Protection coordination audit

11 kV airport distribution network

11 kV ring (N/O at DSS ATCT-F) · 17 transformers · New DSS · 1 MW solar PV · 1 MVA frequency converter

PowerFactory project	**610517**
Active study case	**Study Case**
Audit date	**2026-05-08**
Prepared by	**Aurora Power Consulting | Morson Praxis**

1. Network

An operating airport, fed from the WPD distribution network at the <XXXXX> substation. On-site protection terminates at an Intake SS within the airport perimeter. From there an 11 kV ring distributes to 17 distribution transformers across the terminal building, fire station, ATCT, B-blocks, fuel terminal and the rest of the airport. A separate dedicated relay set protects the new DSS — a 2 MVA transformer feeding a 1 MVA frequency converter for ground-power and spaceport applications. 1 MW of embedded solar PV is connected to the ring via a dedicated feeder out of Intake SS.

The 11 kV ring is operated normally open at DSS ATCT-F / Cub_1 (Line 9). Two ring feeders out of Intake SS (Cub_2 to the DSS L side and Cub_3 to the DSS B1b side) each carry a fixed half of the ring to that open point. The second ring-feeder relay set at Intake SS is therefore a permanent half-ring protection rather than a true twin pair.

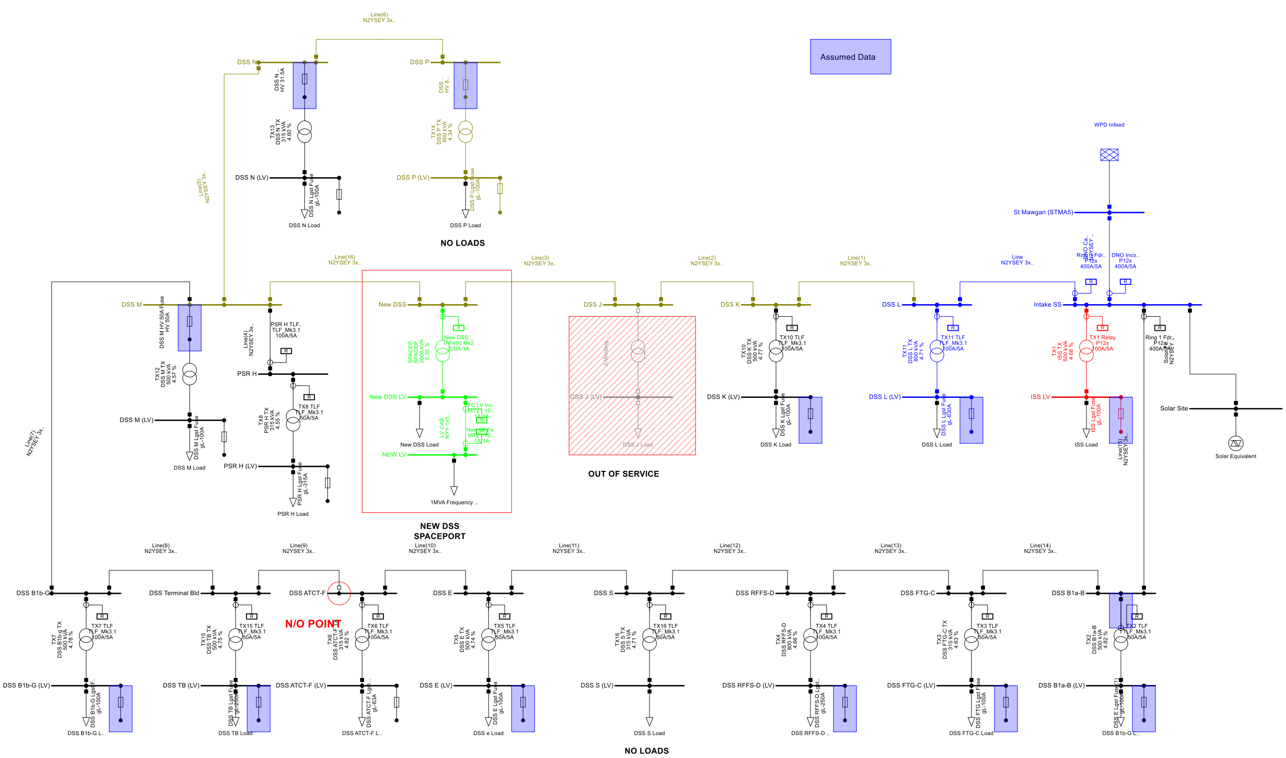

Figure 1. Single-line diagram (extract) showing the WPD intake, the Intake SS and the 11 kV ring out to the airport substations.

1.1 WPD Infeed

- **Source impedance:** Skss = 68.78 MVA max, 66.68 MVA min
- **R/X:** R/X = 0.267 max / 0.10 min
- **Earthing:** Star-point grounded via NER (Re = 4.234 Ω, Xe = 0); X0/X1 = 1, R0/X0 = 0.1, Z2/Z1 = 1
- **EF:** Analytical earth-fault current at the Intake SS 11 kV bus ≈ 1.3 kA primary, consistent with the MaxSC-EF reference used on the coordination plot pages

1.2 Transformers (17 in service)

Tx	Substation	kVA	uk %
TX1	Intake SS LV (ISS TX)	500	4.66
TX2	DSS B1a-B	500	4.82
TX3	DSS FTG-C	315	4.63
TX4	DSS RFFS-D	800	4.66
TX5	DSS E	500	4.74
TX6	DSS ATCT-F	315	4.82
TX7	DSS B1b-G	500	4.78
TX8	PSR H	315	4.55
TX10	DSS K	500	4.77
TX11	DSS L	800	4.71
TX12	DSS M	500	4.57
TX13	DSS N	315	4.60
TX14	DSS P	800	4.34
TX15	DSS Terminal Bld	500	4.75
TX16	DSS S	315	4.71
SPACEPORT	New DSS (Spaceport)	2000	6.00
2-Wdg Tx (2)	(unknown — no type assigned in model)	—	—

1.3 Cables, loads and embedded generation

- **Cables:** 20 cables, all single-circuit, no derating applied (fline = 1.0). Mix of NA2YSY 3×150se and 1×185rm types per ring section.
- **Loads:** 18 ElmLod modelled across the ring; total ≈ 3.3 MW. Includes a 1 MVA frequency converter on the new DSS LV bus (400 Hz / spaceport).
- **Embedded gen:** 1 MW solar PV at Solar Site (Solar Equivalent ElmGenstat).

2. Protection inventory

19 relays and 17 fuses across the site. The mix splits into four groups: strategic numerical relays at the Intake SS, custom TLF emulators on each distribution transformer, dedicated HV TLF fuses on three smaller substations, and a new Spaceport DSS protected by a Schneider VIP400 Mk2 numerical and two MasterPact MTZ 1600 A LV ACBs.

2.1 Strategic relays at Intake SS

Relay	Position	I> primary	Tpset	Curve	Role
DNO Incomer	Intake SS Cub_4	256 A	0.225	IEC SI	WPD interface
Ring 1 Fdr (DSS L)	Intake SS Cub_2	200 A	0.225	IEC VI	Ring feeder, DSS L side
Ring 1 Fdr (DSS B1b)	Intake SS Cub_3	200 A	0.20	IEC VI	Ring feeder, DSS B1b side
TX1 Relay	Intake SS Cub_3(1)	50 A	0.175	IEC EI	ISS step-down Tx (TX1, 500 kVA)

Relay	Position	Ie> primary	Tpset	Curve	Notes
DNO Incomer	Intake SS Cub_4	128 A	0.20	IEC SI	WPD interface — agreed setting (assumed)
Ring 1 Fdr (DSS L)	Intake SS Cub_2	80 A	0.10	IEC SI	Half-ring (DSS L side)
Ring 1 Fdr (DSS B1b)	Intake SS Cub_3	80 A	0.15	IEC VI	Half-ring (DSS B1b side) — different curve from twin
TX1 Relay	Intake SS Cub_3(1)	30 A	0.05	IEC SI	ISS step-down Tx (TX1, 500 kVA)

All four are Schneider P12x. I2>, I>>, Ie>>, Therm stages are out of service across the set (P12x template defaults).

2.2 Distribution — 12 TLF emulators

One TLF emulator per substation transformer. Fitted ratings versus ESI 12-6 / Schneider Ringmaster recommended TLF for the Tx kVA:

Tx	Substation	kVA	Fitted TLF	ESI 12-6	Verdict
TX10	DSS K	500	3 A	6.3 / 10 A	Severely undersized
TX12	DSS M	500	3 A	6.3 / 10 A	Severely undersized
TX8	PSR H	315	3 A	6.3 A	Undersized
TX3	DSS FTG-C	315	3 A	6.3 A	Undersized
TX11	DSS L	800	7.5 A	16 A	Significantly undersized
TX4	DSS RFFS-D	800	10 A	16 A	Undersized
TX2	DSS B1a-B	500	10 A	6.3 / 10 A	OK
TX5	DSS E	500	10 A	6.3 / 10 A	OK
TX7	DSS B1b-G	500	10 A	6.3 / 10 A	OK
TX15	DSS Terminal Bld	500	10 A	6.3 / 10 A	OK
TX6	DSS ATCT-F	315	10 A	6.3 A	Oversized
TX16	DSS S	315	10 A	6.3 A	Oversized

2.3 HV TLF fuses (3)

- DSS N HV 32 A Fuse — DSS N (TX13, 315 kVA)
- DSS M HV 50 A Fuse — DSS M (TX12, 500 kVA)
- DSS P HV 80 A Fuse — DSS P (TX14, 800 kVA)

Plus 14 LV "largest-fuse" representations (gL-63 / 100 / 250 / 315 / 630 A) on the LV side of each substation, modelled for downstream coordination only.

2.4 New DSS (new build)

Relay	Type	I> primary	I>> primary	Role
New DSS HV Relay	Schneider VIP400 Mk2	130 A	4 kA (DT 50 ms)	Protects SPACEPORT TX (2 MVA)
New LV Feeder	MasterPact MTZ1 16 1600 A	1600 A LT (4 s)	3200 A ST (DT 100 ms)	Spaceport LV feeder
FC LV Incomer	MasterPact MTZ1 16 1600 A	1600 A LT (0.5 s)	2400 A ST (DT 0)	Frequency Converter LV bus

2.5 Overcurrent settings review

Five strategic relays carry an in-service phase overcurrent stage. The 12 TLF emulators on distribution transformers carry an I> stage tuned to the TLF blow curve — these are addressed against ESI 12-6 in the Findings section and not repeated here.

2.5.1 Phase overcurrent stages in service

Relay	Position	I> primary	Tpset	Curve	I>> primary	Notes
DNO Incomer	Intake SS Cub_4	256 A	0.225	IEC SI	OOS	WPD interface — agreed setting (assumed)
Ring 1 Fdr (DSS L)	Intake SS Cub_2	200 A	0.225	IEC VI	OOS	Half-ring (DSS L side)
Ring 1 Fdr (DSS B1b)	Intake SS Cub_3	200 A	0.20	IEC VI	OOS	Half-ring (DSS B1b side) — different Tpset from twin
TX1 Relay	Intake SS Cub_3(1)	50 A	0.175	IEC EI	650 A DT 30 ms	TX1 (500 kVA, FLC HV ≈ 26 A) — pickup at 191 % FLC
New DSS HV Relay	New DSS Cub_3	130 A	0.20	VIT/B IEC/B VI	4 kA DT 50 ms	Spaceport TX (2 MVA, FLC HV ≈ 105 A) — pickup at 124 % FLC ✓

I2> (negative-sequence) and Therm stages on the four P12x relays are out of service with their template defaults (Ipset 0.10 / Tpset 1.0 and Ipset 0.40 / Tpset 60 respectively). Ie>> high-set EF stages are also OOS — see the Earth fault settings review below.

2.5.2 Coordination at MaxSC-HV (≈ 3.6 kA primary)

Operating times computed at the WPD source three-phase fault current of approximately 3.6 kA primary (IEC SI: $t = 0.14 / (M^{0.02} - 1) \times Tpset$; IEC VI: $t = 13.5 / (M - 1) \times Tpset$; IEC EI: $t = 80 / (M^2 - 1) \times Tpset$).

Relay	M = I_max / I>	Operating time	Margin to upstream
TX1 Relay (I> → I>>)	72.0	≈ 0.003 s on I>; I>> at 30 ms DT	Base of chain — separate fault zone (TX1 only)
New DSS HV Relay	27.7	≈ 0.10 s	Base of chain — separate fault zone (Spaceport TX)
Ring 1 Fdr (DSS B1b)	18.0	≈ 0.16 s	n/a — sees ring half only
Ring 1 Fdr (DSS L)	18.0	≈ 0.18 s	n/a — sees ring half only
DNO Incomer	14.1	≈ 0.58 s	0.40 s over Ring Fdr (DSS L) ✓ / 0.42 s over Ring Fdr (DSS B1b) ✓

Cable impedance reduces fault current at downstream substation buses; coordination at the remote ring positions should be re-checked against the per-bus ComShc IEC 60909 results before signing off the figures above.

2.5.3 Observations

- **DNO Incomer ↔ Ring Fdr coordination is clean.** 0.40 s margin at MaxSC-HV against the DSS L feeder, 0.42 s against DSS B1b — both well above the 250 ms target.
- **Ring Fdr Tpset asymmetry between the two ring feeders.** DSS L side at 0.225 vs DSS B1b side at 0.20 on phase OC — small, possibly deliberate, but combined with the EF curve-type difference flagged separately, the two ring halves do not carry identical protection characteristics.
- **TX1 Relay pickup at 191 % of HV FLC.** High pickup for a Tx feeder, but the IEC EI curve drops operating time fast at moderate fault currents and the I>> at 650 A primary (30 ms DT) gives instantaneous clearance for HV-side faults. Combined the Tx is well-protected.
- **New DSS HV Relay pickup at 124 % of HV FLC ✓.** Sits in the standard 100 - 150 % FLC band. The I>> at 4 kA primary (50 ms DT) handles HV-side Tx faults instantaneously; sits comfortably above the SPACEPORT TX maximum through-fault (~ 1.75 kA), in line with the > 120 % rule for transformer high-set OC.
- **Mixed curve types across the chain.** DNO Incomer = SI; Ring Fdr = VI; TX1 = EI; Spaceport = VIT/B (IEC VI variant). Each is appropriate in context (DNO uses SI per UK convention, EI gives steep grading on a Tx feeder, VI is standard for distribution OC) but means there is no single curve type running through the protection chain.

2.5.4 Suggested actions

- Align Ring 1 Fdr (DSS B1b) Tpset to 0.225 (matching DSS L) unless the difference is deliberate — keeps a single phase OC setting across the two ring feeders.
- Confirm the WPD agreed I> setting on the DNO Incomer (Ipset, Tpset, presence of any I>> instantaneous on the WPD side). The 256 A / 0.225 / IEC SI figure is treated as fixed in this audit.
- Run ComShc IEC 60909 maximum-fault at every 11 kV substation bus to verify operating-time margins under worst-case fault conditions, especially for ring topology variants where the N/O point may be shifted manually.

2.6 Earth fault settings review

Five strategic relays carry an in-service earth-fault stage. The TLF emulators on the distribution transformers and the LV ACBs on the new Spaceport build all run with their EF stages out of service — earth-fault detection on the distribution side relies on the upstream Intake SS relays, which is appropriate for the NER-limited 11 kV system (analytical I_EF ≈ 1.3 kA at the source bus).

2.6.1 Earth-fault stages in service

Relay	Position	Ie> primary	Tpset (s)	Curve	Notes
DNO Incomer	Intake SS Cub_4	128 A	0.20	IEC SI	WPD interface — agreed setting (assumed)
Ring 1 Fdr (DSS L)	Intake SS Cub_2	80 A	0.10	IEC SI	Half-ring (DSS L side)
Ring 1 Fdr (DSS B1b)	Intake SS Cub_3	80 A	0.15	IEC VI	Half-ring (DSS B1b side) — different curve from twin
TX1 Relay	Intake SS Cub_3(1)	30 A	0.05	IEC SI	ISS step-down Tx (TX1, 500 kVA, FLC HV ≈ 26 A) — pickup at 114 % FLC
New DSS HV Relay	New DSS Cub_3	30 A	0.02	IEC SIT/A SI	Spaceport TX (2 MVA, FLC HV ≈ 105 A) — pickup at 29 % FLC ✓

Ie>> high-set EF stages on all five relays are out of service with their P12x / VIP400 template defaults (Ipset 0.80 × CT, Tpset 0.25 - 0.50, ANSI EI). Bringing them into service would require explicit tuning against the NER-capped fault current.

2.6.2 Coordination at MaxSC-EF (≈ 1.3 kA primary)

Operating times computed at the source-bus EF current of approximately 1.3 kA primary, from the relay curve formulae (IEC SI: t = 0.14 / (M^0.02 - 1) × Tpset; IEC VI: t = 13.5 / (M - 1) × Tpset).

Relay	M = I_EF / Ie>	Operating time	Margin to upstream
New DSS HV Relay	43.3	≈ 0.04 s	Base of chain
TX1 Relay	43.3	≈ 0.09 s	Base of chain
Ring 1 Fdr (DSS L)	16.3	≈ 0.25 s	0.16 s over downstream — borderline
Ring 1 Fdr (DSS B1b)	16.3	≈ 0.13 s	0.04 s over downstream — inadequate (curve type)
DNO Incomer	10.2	≈ 0.59 s	0.34 s over Ring Fdr (DSS L) ✓

Run ComShc IEC 60909 minimum-fault to verify the Ie> stages remain sensitive at the lowest practical EF current (e.g. arc-fault scenarios where fault impedance is significant) before signing off the figures above.

2.6.3 Observations

- **DNO Incomer ↔ Ring Fdr coordination is comfortable.** 0.34 s margin at MaxSC-EF against the DSS L feeder (which uses the same SI curve) sits well above the 250 ms target.
- **Ring Fdr (DSS B1b) ↔ downstream margin is inadequate at high EF.** With IEC VI rather than IEC SI, the operating time at MaxSC-EF drops to ~ 0.13 s — only 40 ms over a downstream Tx-relay EF stage. This is a direct consequence of the curve-type asymmetry already flagged in 'Ring-feeder twin pair'.
- **TX1 Relay Ie> at 30 A primary = 114 % of TX1 HV FLC.** Detects an HV-side EF on the Tx adequately but is not a sensitive ground-fault detector — a textbook setting would target 20 - 30 % FLC (5 - 8 A primary). The Dyn winding blocks LV-side ZPS so a downstream LV ground fault is invisible to this stage either way; the question is whether the engineer wants more sensitivity to high-impedance HV faults.
- **New DSS HV Relay Ie> sits in the 20 - 30 % FLC band ✓** with Tpset = 20 ms it is essentially instantaneous. No upstream EF backup unless the Spaceport feeder routes through one of the Ring Fdr relays — confirm the topology.
- **All TLF Ig> stages and both LV ACB Earth-fault stages are out of service.** Standard for TLF emulators (EF protection sits on the upstream side or on the LV ACB) and acceptable for TN-S / TN-C-S LV systems where the LV trip curve covers ground faults — confirm philosophy.

2.6.4 Suggested actions

- Align Ring 1 Fdr (DSS B1b) Ie> to IEC SI with Tpset = 0.10, matching the DSS L feeder. Restores Tier 2 ↔ Tier 3 EF margin and removes the curve-type asymmetry between the two ring halves.
- Confirm the WPD agreed Ie> setting on the DNO Incomer (Ipset, Tpset, curve). The 128 A / 0.20 s figure is treated as fixed in this audit; if the agreed record differs, the coordination above shifts.
- Run ComShc IEC 60909 minimum-fault at every 11 kV substation bus to verify each Ie> stage picks up at the lowest practical EF current, especially with arc-fault / high-impedance scenarios.
- Review whether the TX1 Relay Ie> pickup at 30 A primary (114 % of HV FLC) is the intended sensitivity. Lowering to 5 - 8 A would bring it into the ESI 12-6 EF band but tightens the margin against any LV-derived neutral-displacement transients that reflect to the HV side.

3. Findings

Five findings. Severity is engineering judgement; these are flags for review rather than unilateral changes.

3.1 TLF ratings — eight of twelve do not align with ESI 12-6

The TLF ratings fitted on eight of the twelve TLF-relayed transformers are outside the ESI 12-6 / Schneider Ringmaster recommended band for the transformer's kVA (see the table in §2). The four 3 A TLFs and the 7.5 A TLF on the 800 kVA DSS L Tx are the most exposed.

These are model values; the audit cannot tell whether the cubicles match the model or have been re-tapped on site.

Suggested action:

- Walk down the cubicles, confirm the fitted TLF tap against the transformer nameplate kVA.
- Where the fitting is wrong: replace with the ESI 12-6 standard rating (6.3 A for 315 kVA, 10 A for 500 kVA, 16 A for 800 kVA).
- Where the fitting matches the model but the model is wrong: update the .pcharac to the standard TLF rating and re-issue the model.

3.2 G99 protection on the DNO Incomer

Solar Equivalent (1 MW / 1 MVA) is connected to the 11 kV ring at Solar Site. Per G98 / G99 / Engineering Recommendation, the DNO interface relay should provide loss-of-mains protection for embedded generation above the G98 threshold — typically F81 (ROCOF + frequency over/under), F27 / F59 (under/over voltage), and optionally F32 (reverse power).

The DNO Incomer relay at Intake SS has phase OC + EF + thermal stages only. RelUlim count across the project is zero. Either a separate G99 device exists outside the model, or this is a compliance gap.

Suggested action:

- Confirm with WPD the loss-of-mains arrangement. If a separate G99 device exists, add it to the model for completeness. If not, raise as a compliance item.

3.3 Ring-feeder twin pair — different EF curve types

Ring 1 Fdr (DSS L) and Ring 1 Fdr (DSS B1b) are the two ring feeders out of the Intake SS. With the ring open at DSS ATCT-F / Cub_1, the two feeders carry different fixed halves of the load — so identical settings are not strictly required. However, the Ie> stages use different curve types (IEC SI on the DSS L feeder, IEC VI on the DSS B1b feeder), which produces different EF operating times against the same downstream TLFs.

Suggested action:

- Confirm whether the curve-type difference is deliberate (asymmetric loading or a specific co-ordination requirement on one half of the ring).
- If not: align both Ie> stages to the same curve and Tpset.

3.4 FC LV Incomer Long-time = 0.5 s

FC LV Incomer (MasterPact MTZ1 16, 1600 A) feeds the 1 MVA frequency converter bus. Long-time Ipset = 1.0 (1600 A) sits at the ACB rating. Tpset = 0.5 s is well below the typical 12 - 20 s LT band — the LT element will time out and trip on the FC's cold-start inrush.

The New LV Feeder ACB on the Spaceport feed has Long-time Tpset = 4 s — also short, but less acute.

Suggested change:

- FC LV Incomer Long-time: Tpset 0.5 → 12 s.
- New LV Feeder Long-time: Tpset 4 → 12 s, for consistency.
- Confirm the FC's startup current profile supports 12 s — some FCs draw heavy inrush over several minutes.

3.5 Transformer with no type assigned in the model

There is a 2-winding transformer in the model with no TypTr2 assigned (typ_id = None). With no type, the transformer has no rating, no impedance, no vector group. It would be invisible to a load flow or short circuit; it is likely the reason DSS J shows zero load.

Suggested action:

- Either delete the placeholder transformer if it is not needed, or assign the correct TypTr2. Re-run load flow to confirm site totals are not silently missing a substation.

4. Open questions for the engineer

- Agreed WPD setting record for the DNO Incomer relay — TMS, Ipset, presence of any I>> instantaneous on the WPD side.
- Loss-of-mains arrangement for the 1 MW solar PV — separate G99 device, or to be installed?
- Frequency Converter cold-start inrush profile — confirms whether 12 s LT band is sufficient (Finding D).
- DSS J connection — appears to have a 2-winding transformer with no type assigned and a zero load. Real or model artefact? (Finding E).
- DSS P and DSS S loads at ~ 1.4 kW — placeholder, or genuinely unloaded substations?
- Confirm the operating philosophy at the DSS ATCT-F / Cub_1 N/O point — does it ever shift, and if so under what conditions?