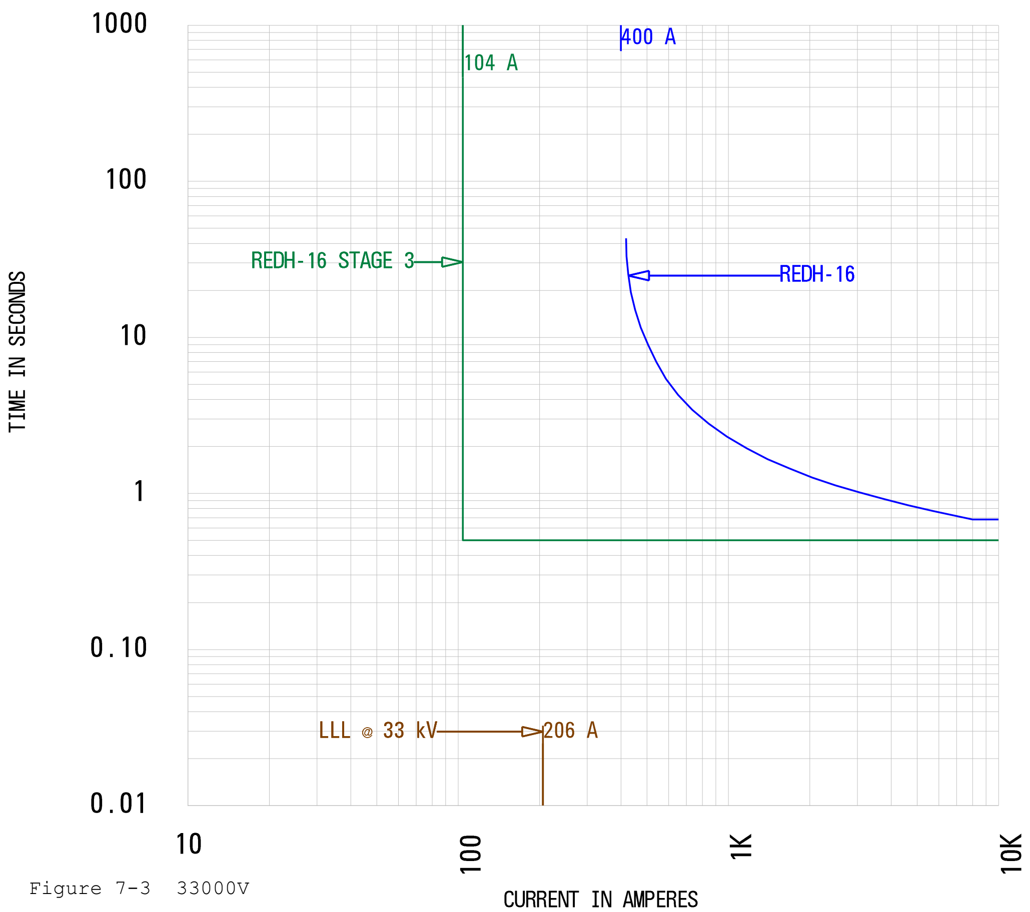
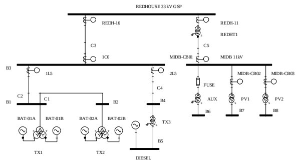


Figure 7.3: Overcurrent Protection at Redhouse GSP 33 kV – Circuit 16

```
LV Breakers
Name/Type        Description         Frame/Sensor/Plug Settings          SC Ratings(kA)
LLL @ 33 kV      Fault Level Marker  0.0A                 FAULT LEVEL    Interrupting 0.0 0
Specialty Device

Relays
Name/Type        Description         CT Ratio (A)      Settings
1C0              SIEMENS             800 / 1              I> 0.43 (344A)
Electronic       7SJ82                                    I> VI 20xDT 0.25
                 50/51 OC 50N/51N EF                      I>> 4 (3200A)
                                                          tI>> 0.5 (sec)


1C0 STAGE 3      SIEMENS             800 / 1              I>>> 0.13 (104A)
Electronic       7SJ82                                    tI>>> 0.75 (sec)
                 50/51 OC 50N/51N EF
```



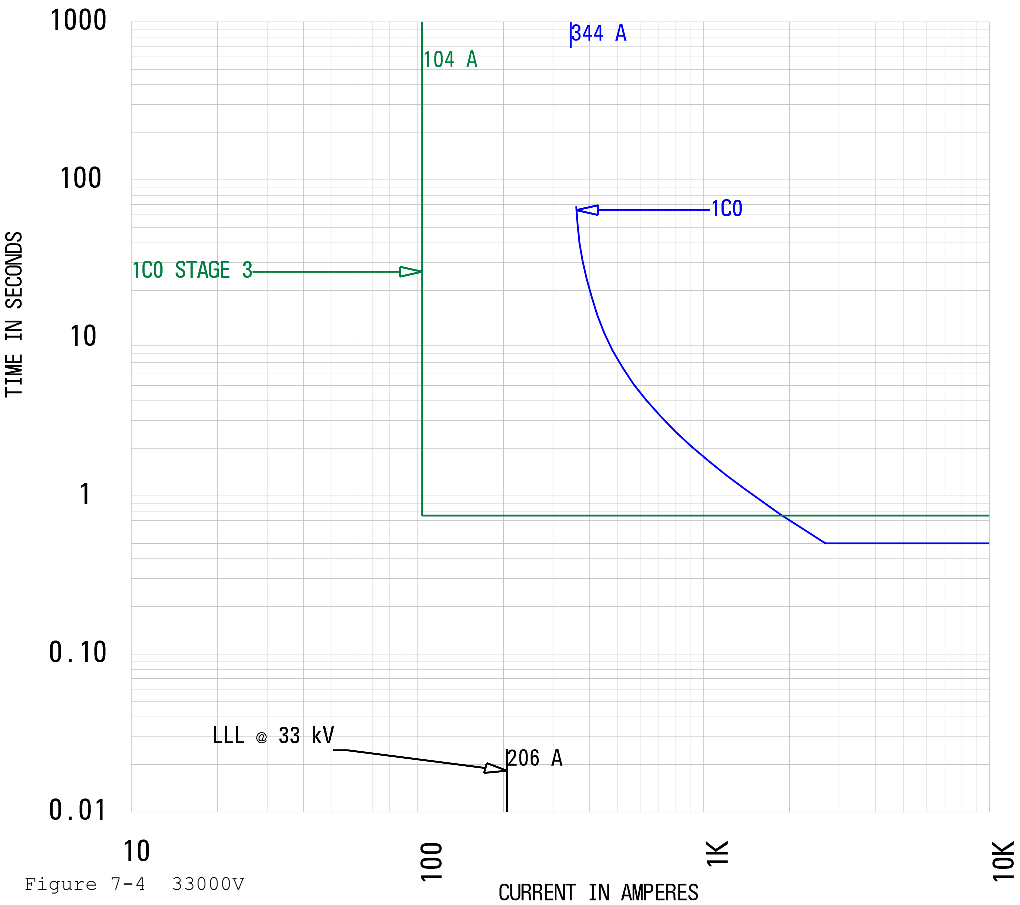
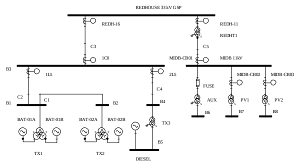


Figure 7.4: Overcurrent Protection at Redhouse BESS/Aggreko Diesel 33 kV – Circuit Breaker 1C0

```
LV Breakers
Name/Type          Description        Frame/Sensor/Plug Settings          SC Ratings(kA)
LLL @ 11 kV        Fault Level Marker  0.0A                 FAULT LEVEL    Interrupting 0.0 0
Specialty Device

LLL @ 33 kV        Fault Level Marker  0.0A                 FAULT LEVEL    Interrupting 0.0 0
Specialty Device

Relays
Name/Type          Description         CT Ratio (A)      Settings
MIDB-CB01 STAGE 3  SCHNEIDER           300 / 1              I>>> 1 (300A)
Electronic         MICOM P341                               tI>>> 0.1 (sec)
                   50/51 OC 50N/51N EF

REDH-11 STAGE 3    SCHNEIDER           400 / 1              I>>> 0.25 (100A)
Electronic         MICOM P14x                               tI>>> 0.3 (sec)
                   50/51 OC 50N/51N EF

REDH-16 STAGE 3    SCHNEIDER           800 / 1              I>>> 0.13 (104A)
Electronic         MICOM P14x                               tI>>> 0.5 (sec)
                   50/51 OC 50N/51N EF

1C0 STAGE 3        SIEMENS             800 / 1              I>>> 0.13 (104A)
Electronic         7SJ82                                    tI>>> 0.75 (sec)
                   50/51 OC 50N/51N EF
```



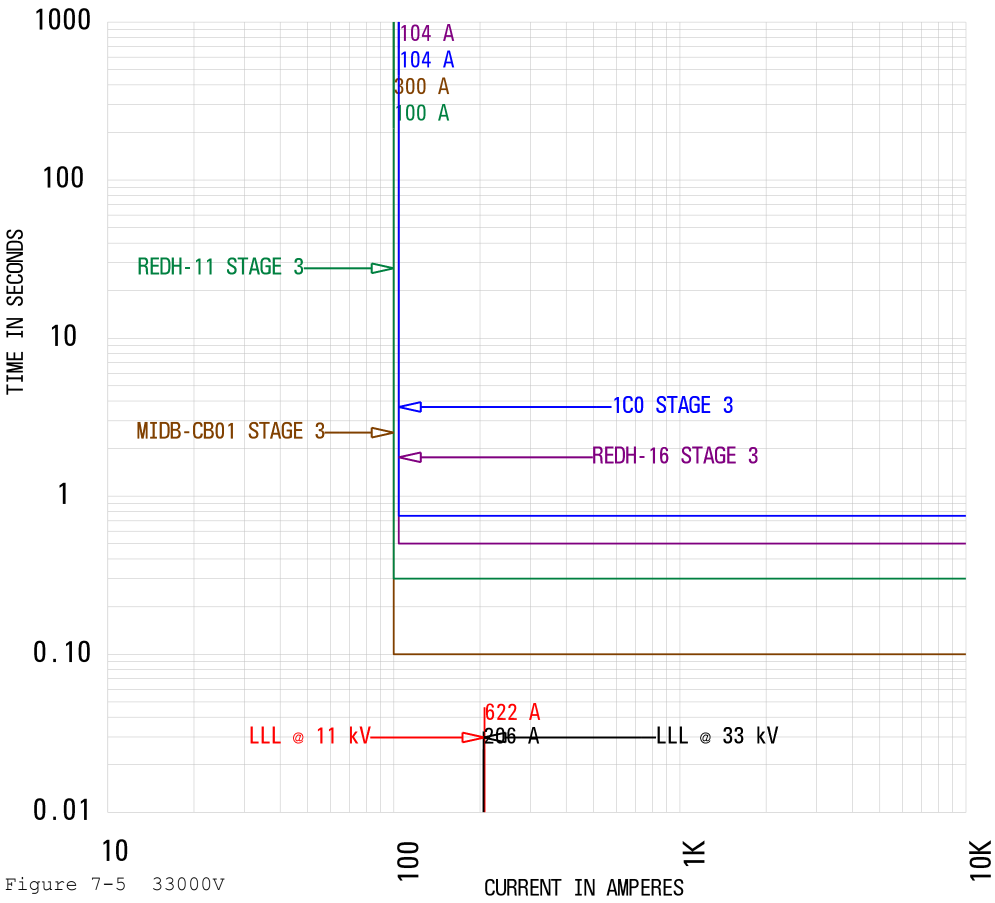


Figure 7.5: Overcurrent Scheme-

8 Other Issues

8.1 Load Flow Considerations

The stage 1 11 kV overcurrent protection at Middle Balbeggie Solar Park is unchanged. The maximum power output from the PV generation is no different from normal operation.

8.2 Earthing Transformer

There is a risk that the Middle Balbeggie PV generation remains connected to the network if 2L5 has tripped and the 33 kV system earth is lost. However, it is assumed the PV generation is grid following rather than grid forming and so cannot remain operational in the absence of an alternative voltage source.

It would be prudent for the tripping on breaker 2L5 (Aggreko Diesel) to intertrip 1L5 (BESS) since loss of 2L5 means loss of the 33 kV earth.

8.3 Power Electronic Interaction

This report does not consider any issues there may be with interaction between the power electronics on the BESS and the Solar PV. Nor does it consider the short circuit ratio achieved at the Balbeggie Solar Park and whether this is sufficient for correct operation of the solar park inverters assuming that these are current source inverters.

Current source inverters rely on a mechanism such as a phased-locked loop (PLL) to stay synchronised to the fundamental component of the voltage waveform. During faults the suppressed voltage magnitude and potentially distorted waveform may lead to those converters falling out of step. This can lead to a “hunting” behaviour manifesting itself in active/reactive power oscillations and/or reduced power/current output during post fault recovery.

Grid Forming voltage source converters, in contrary, do not rely on PLLs as they can generate their own voltage waveform, including during times when they ride through faults. This property enables BESS grid forming converters to be recognised as contributors to fault current as they can temporarily provide fault current in excess of their continuous rating.

9 Conclusions and Recommendations

The conclusions of the protection study undertaken for the Redhouse trial and Middle Balbeggie Solar Park are detailed below.

9.1 Conclusions

9.1.1 The suitability of the Dynamic Voltage Support method for representing the Redhouse BESS in Digsilent should be reviewed by SPEN.

9.1.2 Revised protection settings are proposed for the Redhouse trial where generation is provided by a BESS and diesel generators. Main protection is provided using overcurrent and earth fault protection, back-up protection is provided by undervoltage relays.

9.1.3 It is proposed to change the overcurrent settings at the following locations: -

- 11 kV Middle Balbeggie Solar Park Incomer
- 33 kV Circuit 11 (Redhouse Primary) at Redhouse GSP
- 33 kV Circuit 16 (Redhouse BESS/Aggreko Diesel) at Redhouse GSP
- 33 kV Circuit Breaker 1C0 at the Redhouse BESS/Aggreko Diesel Busbar

Proposed overcurrent settings are detailed in Appendix C.

9.1.4 It is proposed to change the undervoltage settings at the following locations: -

- 33 kV Circuit Breaker 1L5 at the Redhouse BESS/Aggreko Diesel Busbar
- 33 kV Circuit Breaker 2L5 at the Redhouse BESS/Aggreko Diesel Busbar

Proposed undervoltage settings are detailed in Appendix C.

Revised settings have been implemented using Stage 1 undervoltage. As an alternative, consideration could be given to implementing the revised settings using Stage 2.

9.1.5 Overcurrent settings have been selected on the assumption that the Redhouse Primary 24 MVA transformer will be energised using point-on-wave switching.

9.1.6 Overcurrent settings have been chosen to ride through energisation of the Middle Balbeggie Solar Park PV 1.95 MVA transformers.

9.1.7 The proposed undervoltage settings should be reviewed to ensure that they do not interfere with the BESS or diesel energisation sequence. If the BESS voltage were to be ramped up sensitive undervoltage settings could be detrimental.

9.1.8 The maximum power output from the PV generation is no different from normal operation.

9.1.9 It would be prudent for the tripping on breaker 2L5 (Aggreko Diesel) to intertrip 1L5 (BESS) since loss of 2L5 means loss of the 33 kV earth.

9.1.10 All auxiliary transformer LV faults will be cleared by the 10 A fuse on the transformer HV winding. No other protection is sensitive enough to detect such faults. This statement is true for the existing system and is not introduced by the Redhouse trial.

9.1.11 PV transformer LV earth faults will not be detectable on the 33 kV or 11 kV systems since the transformer winding configuration is Dy11. An alternative method such as insulation monitoring will be required. This statement is true for the existing system and is not introduced by the Redhouse trial.

9.1.12 Revised settings are tabulated in Appendix C and illustrated in Appendix D using yellow highlighting.

9.2 Recommendations

9.2.1 Setting philosophy using overcurrent and undervoltage protection should be reviewed to ensure there is not technical conflict with the energising/testing philosophy to be used during the Redhouse trial. A quick reference to the protection philosophy can be made with reference to Appendix D.

9.2.2 Settings detailed in Appendix C should be implemented during the Redhouse trial.

10 References

1 Arcadis Proposal, 10607755 - Quotation for Distributed ReStart - Redhouse Protection Middle Balbeggie, 24 February 2023

2 Digsilent Model, LTDS v2018_2021-02-11 Redhouse BESS.PFD

3 Dynamic Voltage Support of Converters during Grid Faults in Accordance with National Grid Code Requirements, www.mdpi.com/journal/energies, Energies 2020, 13, 2484; doi:10.3390/en13102484 (#018)

4 Digsilent TechRef_StaticGenerator (#019)

5 Email from D. Conkie of SPEN to J. Evans of Arcadis, Regarding BESS Overcurrent Settings on Breaker 1C0, 25 April 2023 (#021)

6 Email from P. Rae of Raelec Engineering Ltd. to J. Evans of Arcadis Regarding BESS and Diesel G99 Protection Settings on Breakers 1L5 and 2L5, 27 April 2023 (#025)

7 Word Document Detailing Protection Settings at Redhouse Grid Supply Point, D Restart Project.DOCX (#013)

8 Middle Balbeggie Solar Park G99 OCC - Middle Balbaggie.PDF (#010)

9 MidBalbeggie_3_24_6_AsBuilt_MV_Electrical SLD.PDF (#003)

10 Schneider Micom P341 Manual, P341_EN_M_Rf7__B5E5__L.PDF (#020)

11 Alsthom Micom P14 Manual, p14x_en_t_c54_ful_maual (#014)

12 Siprotec Manual SIP5_7SJ82-85_V09.50_Manual_C017-K_en (#027)

13 Email from D. Conkie including B1021_Tec_SCS2900_Technical Description 10/5/23

14 Email from D. Conkie – protection analysis check in attachment 12/5/23.

APPENDIX A

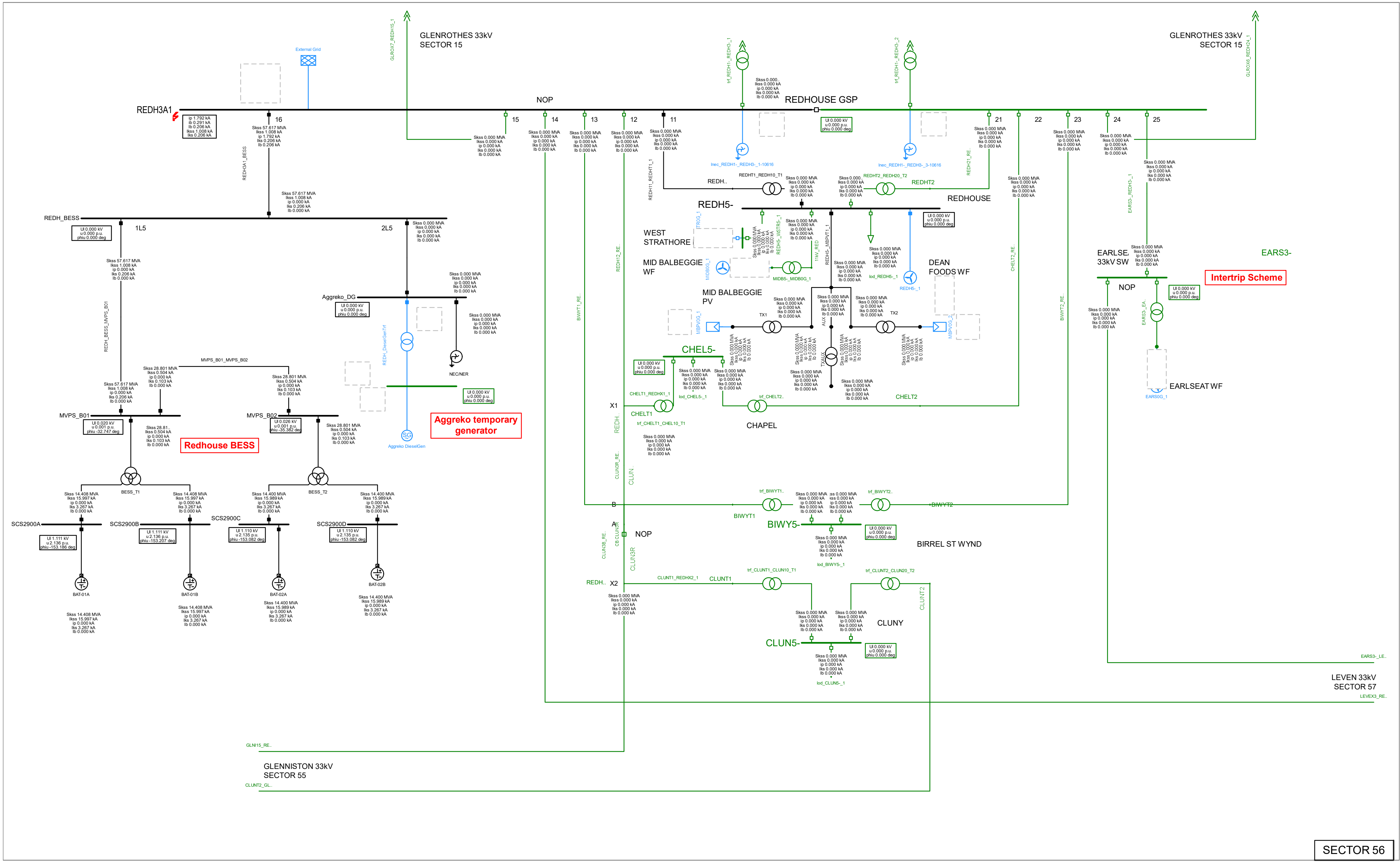
Digsilent Fault Level Plots

STUDY	FAULT TYPE	REDHOUSE BESS STATUS	AGGREKO DIESEL STATUS	NODE NAME	FAULT LOCATION
SC1	LLL	IN	OUT	REDH_BESS	REDHOUSE GSP 33 KV
SC2	LLL	IN	OUT	REDH5-	REDHOUSE PRIMARY 11 KV
SC3	LLL	IN	OUT	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC4	LLL	IN	OUT	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC5	LLL	IN	OUT	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC6	LL	IN	OUT	REDH_BESS	REDHOUSE GSP 33 KV
SC7	LL	IN	OUT	REDH5-	REDHOUSE PRIMARY 11 KV
SC8	LL	IN	OUT	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC9	LL	IN	OUT	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC10	LL	IN	OUT	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC11	LG	IN	OUT	REDH_BESS	REDHOUSE GSP 33 KV
SC12	LG	IN	OUT	REDH5-	REDHOUSE PRIMARY 11 KV
SC13	LG	IN	OUT	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC14	LG	IN	OUT	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC15	LG	IN	OUT	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC16	LLL	IN	IN	REDH_BESS	REDHOUSE GSP 33 KV
SC17	LLL	IN	IN	REDH5-	REDHOUSE PRIMARY 11 KV
SC18	LLL	IN	IN	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC19	LLL	IN	IN	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC20	LLL	IN	IN	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC21	LL	IN	IN	REDH_BESS	REDHOUSE GSP 33 KV
SC22	LL	IN	IN	REDH5-	REDHOUSE PRIMARY 11 KV
SC23	LL	IN	IN	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC24	LL	IN	IN	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC25	LL	IN	IN	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV
SC26	LG	IN	IN	REDH_BESS	REDHOUSE GSP 33 KV
SC27	LG	IN	IN	REDH5-	REDHOUSE PRIMARY 11 KV
SC28	LG	IN	IN	MBPV0G	MIDDLE BALBEGGIE 11 KV
SC29	LG	IN	IN	PV1	MIDDLE BALBEGGIE PV 0.44 KV
SC30	LG	IN	IN	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV

NOTE: SC14 and SC29 have not been conducted since the PV transformers are Dy11 connection (unearthed on the LV) since no fault current flows during these faults.

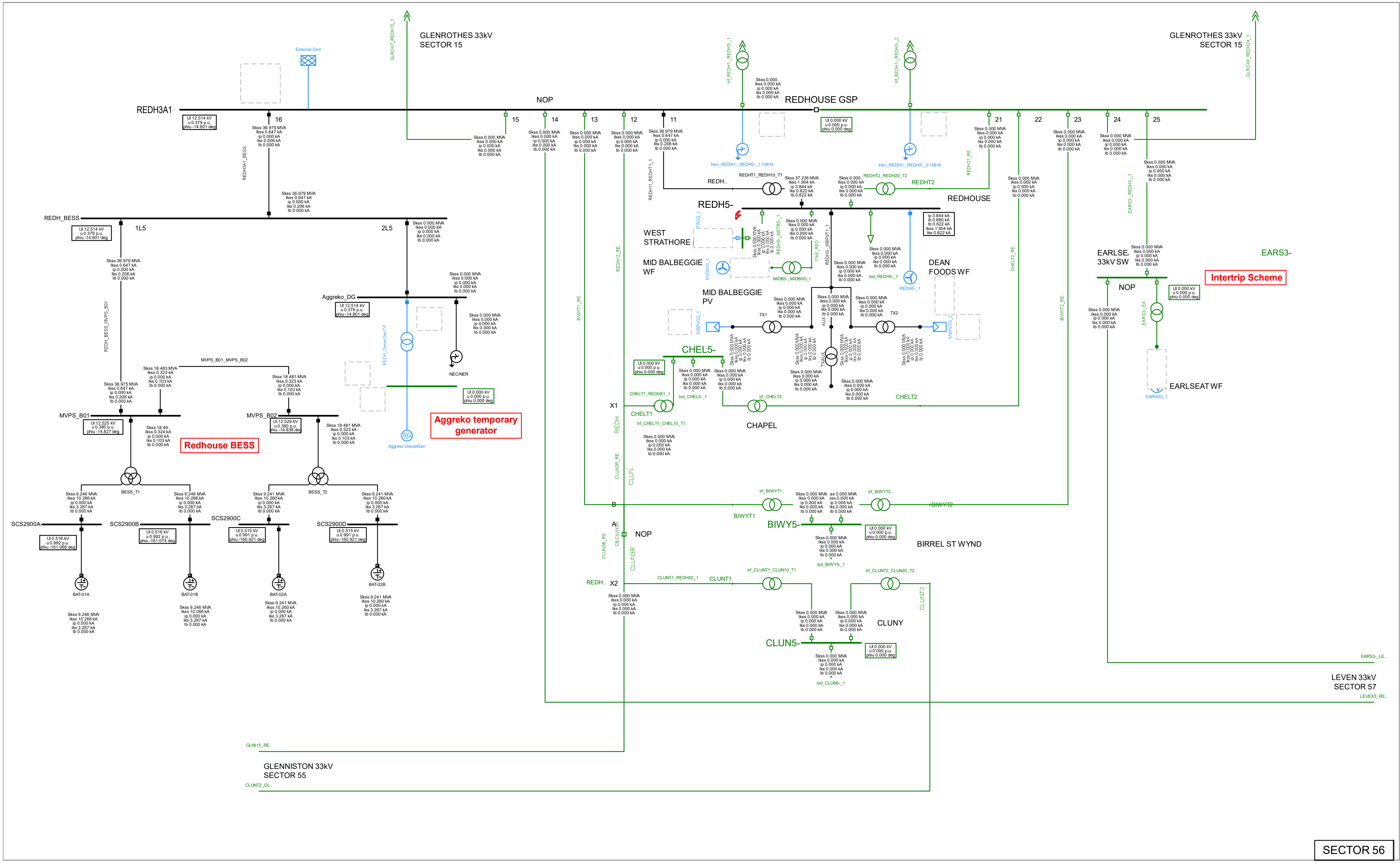
Table A.1: Short-Circuit Studies

SC1 LLL

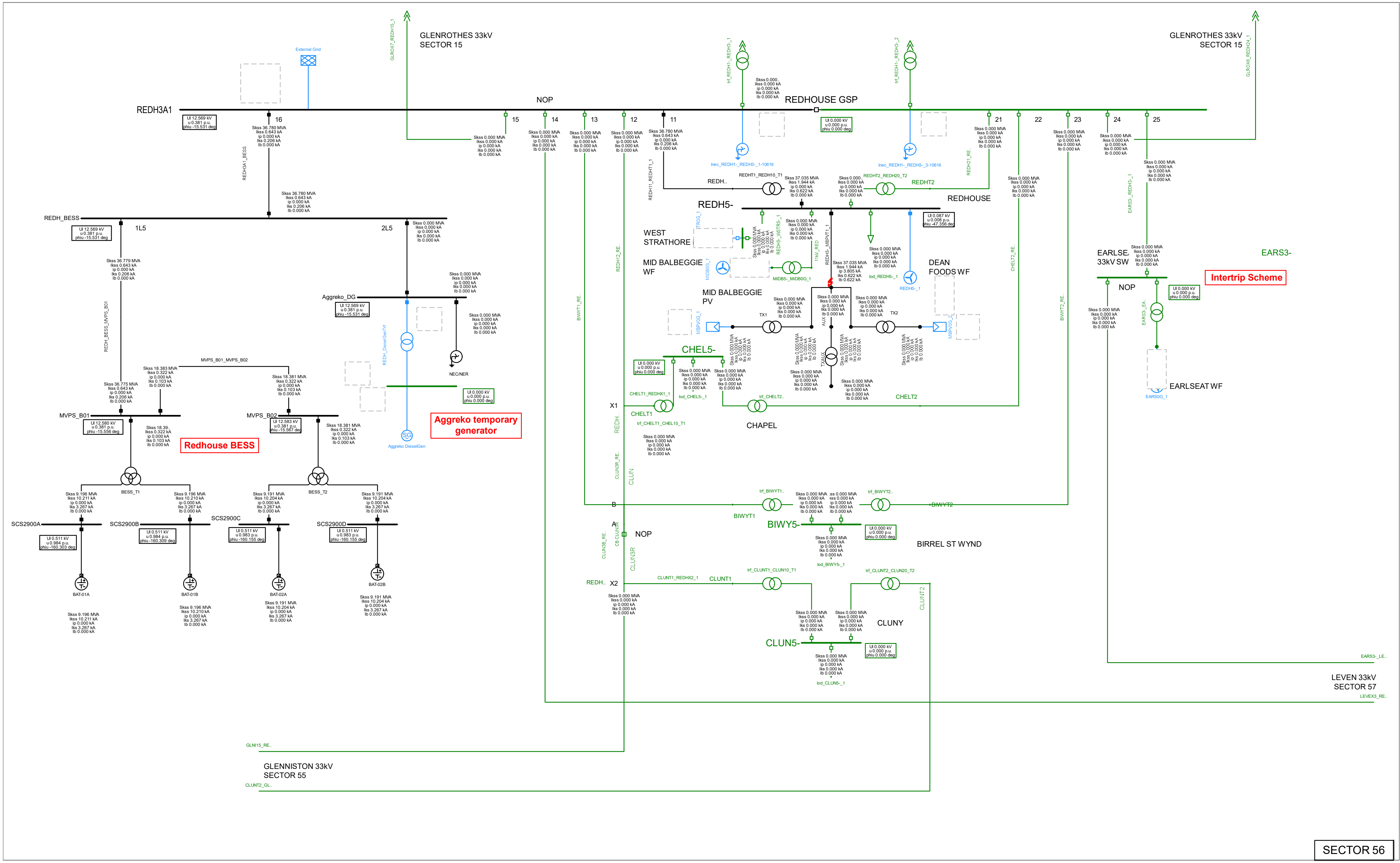


GLENROTHES 33kV
SECTOR 15
REDH3A1
REDHOUSE GSP
NOP
External Grid
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01_MVPS_B02
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
NEC/NER
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
REDHT2
WEST STRATHORE
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
TX1
TX2
CHEL5-
CHELT1
CHELT2
CHAPEL
EARLSE 33kV SW
EARS3-
Intertrip Scheme
EARLSEAT WF
BIWYT1
BIWYT2
BIWY5-
BIRREL ST WYND
CLUNT1
CLUNT2
CLUN5-
CLUNY
X1
X2
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC2 LLL

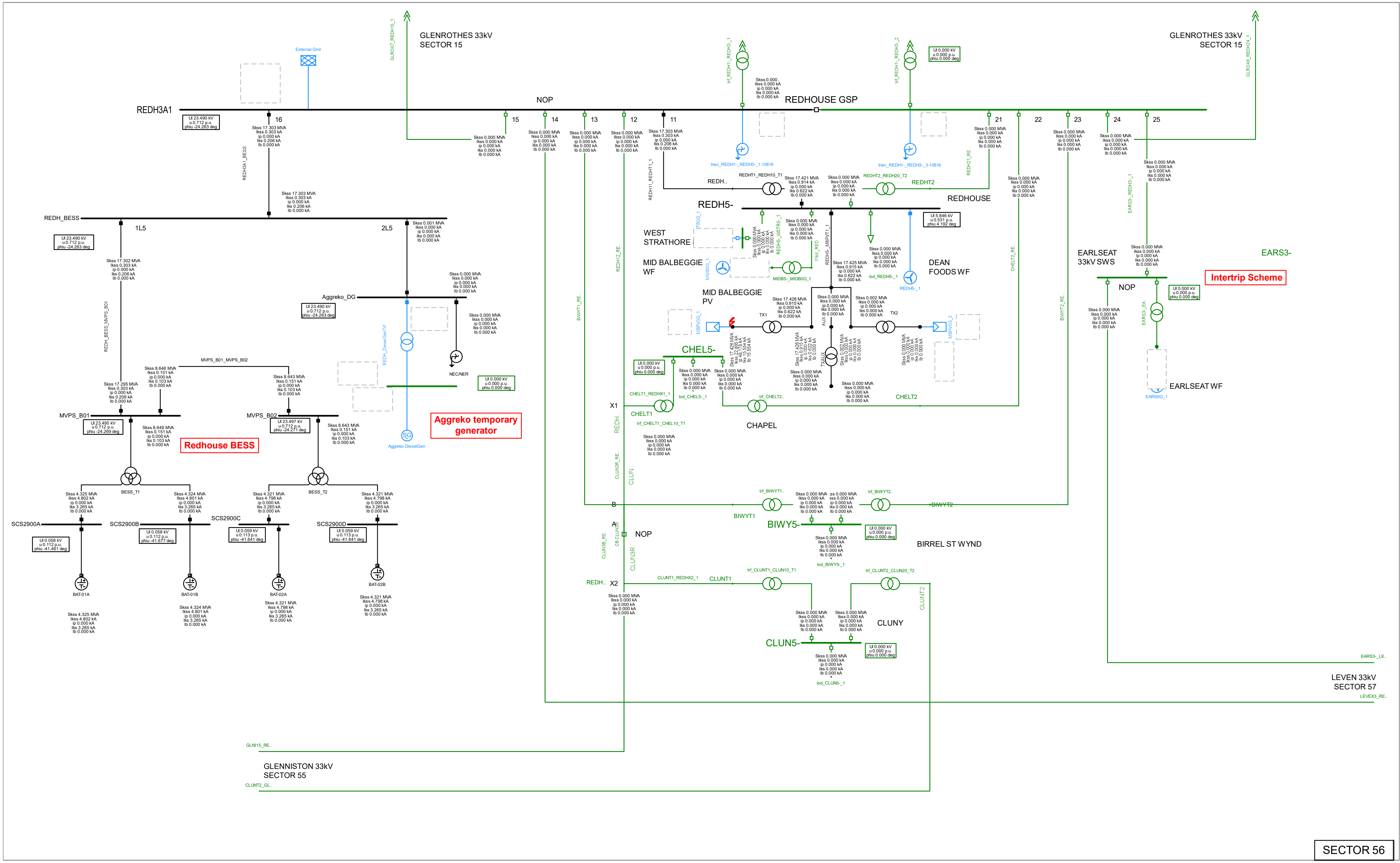

GLENROTHES 33kV SECTOR 15
REDH3A1
NOP
REDHOUSE GSP
GLENROTHES 33kV SECTOR 15
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
NEC/NER
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
WEST STRATHORE
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
TX1
TX2
CHEL5-
CHELT1
CHELT2
CHAPEL
EARLSE 33kV SW
NOP
EARS3-
Intertrip Scheme
EARLSEAT WF
BIWYT1
BIWY5-
BIRREL ST WYND
NOP
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV SECTOR 57
GLENNISTON 33kV SECTOR 55
SECTOR 56

SC3 LLL

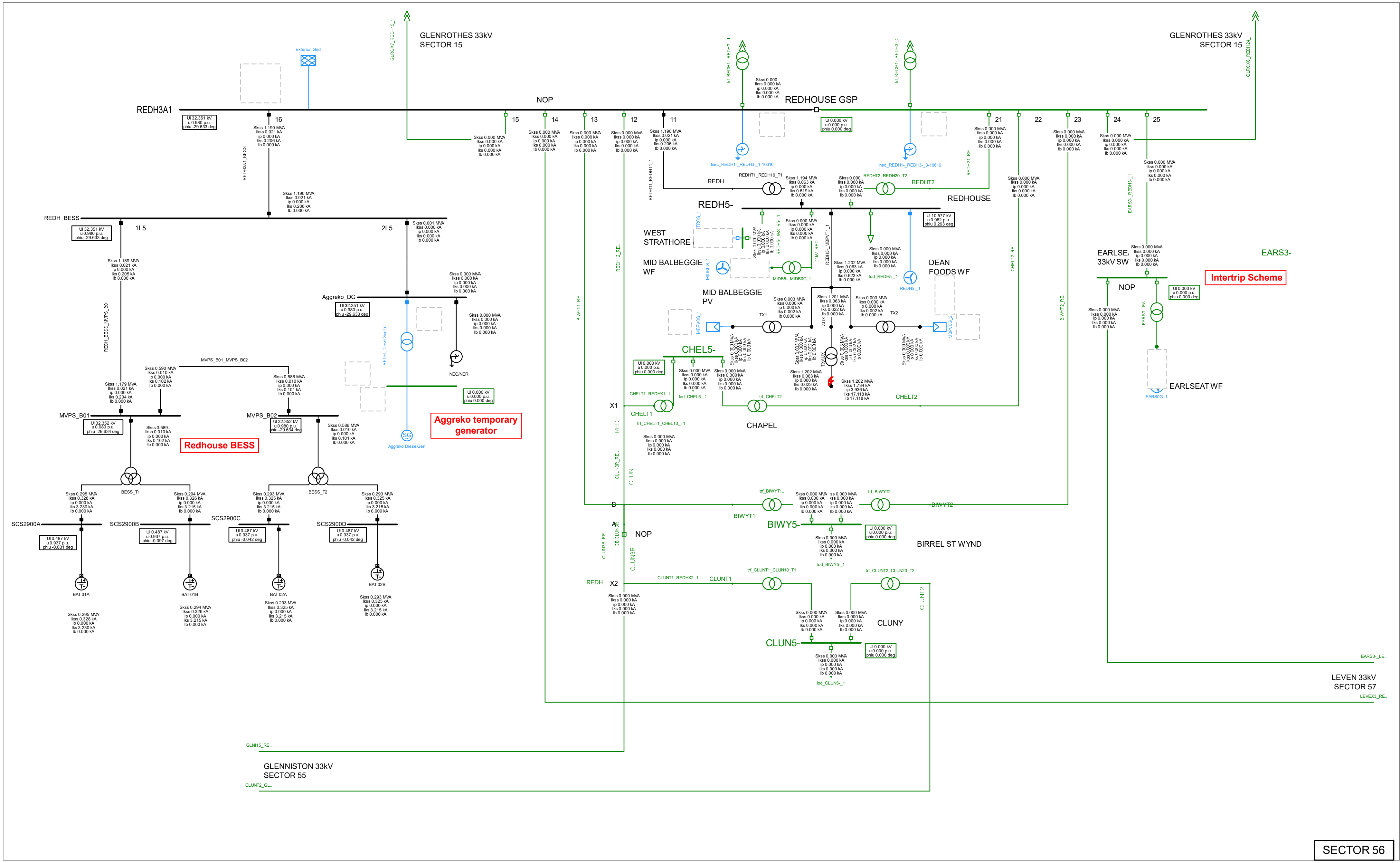


GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
16
15
14
13
12
11
21
22
23
24
25
GLENROTHES 33kV
SECTOR 15
REDH_BESS
1L5
2L5
REDH..
REDHT2
REDHOUSE
REDH5-
WEST
STRATHORE
MID BALBEGGIE
WF
MID BALBEGGIE
PV
DEAN
FOODS WF
EARLSE
33kV SW
EARS3-
Intertrip Scheme
NOP
Aggreko_DG
TX1
TX2
CHEL5-
EARLSEAT WF
NEC/NER
MVPS_B01_MVPS_B02
X1
CHELT1
CHAPEL
CHELT2
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary
generator
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
B
BIWYT1
BIWY5-
BIWYT2
A
NOP
BIRREL ST WYND
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH..
X2
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC4 LLL

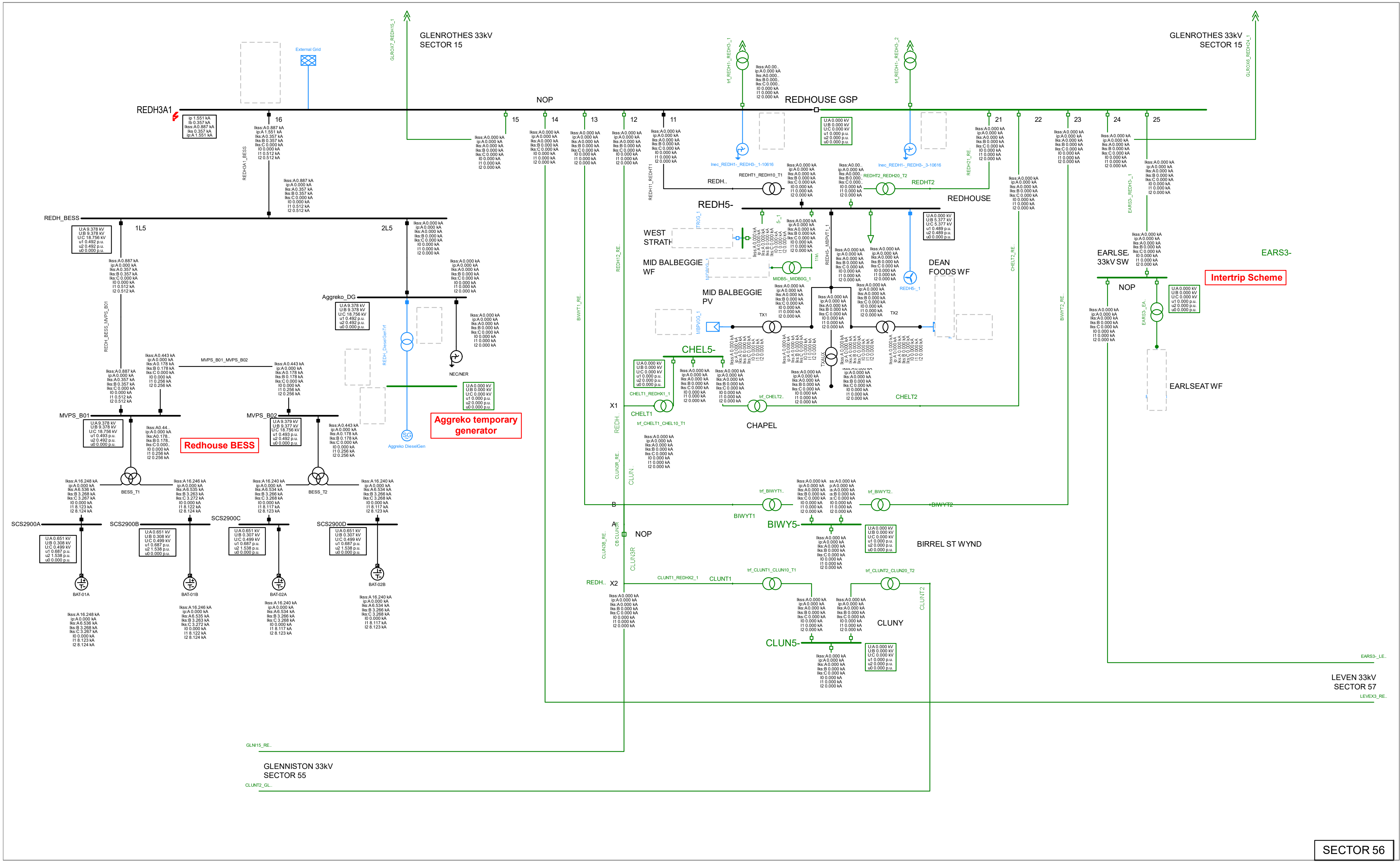

GLENROTHES 33kV
SECTOR 15
REDH3A1
NOP
REDHOUSE GSP
GLENROTHES 33kV
SECTOR 15
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
WEST STRATHONE
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
CHEL5-
CHELT1
CHELT2
CHAPEL
TX1
TX2
EARLSEAT 33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
BIWYT1
BIWY5-
BIRREL ST WYND
NOP
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC5 LLL



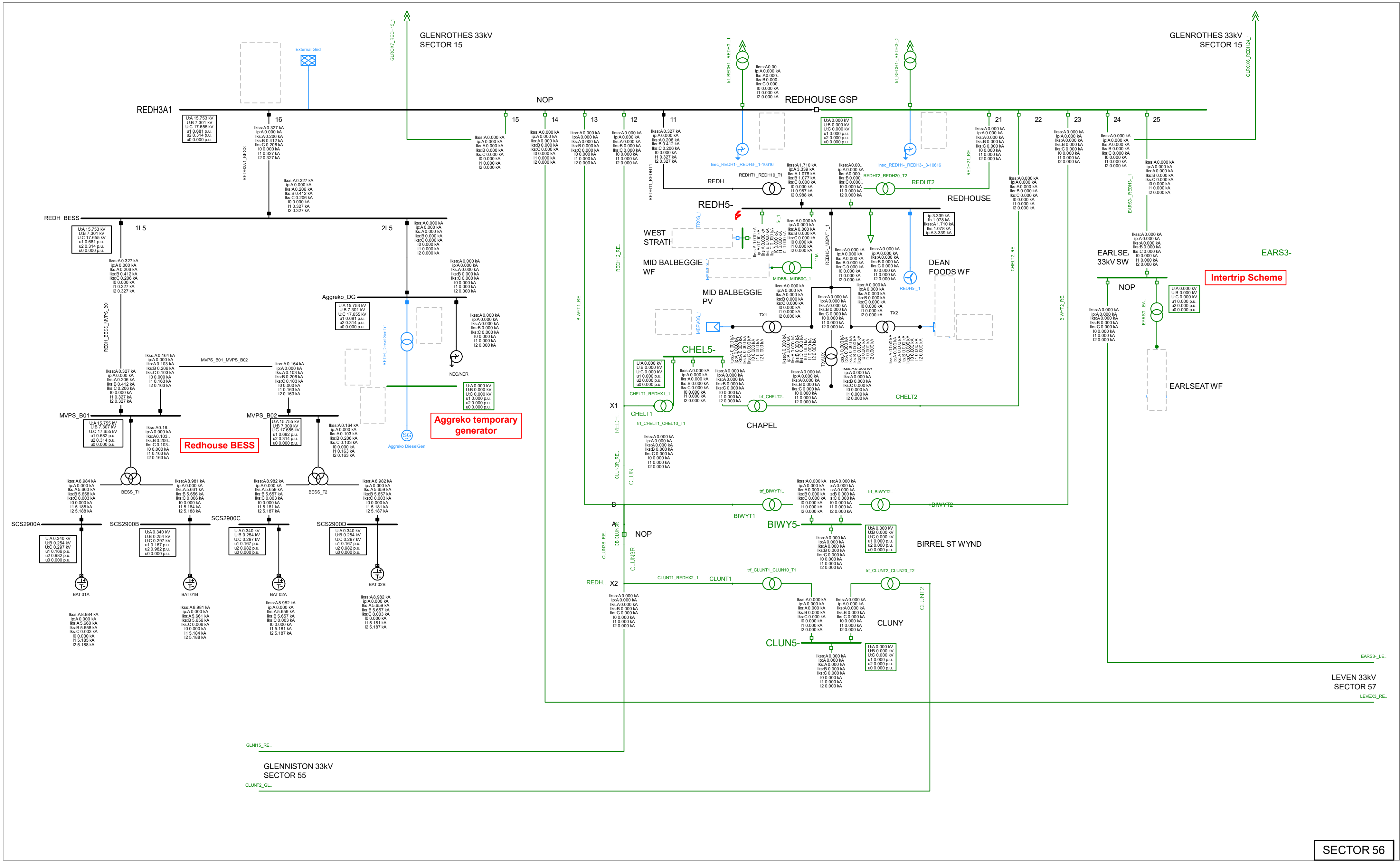
GLENROTHES 33kV
SECTOR 15
REDH3A1
NOP
REDHOUSE GSP
REDH_BESS
1L5
2L5
Aggreko_DG
REDH5-
REDHOUSE
REDHT2
WEST STRATHORE
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
EARLSE 33kV SW
EARS3-
Intertrip Scheme
EARLSEAT WF
CHEL5-
CHELT1
CHELT2
CHAPEL
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
BIWYT1
BIWY5-
BIRREL ST WYND
CLUNT1
CLUN5-
CLUNY
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC6 LL



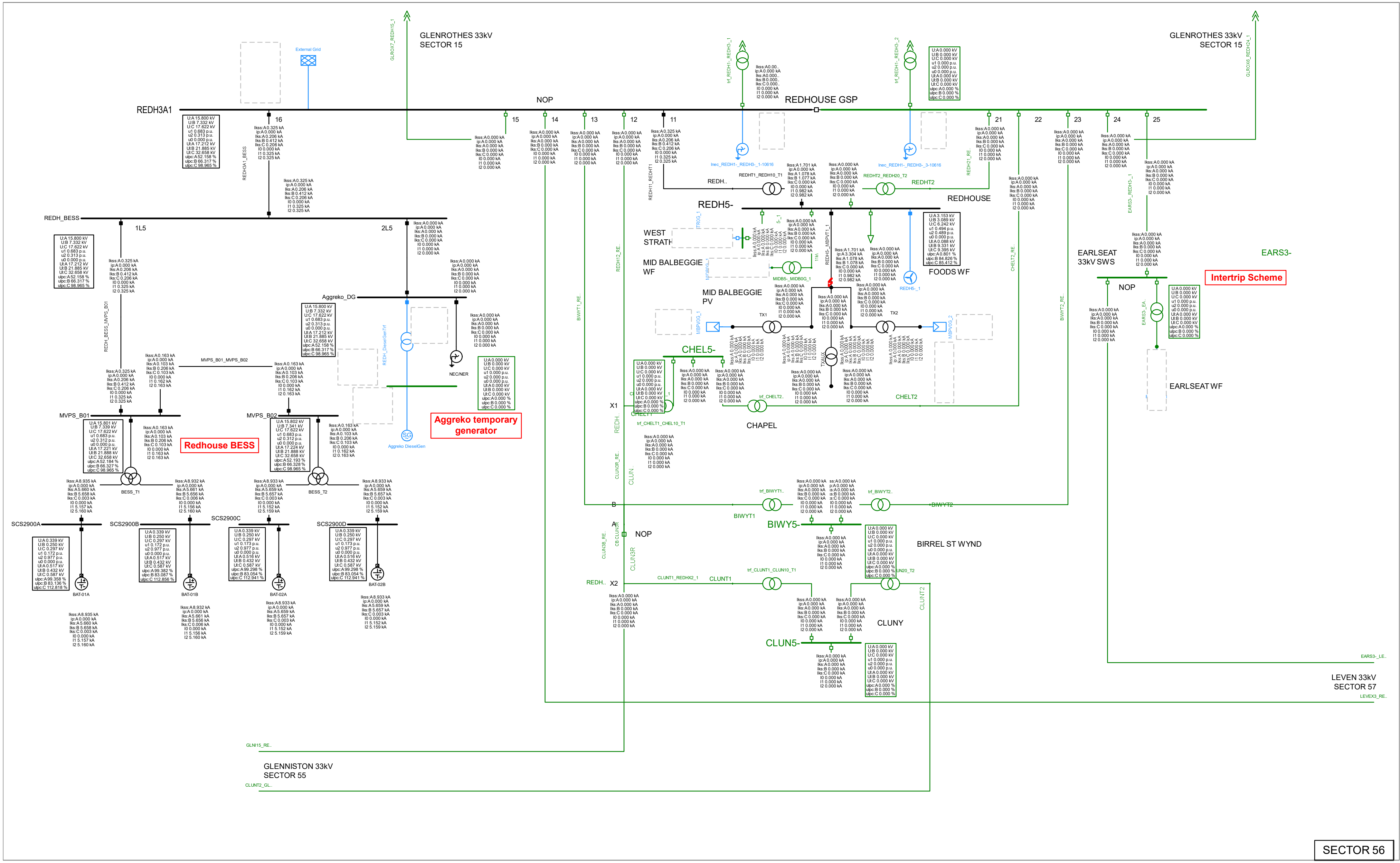
SECTOR 56

SC7 LL

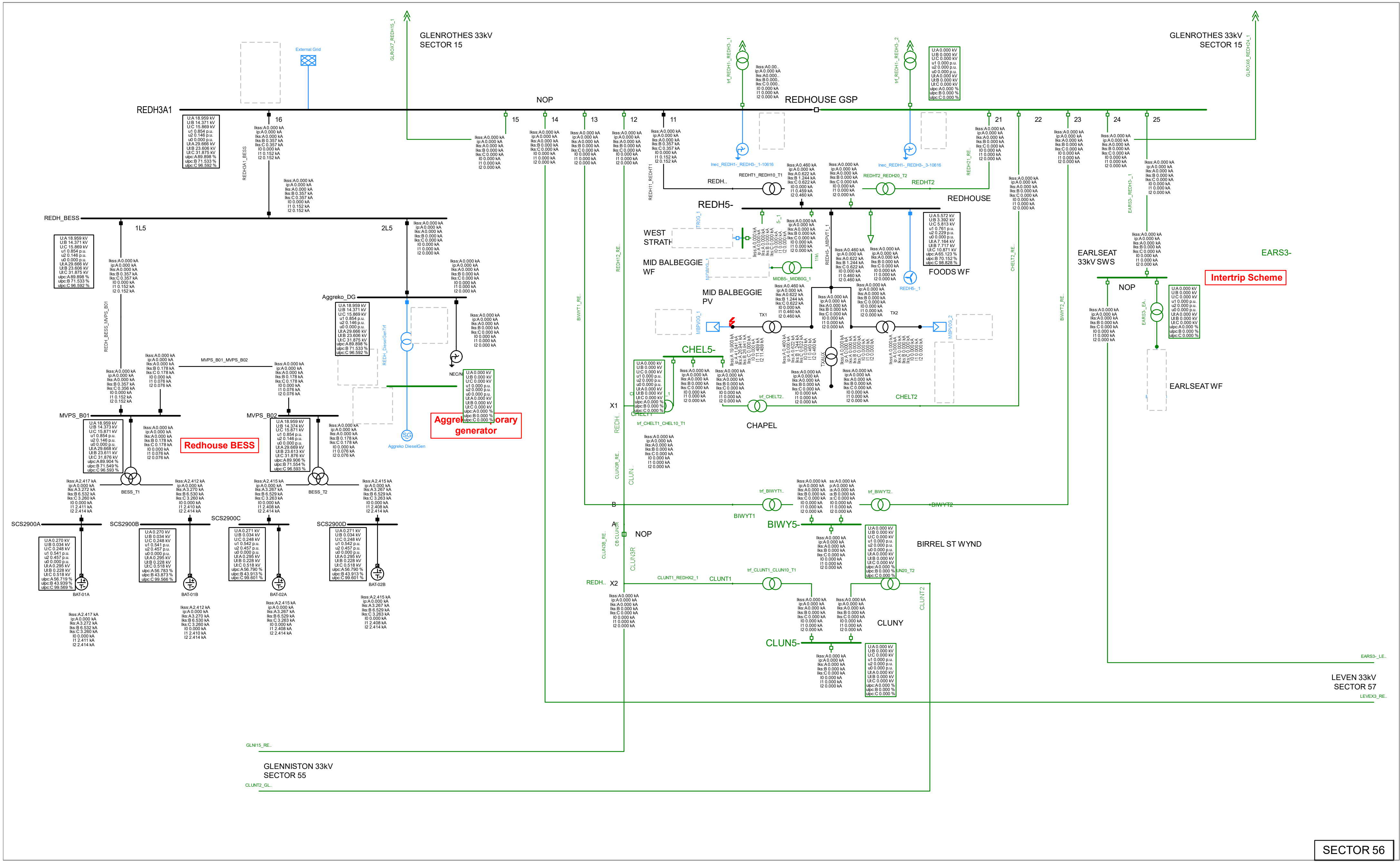


SECTOR 56

SC8 LL

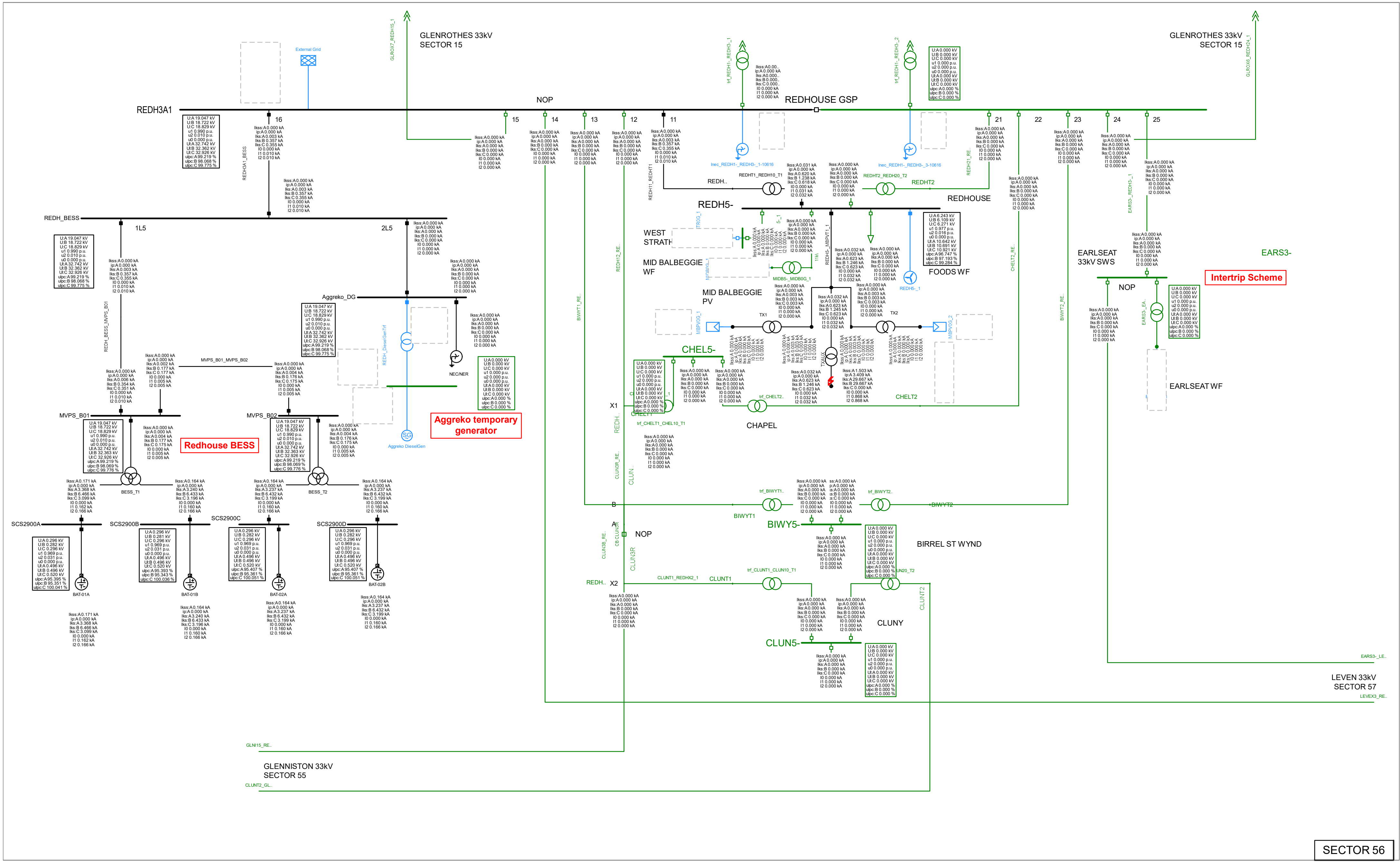

GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
GLENROTHES 33kV
SECTOR 15
16
15
14
13
12
11
21
22
23
24
25
REDH_BESS
1L5
2L5
Aggreko_DG
REDH5-
REDHOUSE
REDHT2
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
FOODS WF
EARLSEAT
33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
TX1
TX2
CHEL5-
CHAPEL
CHELT2
NEC/NER
Aggreko temporary
generator
Aggreko DieselGen
MVPS_B01
MVPS_B02
MVPS_B01_MVPS_B02
Redhouse BESS
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
X1
B
A
NOP
X2
BIWYT1
BIWY5-
BIRREL ST WYND
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC9 LL

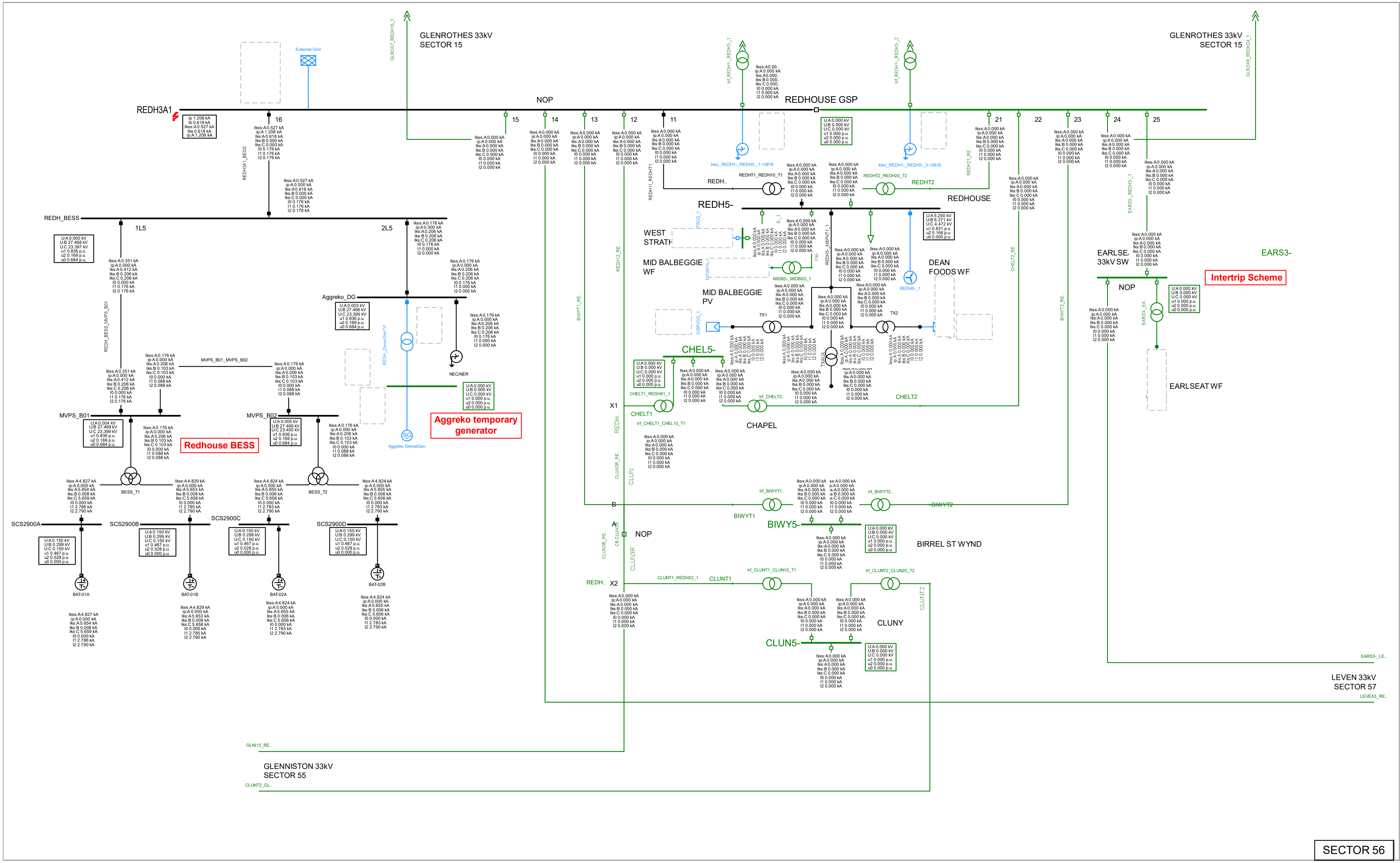


GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01_MVPS_B02
MVPS_B01
MVPS_B02
Redhouse BESS
generator
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
Aggreko DieselGen
REDH5-
REDHOUSE
REDHT2
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
TX1
TX2
FOODS WF
CHEL5-
CHELT2
CHAPEL
X1
B
A
NOP
X2
BIWYT1
BIWY5-
BIWYT2
BIRREL ST WYND
CLUNT1
CLUNY
CLUN5-
EARLSEAT
33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

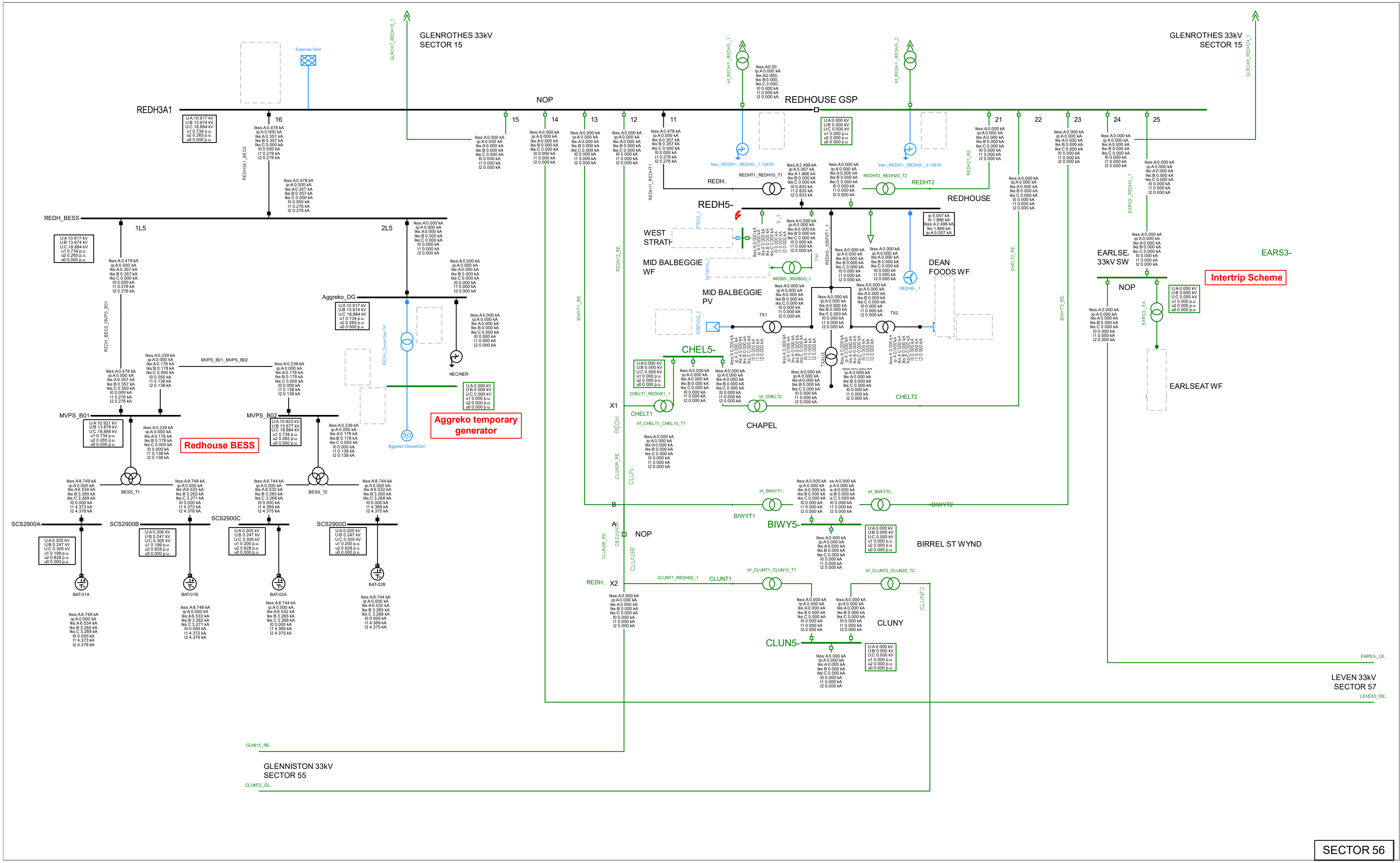
SC10 LL


GLENROTHES 33kV
SECTOR 15
NOP
REDH3A1
REDHOUSE GSP
External Grid
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01_MVPS_B02
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
NEC/NER
Aggreko DieselGen
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
REDHT2
WEST STRATH
MID BALBEGGIE WF
MID BALBEGGIE PV
FOODS WF
TX1
TX2
CHEL5-
CHAPEL
CHELT2
X1
X2
B
A
NOP
BIWYT1
BIWY5-
BIRREL ST WYND
CLUNT1
CLUN5-
CLUNY
EARLSEAT 33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

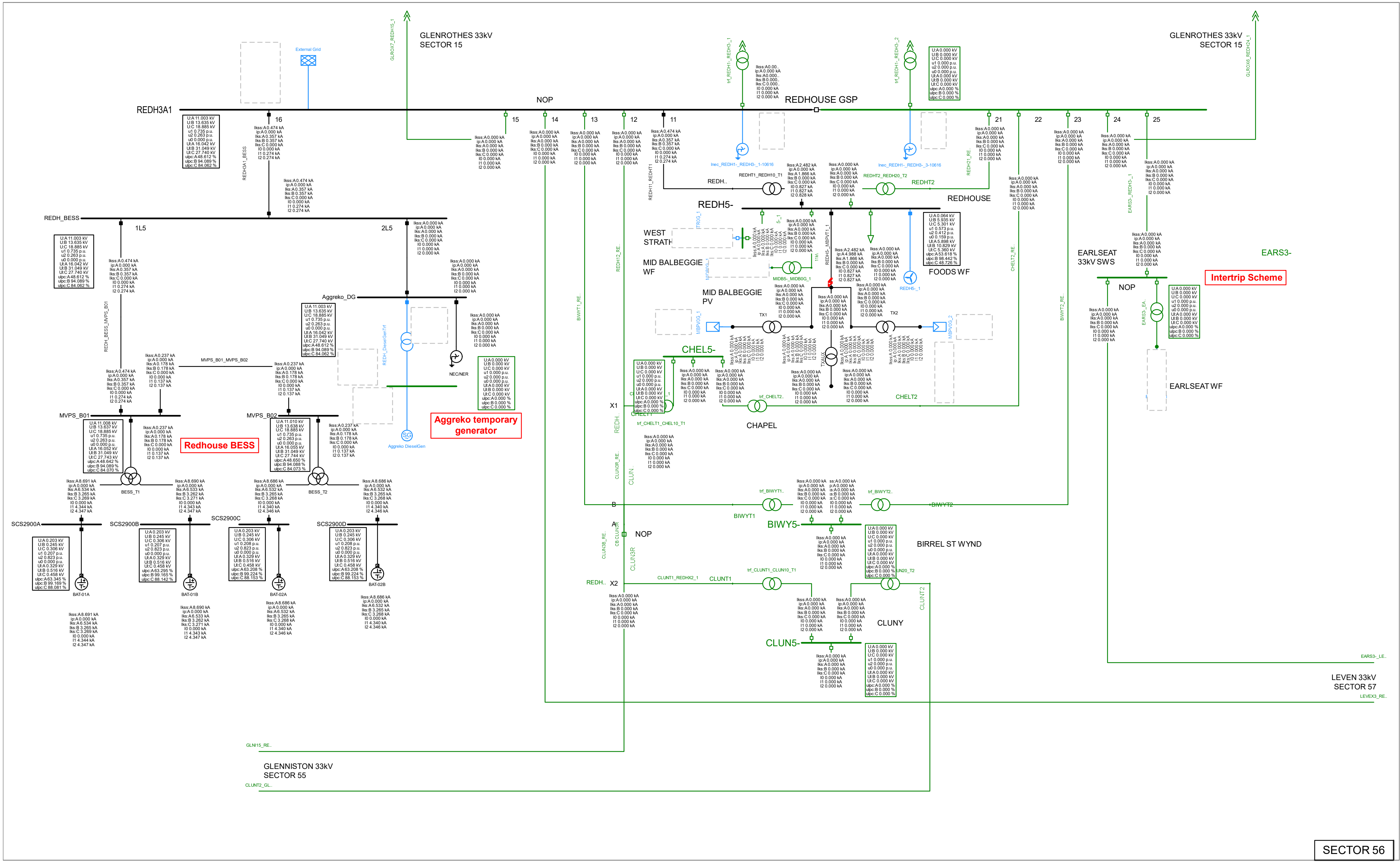
SC11 LG


GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
GLENROTHES 33kV
SECTOR 15
REDH_BESS
1L5
2L5
Aggreko_DG
REDH5-
REDHOUSE
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
DEAN
FOODS WF
EARLSE
33kV SW
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
MVPS_B01
MVPS_B02
MVPS_B01_MVPS_B02
NEC/NER
Aggreko temporary
generator
Redhouse BESS
CHEL5-
CHELT1
CHELT2
CHAPEL
X1
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
BIWY5-
BIRREL ST WYND
NOP
CLUNT1
CLUN5-
CLUNY
X2
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC12 LG

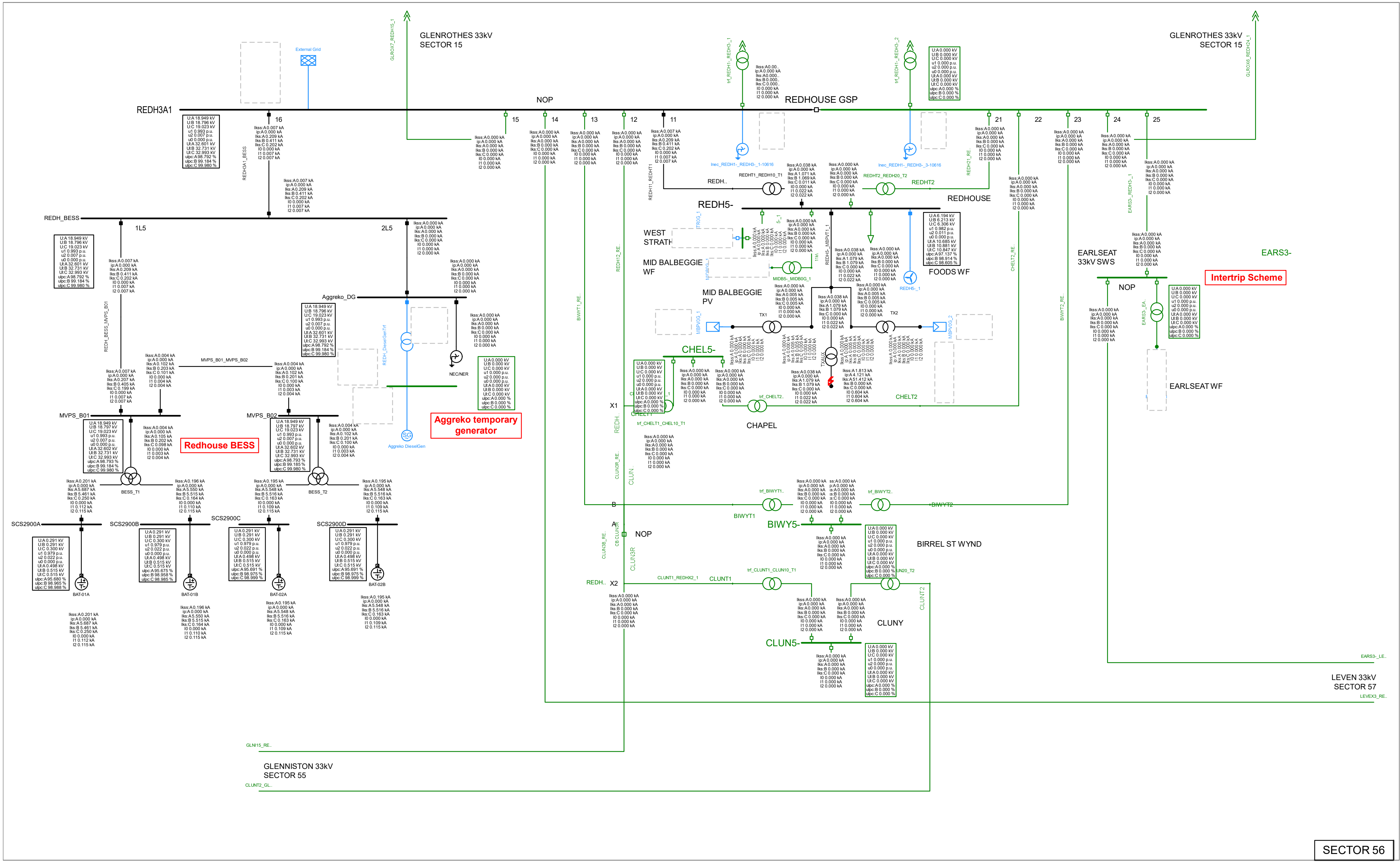

GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01_MVPS_B02
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
Aggreko DieselGen
NEC/NER
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHT2
REDHOUSE
WEST STRATH
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
TX1
TX2
CHEL5-
CHELT1
CHELT2
CHAPEL
X1
X2
EARLSE 33kV SW
EARS3-
Intertrip Scheme
EARLSEAT WF
BIWYT1
BIWY5-
BIRREL ST WYND
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC13 LG



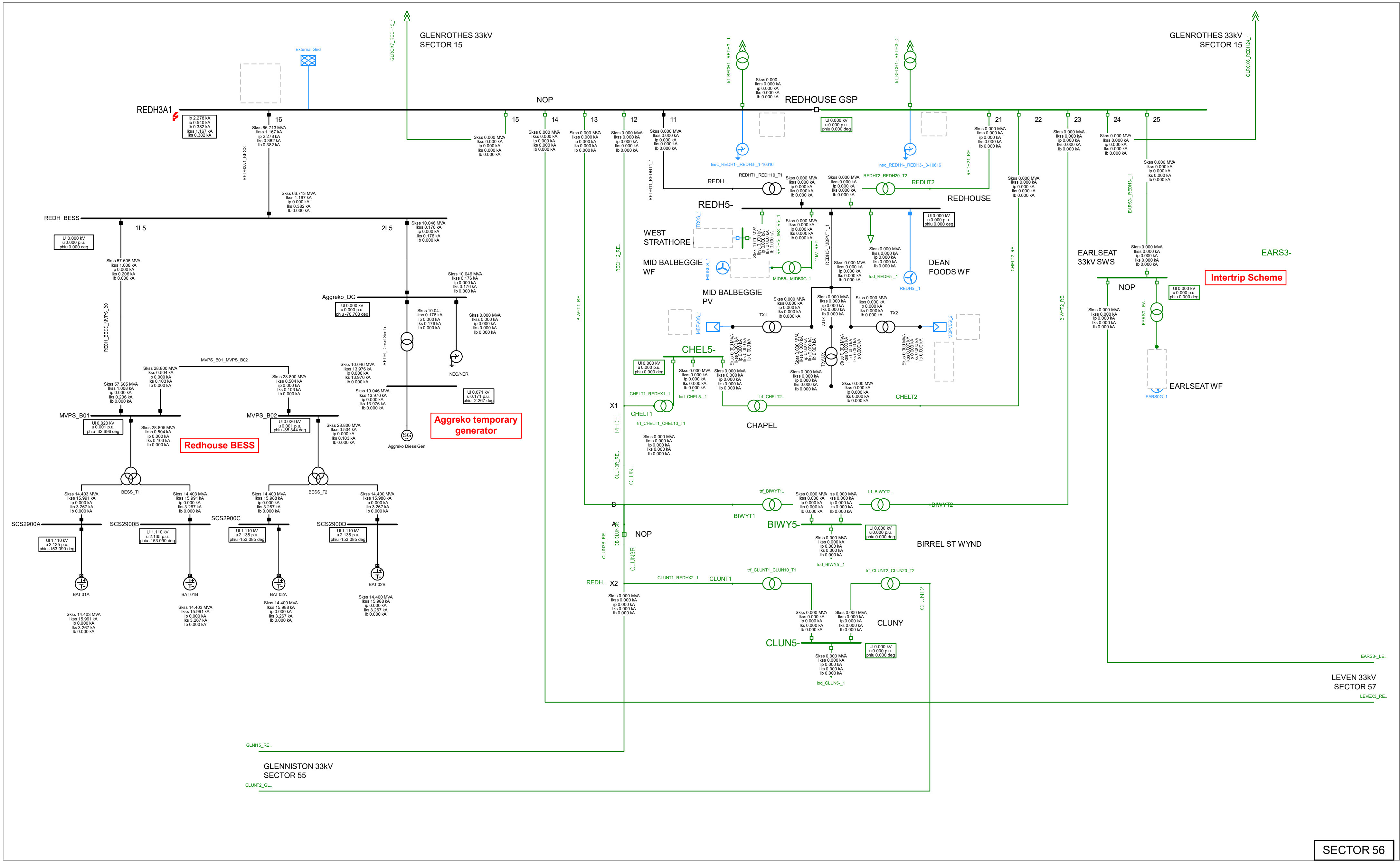
GLENROTHES 33kV
SECTOR 15
GLENROTHES 33kV
SECTOR 15
REDH3A1
NOP
REDHOUSE GSP
REDH_BESS
1L5
2L5
Aggreko_DG
REDH5-
REDHOUSE
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
FOODS WF
EARLSEAT
33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
CHEL5-
CHAPEL
CHELT2
MVPS_B01
MVPS_B02
MVPS_B01_MVPS_B02
Redhouse BESS
Aggreko temporary
generator
NEC/NER
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
X1
B
A
NOP
X2
BIWYT1
BIWY5-
BIRREL ST WYND
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC15 LG



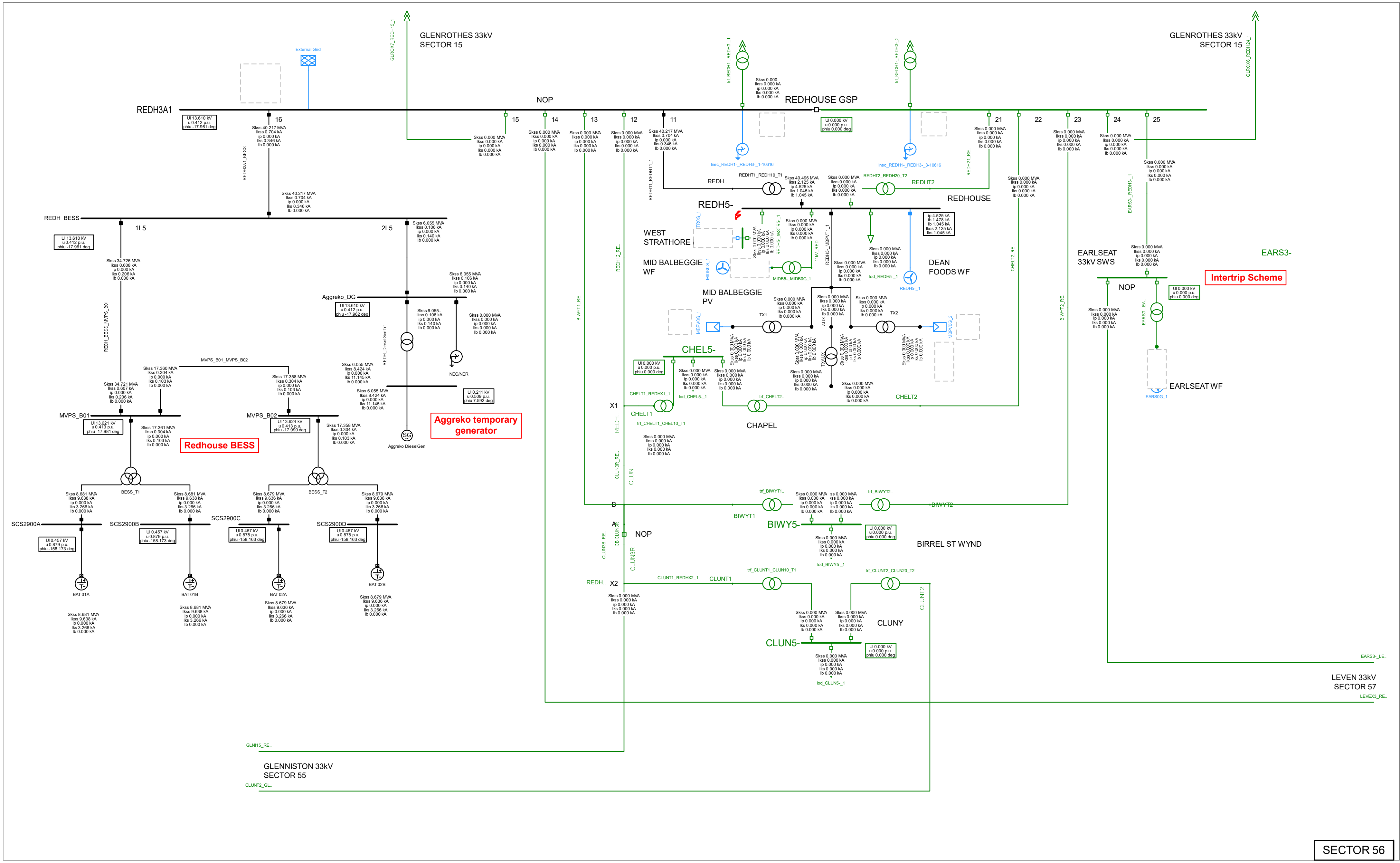
GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
GLENROTHES 33kV
SECTOR 15
REDH_BESS
1L5
2L5
Aggreko_DG
REDH5-
REDHOUSE
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
FOODS WF
EARLSEAT
33kV SWS
EARS3-
NOP
Intertrip Scheme
EARLSEAT WF
CHEL5-
CHAPEL
CHELT2
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary
generator
NEC/NER
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
X1
B
A
NOP
X2
BIWYT1
BIWY5-
BIRREL ST WYND
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC16 LLL



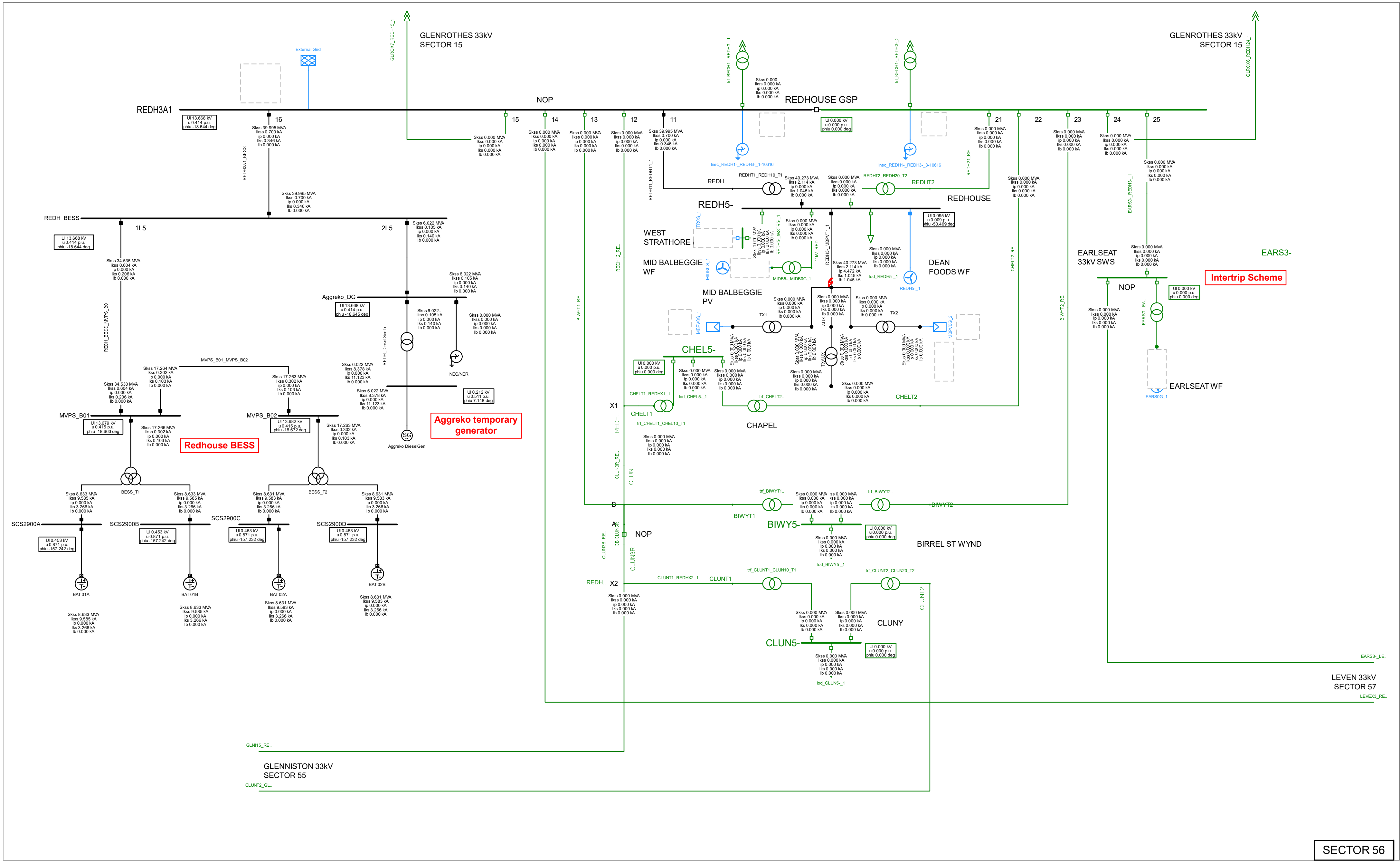
SECTOR 56

SC17 LLL



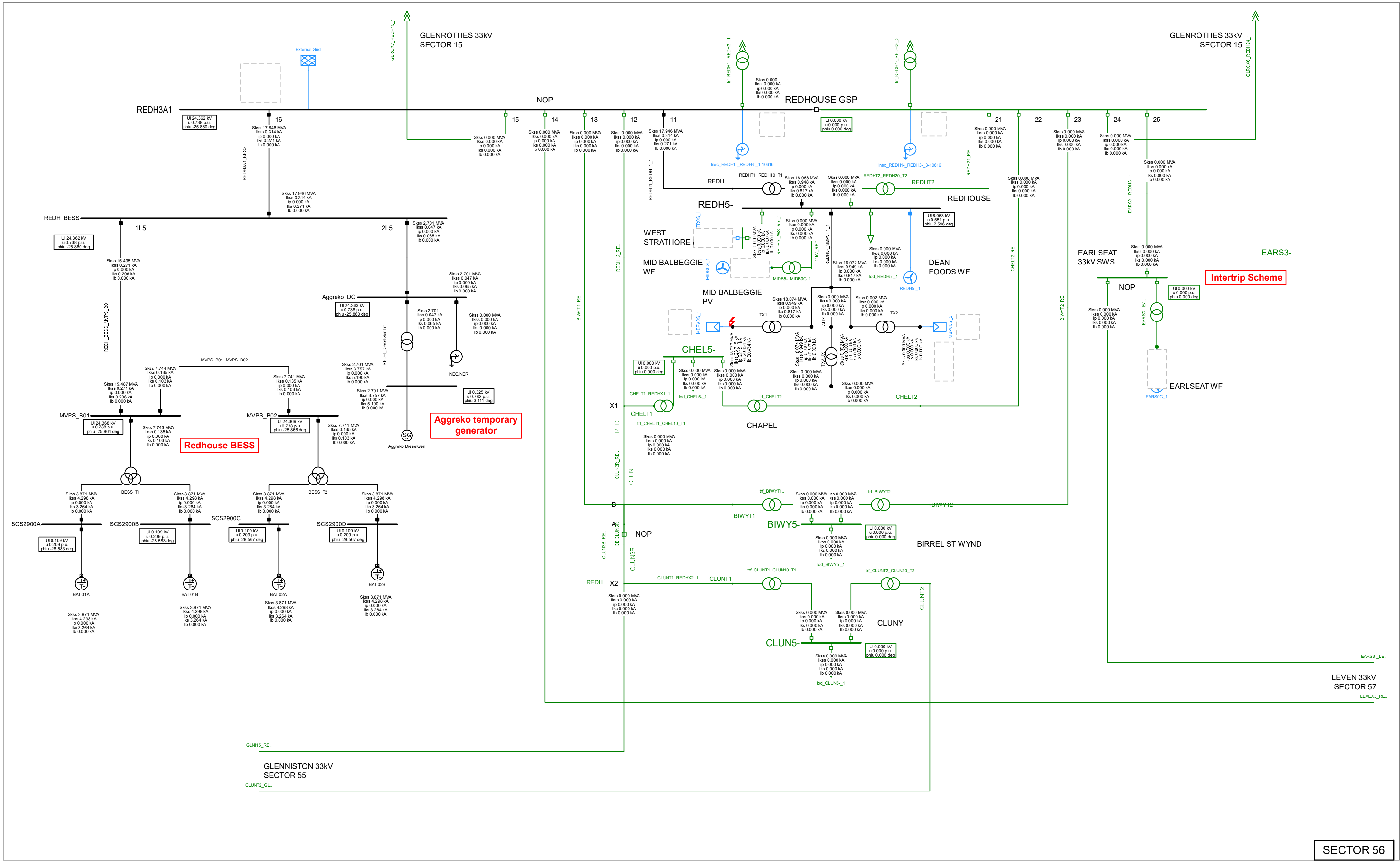
GLENROTHES 33kV
SECTOR 15
REDH3A1
NOP
REDHOUSE GSP
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BESS_T1
BESS_T2
BAT-01A
BAT-01B
BAT-02A
BAT-02B
NEC/NER
Aggreko DieselGen
REDH5-
REDHOUSE
WEST STRATHORE
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
TX1
TX2
CHEL5-
CHELT1
CHELT2
CHAPEL
EARLSEAT 33kV SWS
EARS3-
Intertrip Scheme
EARLSEAT WF
BIWY5-
BIWYT1
BIRREL ST WYND
CLUNT1
CLUNT2
CLUN5-
CLUNY
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
15
14
13
12
11
16
21
22
23
24
25
X1
X2
SECTOR 56

SC18 LLL



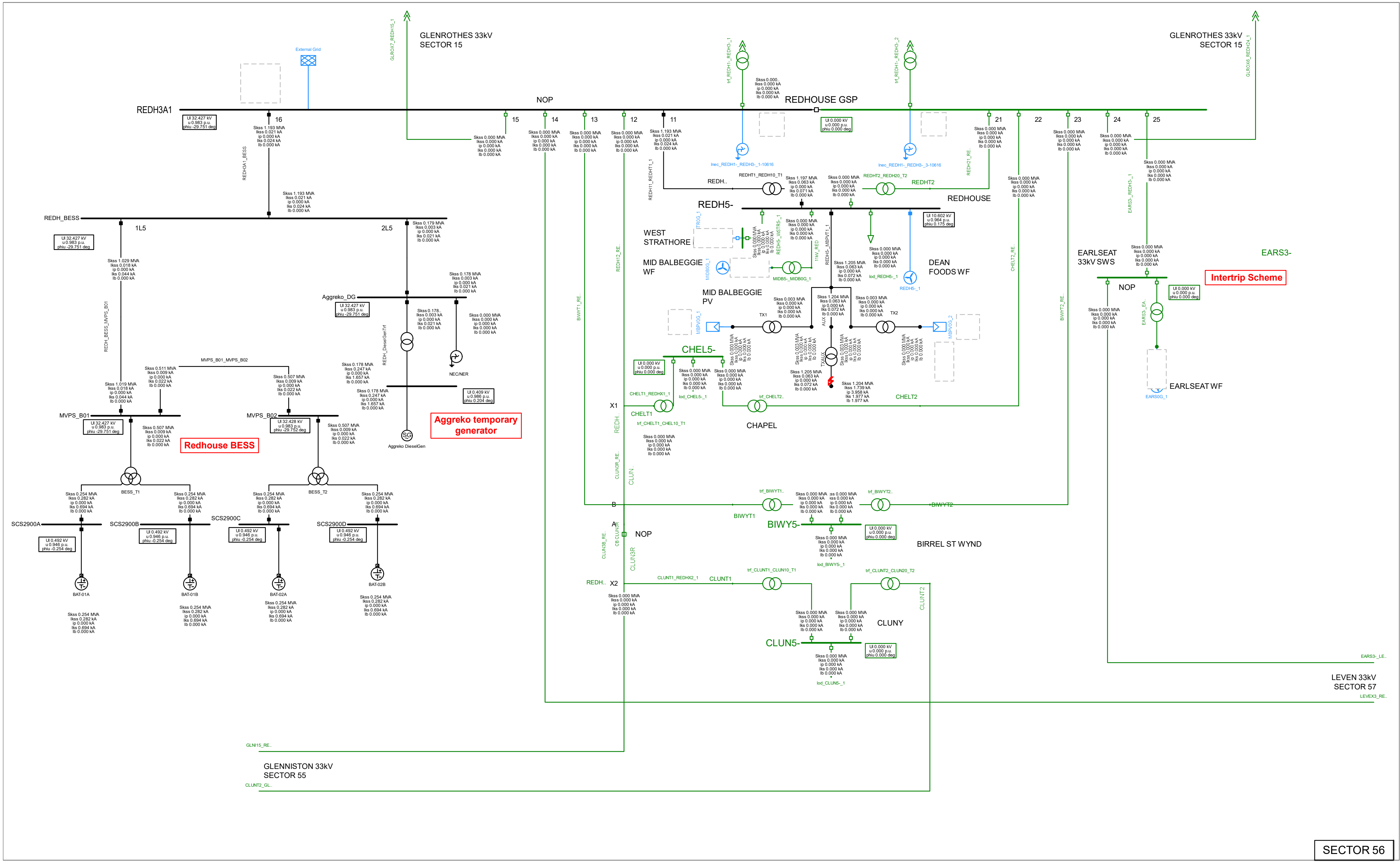
SECTOR 56

SC19 LLL



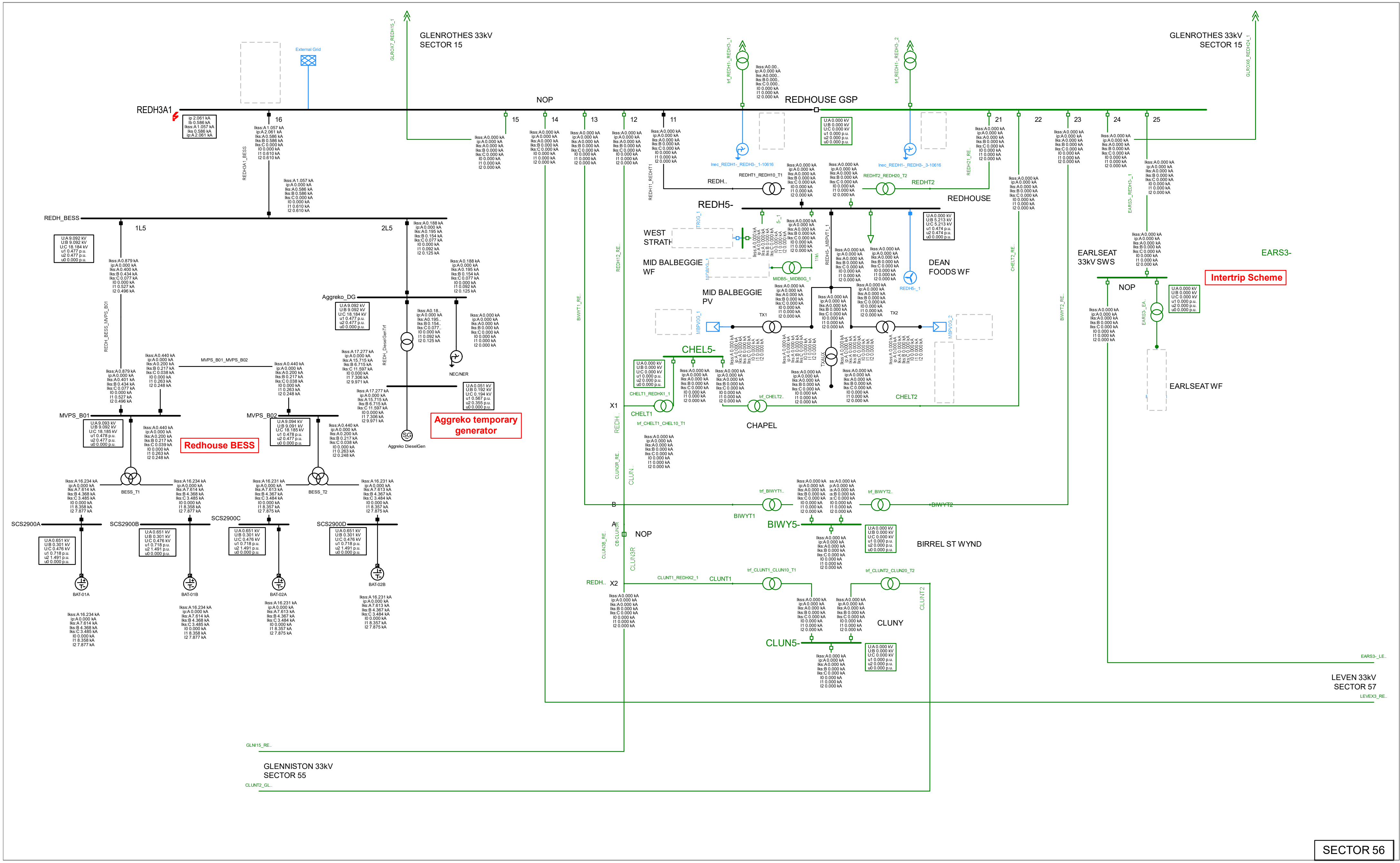
GLENROTHES 33kV
SECTOR 15
REDH3A1
NOP
REDHOUSE GSP
External Grid
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01_MVPS_B02
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
Aggreko DieselGen
NEC/NER
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
REDHT2
WEST STRATHORE
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
TX1
TX2
CHEL5-
CHELT1
CHELT2
CHAPEL
EARLSEAT 33kV SWS
EARS3-
Intertrip Scheme
EARLSEAT WF
BIWYT1
BIWYT2
BIWY5-
BIRREL ST WYND
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC20 LLL



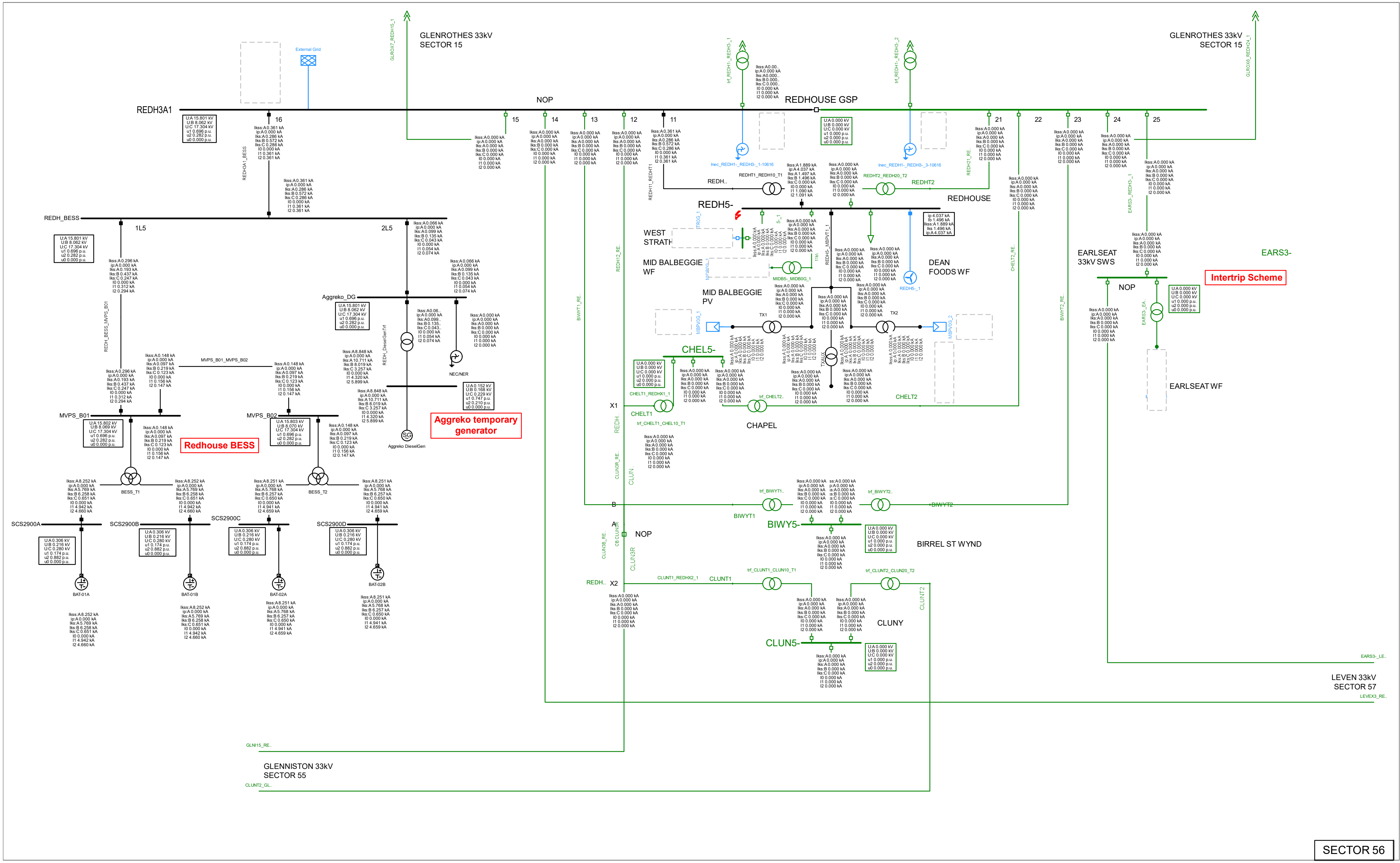
GLENROTHES 33kV
SECTOR 15
REDH3A1
NOP
REDHOUSE GSP
16
15
14
13
12
11
21
22
23
24
25
REDH_BESS
1L5
2L5
Aggreko_DG
REDH5-
REDHOUSE
WEST
STRATHORE
MID BALBEGGIE
WF
MID BALBEGGIE
PV
DEAN
FOODS WF
EARLSEAT
33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
CHEL5-
CHAPEL
CHELT1
CHELT2
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary
generator
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
BIWY5-
BIRREL ST WYND
NOP
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC21 LL

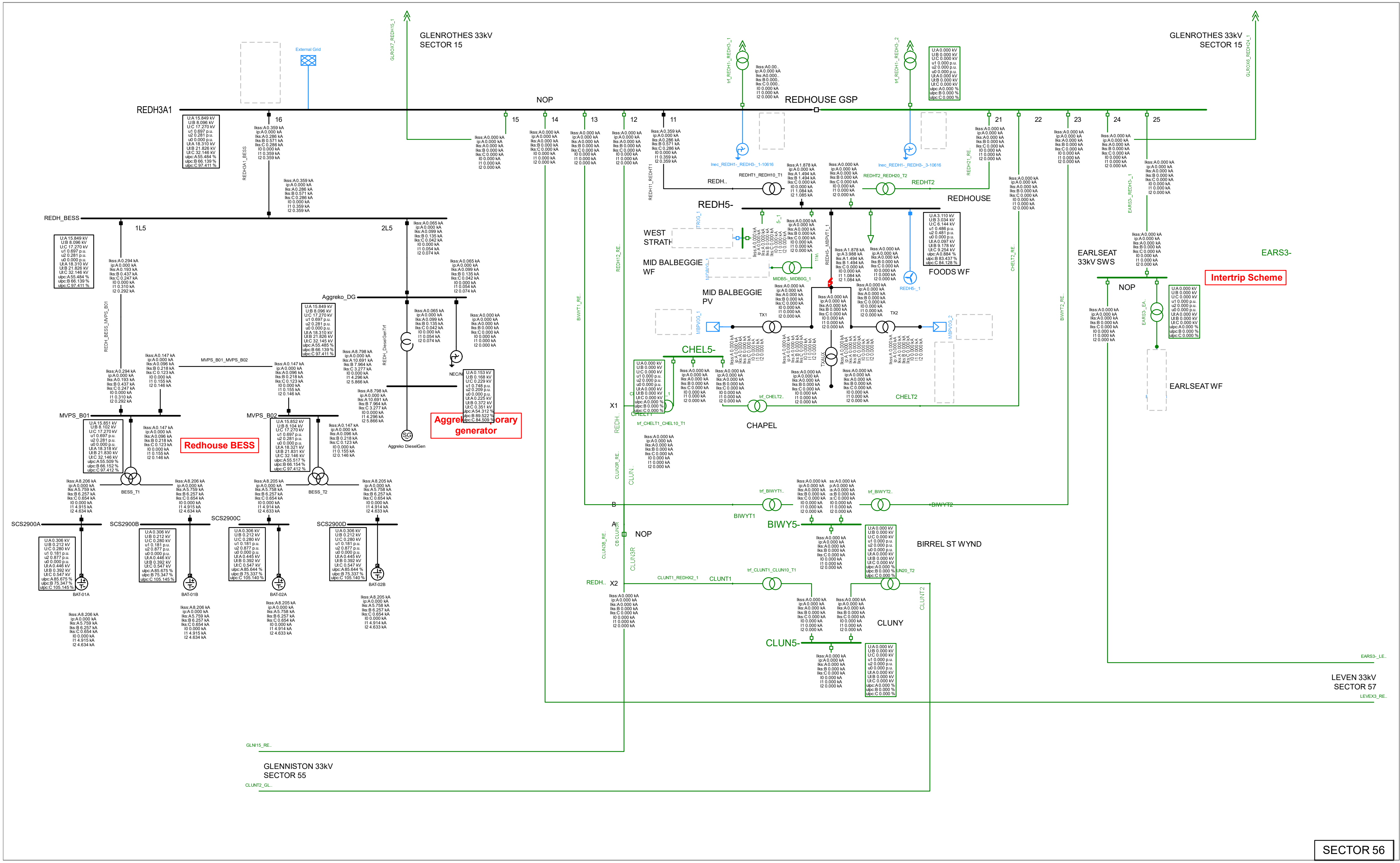


SECTOR 56

SC22 LL

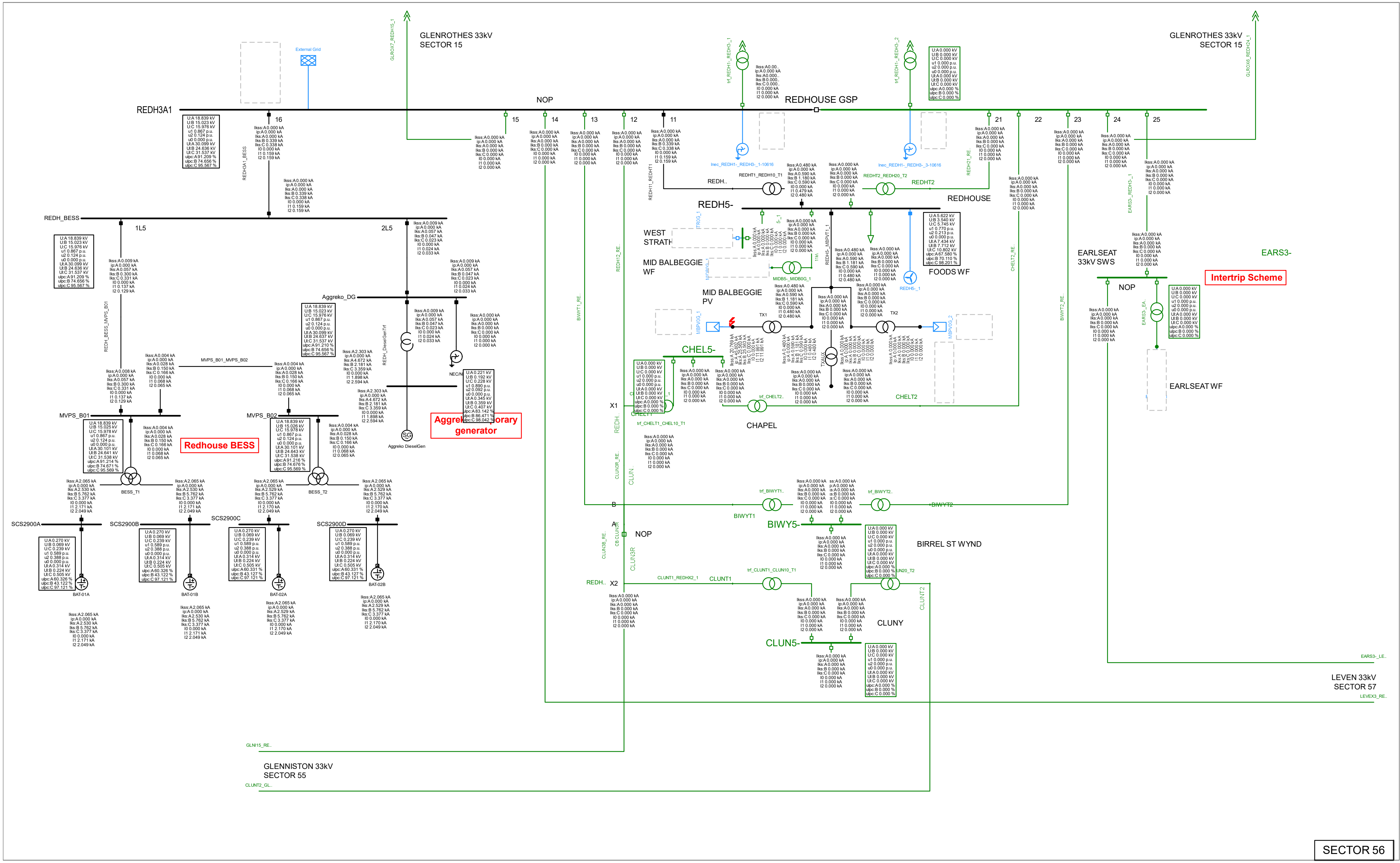

GLENROTHES 33kV
SECTOR 15
REDH3A1
NOP
REDHOUSE GSP
REDH_BESS
1L5
2L5
Aggreko_DG
REDH5-
REDHOUSE
REDHT2
WEST STRATH
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
EARLSEAT 33kV SWS
EARS3-
Intertrip Scheme
EARLSEAT WF
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
SCS2900A
SCS2900B
SCS2900C
SCS2900D
CHEL5-
CHELT1
CHELT2
CHAPEL
X1
B
A
NOP
X2
BIWYT1
BIWY5-
BIRREL ST WYND
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC23 LL

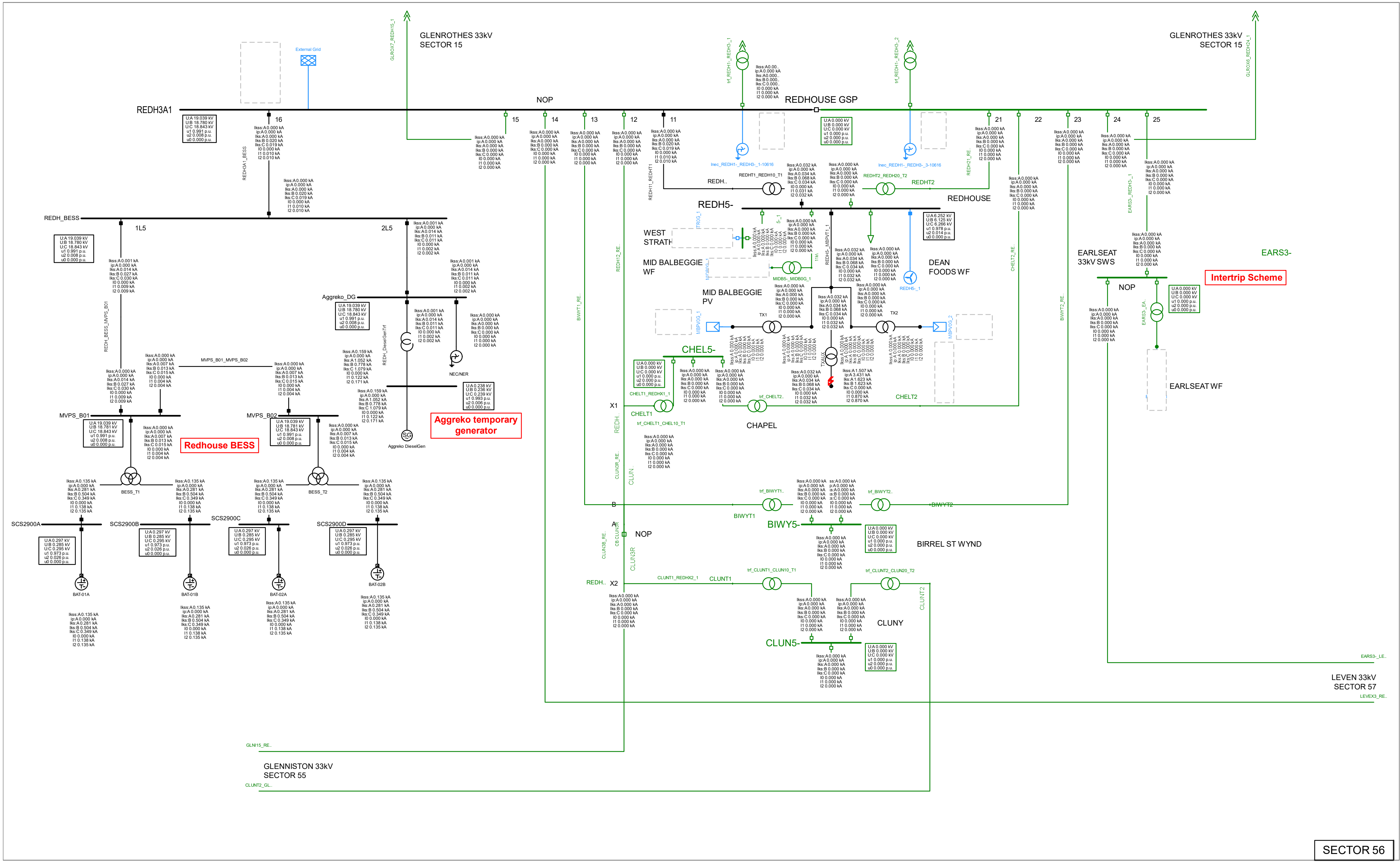


GLENROTHES 33kV
SECTOR 15
REDH3A1
External Grid
NOP
REDHOUSE GSP
GLENROTHES 33kV
SECTOR 15
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01_MVPS_B02
MVPS_B01
MVPS_B02
Redhouse BESS
generator
Aggreko DieselGen
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
REDHT2
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
FOODS WF
TX1
TX2
CHEL5-
CHAPEL
CHELT2
X1
EARLSEAT
33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
BIWY5-
BIRREL ST WYND
BIWYT1
NOP
X2
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC24 LL

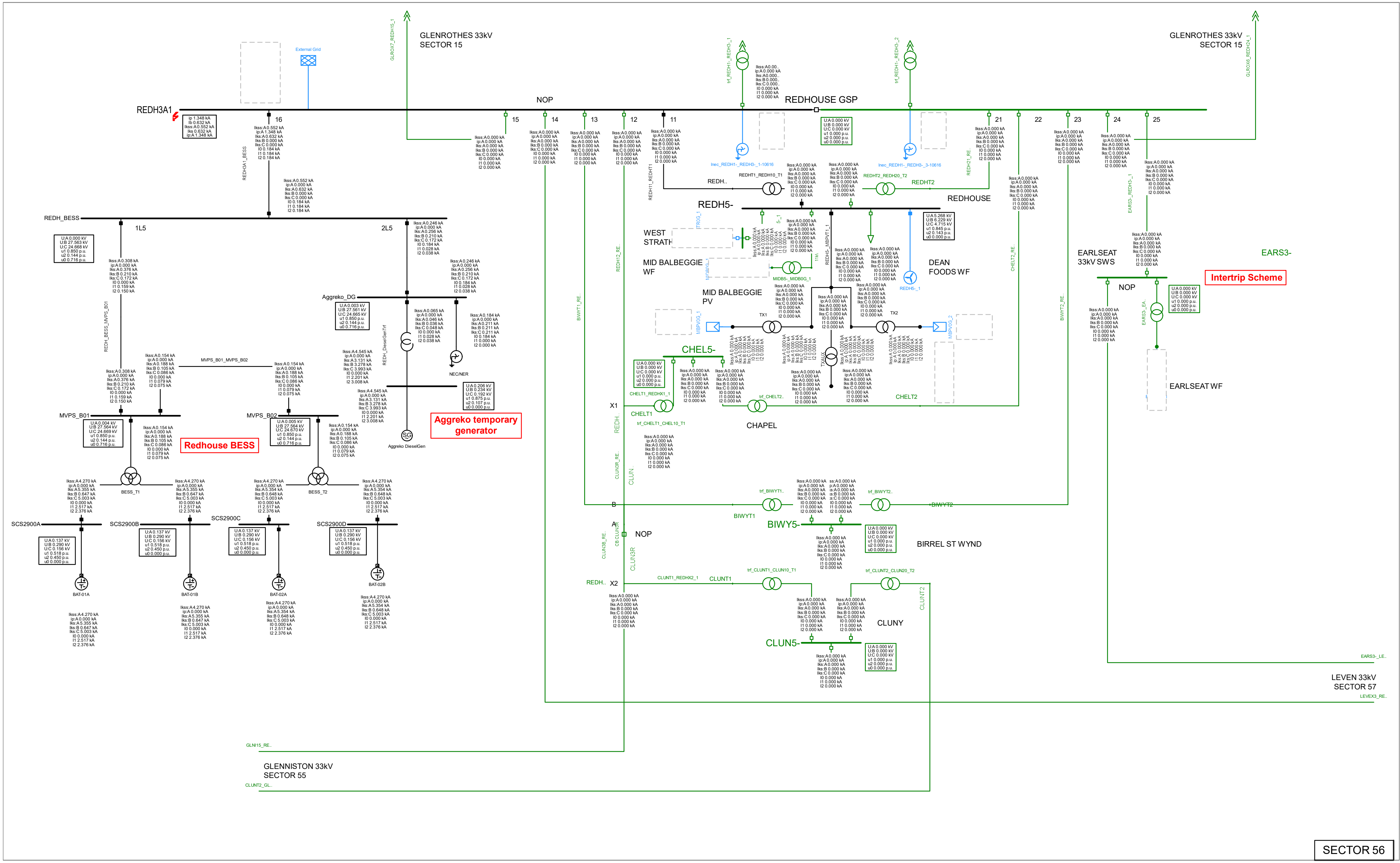

GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01_MVPS_B02
MVPS_B01
MVPS_B02
Redhouse BESS
generator
Aggreko DieselGen
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
REDH2
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
FOODS WF
TX1
TX2
CHEL5-
CHELT2
CHAPEL
X1
BIWYT1
BIWY5-
BIRREL ST WYND
NOP
X2
CLUNT1
CLUNY
CLUN5-
EARLSEAT
33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
GLENROTHES 33kV
SECTOR 15
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC25 LL



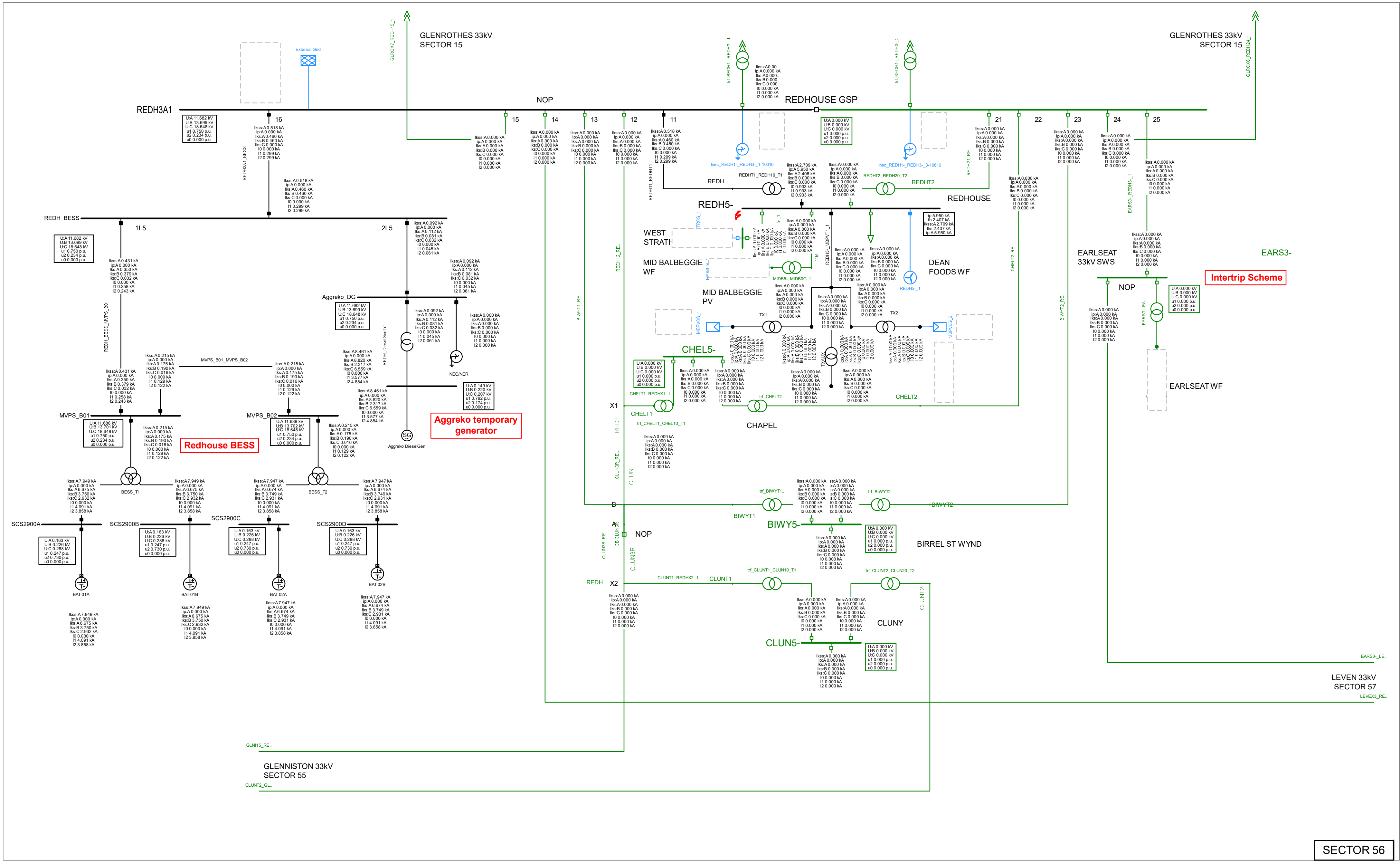
GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
REDHOUSE
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01
MVPS_B02
MVPS_B01_MVPS_B02
Redhouse BESS
Aggreko temporary generator
NEC/NER
Aggreko DieselGen
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHT2
WEST STRATH
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
TX1
TX2
CHEL5-
CHELT1
CHELT2
CHAPEL
X1
X2
A
B
BIWYT1
BIWY5-
BIRREL ST WYND
CLUNT1
CLUN5-
CLUNY
EARLSEAT 33kV SWS
EARS3-
Intertrip Scheme
EARLSEAT WF
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC26 LG



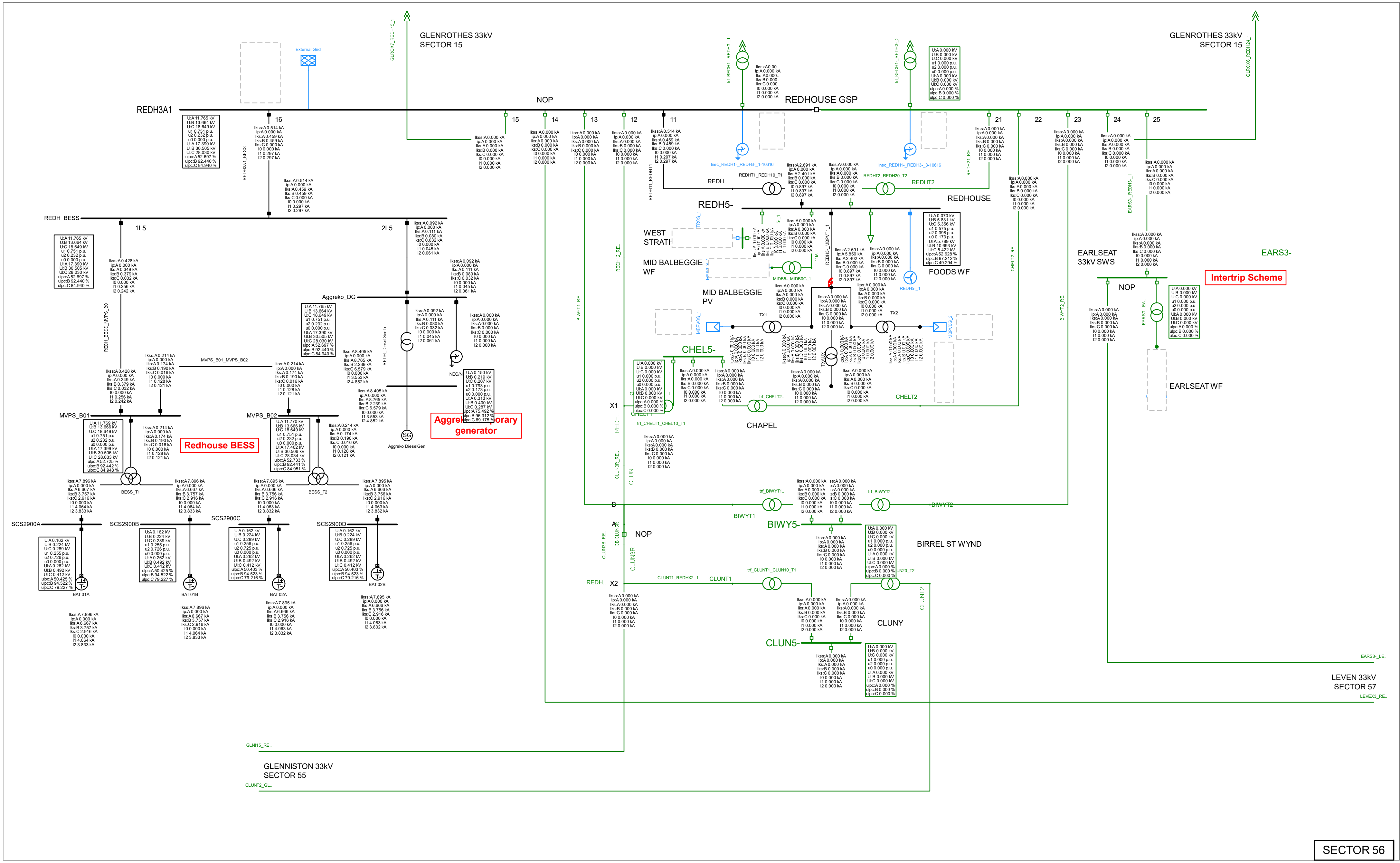
GLENROTHES 33kV
SECTOR 15
External Grid
REDH3A1
NOP
REDHOUSE GSP
GLENROTHES 33kV
SECTOR 15
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01_MVPS_B02
NEC/NER
MVPS_B01
MVPS_B02
Redhouse BESS
Aggreko temporary generator
Aggreko DieselGen
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
TX1
TX2
DEAN
FOODS WF
EARLSEAT
33kV SWS
EARS3-
Intertrip Scheme
NOP
EARLSEAT WF
CHEL5-
CHELT1
CHELT2
CHAPEL
X1
BIWY5-
BIWYT1
BIWYT2
BIRREL ST WYND
NOP
X2
CLUNT1
CLUNY
CLUN5-
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC27 LG



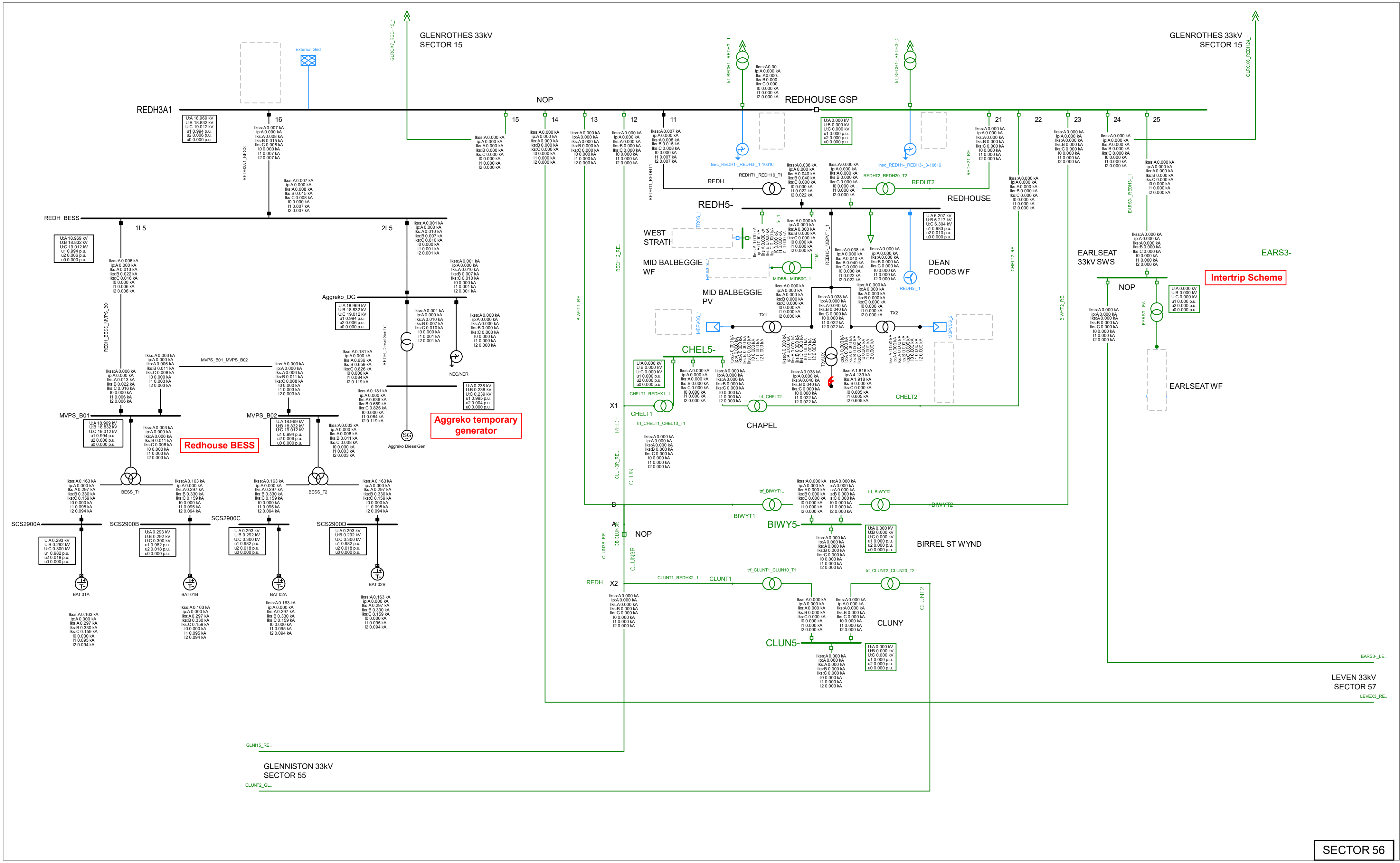
GLENROTHES 33kV
SECTOR 15
NOP
REDH3A1
REDHOUSE GSP
External Grid
REDH_BESS
1L5
2L5
Aggreko_DG
MVPS_B01
MVPS_B02
MVPS_B01_MVPS_B02
Redhouse BESS
Aggreko temporary generator
Aggreko DieselGen
NEC/NER
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
REDH5-
REDHOUSE
REDHT2
WEST STRATH
MID BALBEGGIE WF
MID BALBEGGIE PV
DEAN FOODS WF
TX1
TX2
CHEL5-
CHELT1
CHELT2
CHAPEL
EARLSEAT 33kV SWS
EARS3-
Intertrip Scheme
EARLSEAT WF
BIWY5-
BIWYT1
BIRREL ST WYND
CLUNT1
CLUN5-
CLUNY
X1
X2
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC28 LG



GLENROTHES 33kV
SECTOR 15
REDH3A1
REDH_BESS
NOP
REDHOUSE GSP
External Grid
REDH5-
REDHOUSE
REDHT2
WEST
STRATH
MID BALBEGGIE
WF
MID BALBEGGIE
PV
FOODS WF
EARLSEAT
33kV SWS
EARS3-
Intertrip Scheme
EARLSEAT WF
Aggreko_DG
Aggreko DieselGen
generator
Redhouse BESS
MVPS_B01
MVPS_B02
MVPS_B01_MVPS_B02
BESS_T1
BESS_T2
SCS2900A
SCS2900B
SCS2900C
SCS2900D
BAT-01A
BAT-01B
BAT-02A
BAT-02B
CHEL5-
CHAPEL
CHELT2
BIWY5-
BIRREL ST WYND
BIWYT1
CLUNT1
CLUN5-
CLUNY
LEVEN 33kV
SECTOR 57
GLENNISTON 33kV
SECTOR 55
SECTOR 56

SC30 LG



SECTOR 56

APPENDIX B

Fault Flows

			BRANCH ID	BESS FAULT INFEED	DIESEL GENERATOR FAULT INFEED	REDHOUSE GENERATION TO REDHOUSE GSP	REDHOUSE PRIMARY TRANSFORMER HV	REDHOUSE PRIMARY TRANSFORMER LV	REDHOUSE PRIMARY TO MIDDLE BALBEGGIE	MIDDLE BALBEGGIE PV TRANSFORMER HV	MIDDLE BALBEGGIE PV TRANSFORMER LV	MIDLLE BALBEGGIE AUX TRANSFORMER HV	MIDLLE BALBEGGIE AUX TRANSFORMER LV
			VOLTAGE (kV)	33	33	33	33	11	11	11	0.44	11	0.4
STUDY	FAULT TYPE	FAULTED NODE	FAULTED NODE DESCRIPTION	I (kA)	I (kA)	I (kA)	I (kA)	I (kA)	I (kA)	I (kA)	I (kA)	I (kA)	I (kA)
SC1	LLL	REDH_BESS	REDHOUSE GSP 33 KV	0.206	0.000	0.206	-	-	-	-	-	-	-
SC2	LLL	REDH5-	REDHOUSE PRIMARY 11 KV	0.206	0.000	0.206	0.206	0.622	-	-	-	-	-
SC3	LLL	MBPV0G	MIDDLE BALBEGGIE 11 KV	0.206	0.000	0.206	0.206	0.622	0.622	-	-	-	-
SC4	LLL	PV1	MIDDLE BALBEGGIE PV 0.44 KV	0.206	0.000	0.206	0.206	0.622	0.622	0.622	15.554	-	-
SC5	LLL	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV	0.206	0.000	0.206	0.206	0.622	0.622	-	-	0.622	17.118
SC6	LL	REDH_BESS	REDHOUSE GSP 33 KV	0.357	0.000	0.357	-	-	-	-	-		-
SC7	LL	REDH5-	REDHOUSE PRIMARY 11 KV	0.412	0.000	0.412	0.412	1.078	-	-	-	-	-
SC8	LL	MBPV0G	MIDDLE BALBEGGIE 11 KV	0.412	0.000	0.412	0.412	1.078	1.078	-	-	-	-
SC9	LL	PV1	MIDDLE BALBEGGIE PV 0.44 KV	0.357	0.000	0.357	0.357	1.244	1.244	1.244	26.941	-	-
SC10	LL	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV	0.351	0.000	0.355	0.355	1.238	1.246	-	-	1.245	29.667
SC11	LG	REDH_BESS	REDHOUSE GSP 33 KV	0.412	0.000	0.618	-	-	-	-	-	-	-
SC12	LG	REDH5-	REDHOUSE PRIMARY 11 KV	0.357	0.000	0.357	0.357	1.866	-	-	-	-	-
SC13	LG	MBPV0G	MIDDLE BALBEGGIE 11 KV	0.357	0.000	0.357	0.357	1.866	1.866	-	-	-	-
SC14	LG	PV1	MIDDLE BALBEGGIE PV 0.44 KV	-	-	-	-	-	-	-	-	-	-
SC15	LG	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV	0.411	0.000	0.411	0.411	1.071	1.079	-	-	1.079	51.412
SC16	LLL	REDH_BESS	REDHOUSE GSP 33 KV	0.206	0.176	0.382	-	-	-	-	-	-	-
SC17	LLL	REDH5-	REDHOUSE PRIMARY 11 KV	0.206	0.140	0.346	0.346	1.045	-	-	-	-	-
SC18	LLL	MBPV0G	MIDDLE BALBEGGIE 11 KV	0.206	0.140	0.345	0.346	1.045	1.045	-	-	-	-
SC19	LLL	PV1	MIDDLE BALBEGGIE PV 0.44 KV	0.206	0.065	0.271	0.271	0.817	0.817	0.817	20.434	-	-
SC20	LLL	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV	0.044	0.021	0.024	0.024	0.071	0.072	-	-	0.072	1.977
SC21	LL	REDH_BESS	REDHOUSE GSP 33 KV	0.434	0.195	0.586	-	-	-	-	-		-
SC22	LL	REDH5-	REDHOUSE PRIMARY 11 KV	0.437	0.135	0.572	0.572	1.497	-	-	-	-	-
SC23	LL	MBPV0G	MIDDLE BALBEGGIE 11 KV	0.437	0.135	0.571	0.571	1.494	1.494	-	-	-	-
SC24	LL	PV1	MIDDLE BALBEGGIE PV 0.44 KV	0.331	0.057	0.339	0.339	1.180	1.181	1.181	25.563	-	-
SC25	LL	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV	0.030	0.014	0.020	0.020	0.068	0.068	-	-	0.068	1.623
SC26	LG	REDH_BESS	REDHOUSE GSP 33 KV	0.376	0.256	0.632	-	-	-	-	-	-	-
SC27	LG	REDH5-	REDHOUSE PRIMARY 11 KV	0.379	0.112	0.460	0.460	2.406	-	-	-	-	-
SC28	LG	MBPV0G	MIDDLE BALBEGGIE 11 KV	0.379	0.111	0.459	0.459	2.401	2.402	-	-	-	-
SC29	LG	PV1	MIDDLE BALBEGGIE PV 0.44 KV	-	-	-	-	-	-	-	-	-	-
SC30	LG	AUX LV	MIDDLE BALBEGGIE AUX 0.4 KV	0.022	0.010	0.015	0.015	0.040	0.040	-	-	0.040	1.918

Table B.1: Transient Current versus Fault Type and Faulted Node

APPENDIX C

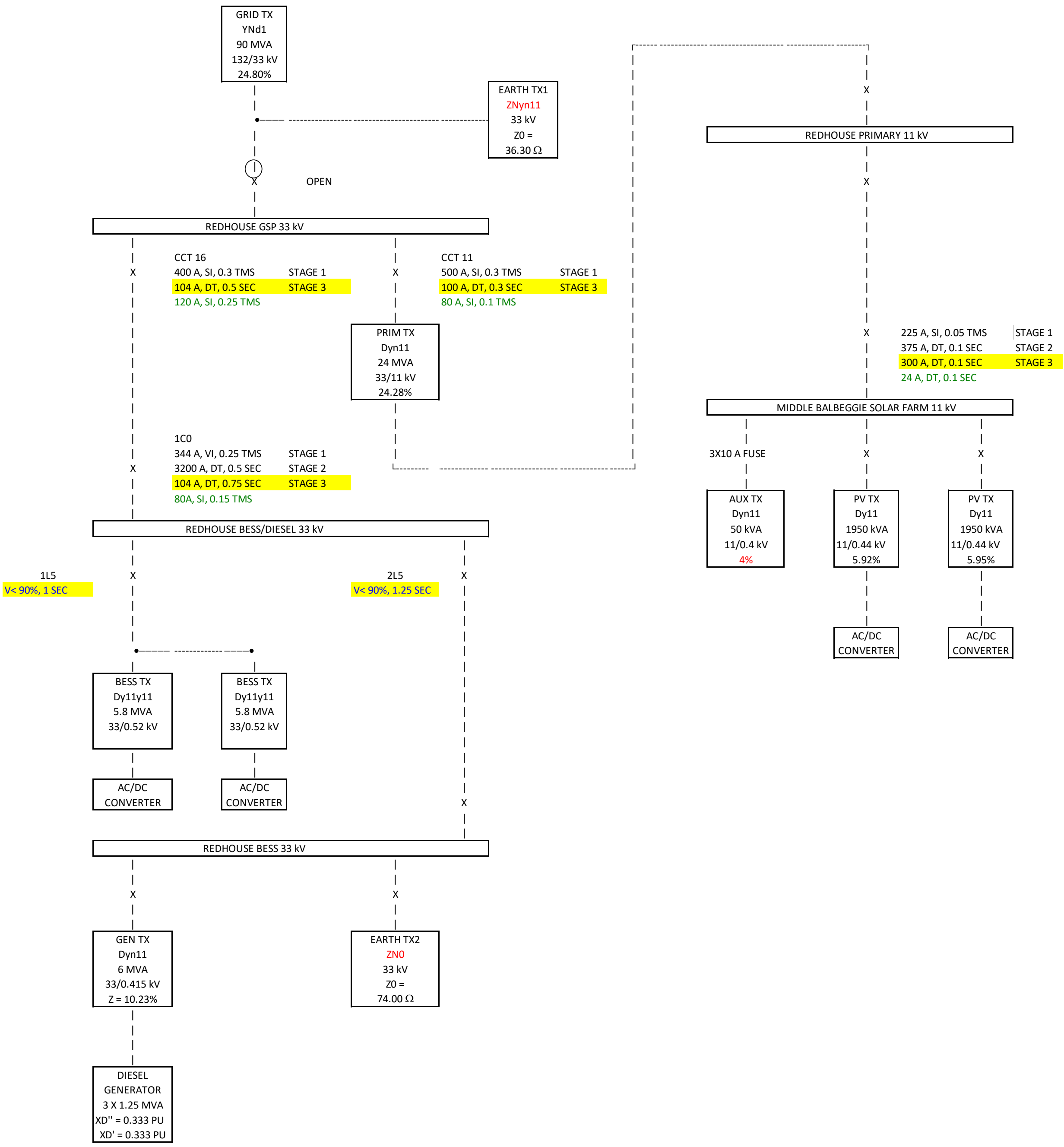
Protection Schedule

Substation	Circuit Name	Protection Function	Scheme Type	Device Type	Second Group Available	Voltage Control Available	Cold Load Pickup	New Relay Required	Rating	Actual Settings	Reference	Trial Settings	Report Section
REDHOUSE BESS/DIESEL BUSBAR 33 KV	1C0	INCOMER	OC STAGE 1	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Green	344 A, VI, 0.25 TMS	#021	NO CHANGE	-
			OC STAGE 2	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Green	3200 A, DT, 0.5 SEC	#021	NO CHANGE	-
			OC STAGE 3	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Amber	OFF		104 A, DT, 0.75 SEC	7.4
			EF STAGE 1	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Green	80 A, SI, 0.15 TMS	#021	NO CHANGE	-
			EF STAGE 2	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Green	OFF	#021	NO CHANGE	-
REDHOUSE BESS/DIESEL BUSBAR 33 KV	1L5	BESS FEEDER	OV STAGE 1	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Green	33000/110 V, 121 V, 1 SEC	#025 #026	NO CHANGE	-
			OV STAGE 2	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Green	33000/110 V, 124.3 V, 0.5 SEC	#025 #026	NO CHANGE	-
			UV STAGE 1	SIPROTEC 5 7SJ82	>	N/A	N/A	NO	Amber	33000/110 V, 88 V, 2.5 SEC	#025 #026	33000/110 V, 99 V, 1 SEC	7.5
REDHOUSE BESS/DIESEL BUSBAR 33 KV	2L5	AGREKKO DIESEL AND EARTHING TX FEEDER	OV STAGE 1	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Green	33000/110 V, 121 V, 1 SEC	#025 #026	NO CHANGE	-
			OV STAGE 2	SIPROTEC 5 7SJ82	?	N/A	N/A	NO	Green	33000/110 V, 124.3 V, 0.5 SEC	#025 #026	NO CHANGE	-
			UV STAGE 1	SIPROTEC 5 7SJ82	>	N/A	N/A	NO	Amber	33000/110 V, 88 V, 2.5 SEC	#025 #026	33000/110 V, 99 V, 1.25 SEC	7.5
REDHOUSE GSP 33 kV CCT16	REDHOUSE AGGREKO 33 kV	BESS & DIESEL GEN FEEDER/ INCOMER	OC STAGE 1	ALSTOM P14N	YES	NO	YES	NO	Green	800/1, 400 A, SI, 0.3 TMS	#013	NO CHANGE	-
			OC STAGE 3	ALSTOM P14N	YES	NO	YES	NO	Amber	OFF		800/1, 104 A, DT, 0.5 SEC	7.3
			EF STAGE 1	ALSTOM P14N	YES	NO	YES	NO	Green	800/1, 80A, SI, 0.1 TMS	#013	NO CHANGE	-
REDHOUSE GSP 33 kV CCT11	REDHOUSE PRIMARY 33 kV	PRIMARY SUBSTATION FEEDER	BEF	MFAC	NO	NO	NO	NO	Green	75 V	#013	NO CHANGE	-
			OC STAGE 1	ALSTOM P14N	YES	NO	YES	NO	Green	400/1, 500 A, SI, 0.3 TMS	#013	NO CHANGE	-
			OC STAGE 3	ALSTOM P14N	YES	NO	YES	NO	Amber	OFF		400/1, 100 A, DT, 0.3 SEC	7.2
			EF STAGE 1	ALSTOM P14N	YES	NO	YES	NO	Green	400/1, 80A, SI, 0.1 TMS	#013	NO CHANGE	-
MIDDLE BALBEGGIE SOLAR PARK INCOMER 11 kV	MIDDLE BALBEGGIE SOLAR 11 kV	PV INCOMER	OV STAGE 1	SCHNEIDER P341	YES	YES	YES	NO	Green	11000/110 V, 121 V, 1 SEC	#009 #010	NO CHANGE	-
			OV STAGE 2	SCHNEIDER P341	YES	YES	YES	NO	Green	11000/110 V, 124.3 V, 0.5 SEC	#009 #010	NO CHANGE	-
			UV STAGE 1	SCHNEIDER P341	YES	YES	YES	NO	Green	11000/110 V, 88 V, 2.5 SEC	#009 #010	NO CHANGE	-
			OC STAGE 1	SCHNEIDER P341	YES	YES	YES	NO	Green	300/1 A, 225 A, SI, 0.05 TMS	#003 #010	NO CHANGE	-
			OC STAGE 2	SCHNEIDER P341	YES	YES	YES	NO	Green	300/1 A, 375 A, DT, 0.1 SEC	#003 #010	NO CHANGE	-
			OC STAGE 3	SCHNEIDER P341	YES	YES	YES	NO	Amber	OFF	N/A	300/1, 300 A, DT, 0.1 SEC	7.1
			EF STAGE 1	SCHNEIDER P341	YES	YES	YES	NO	Green	300/1 A, 24 A, DT, 0.1 SEC	#003 #010	NO CHANGE	-

KEY	
Green	No Change
Amber	Setting Change Required
Red	New Relay or Solution Not Confirmed

APPENDIX D

Protection Schematic



NOTE 1: VALUES SHOWN IN RED ARE ASSUMED
NOTE 2: OVERCURRENT PROTECTION SETTINGS ARE SHOWN IN BLACK
NOTE 3: EARTH FAULT PROTECTION SETTINGS ARE SHOWN IN GREEN
NOTE 4: UNDERVOLTAGE PROTECTION SETTINGS ARE SHOWN IN BLUE
NOTE 5: NEW/REVISED PROTECTION SETTINGS ARE HIGHLIGHTED IN YELLOW

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