NZ Power Industry Space Weather Operational Response

TRANSPOWER

CEP2025, Andrew Renton May 2025

Agenda

- Takeaways
- Who is Transpower
- GIC Context & risk
- What are we doing
- Plans for the future

Takeaways

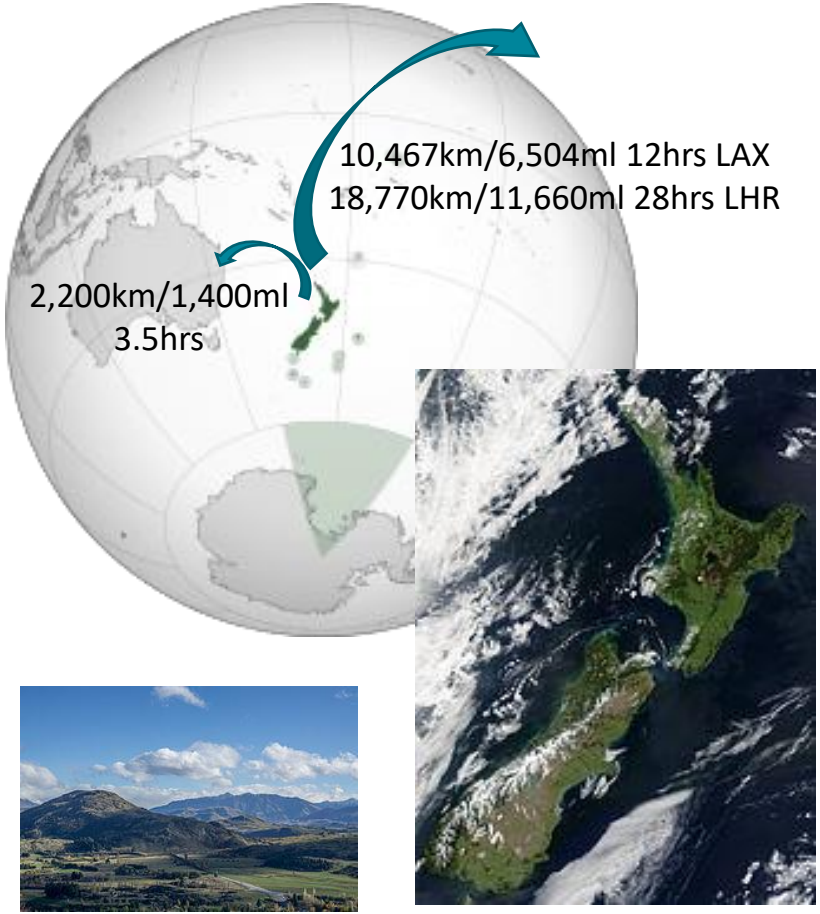
Take aways

- No human health impacts at ground level - only to technical infrastructure, but with effects varying across the country and lasting from 24 to 36 hours. If you already have an emergency plan for dealing with disruptions to your lifeline services from flooding, earthquake, volcanic eruption, or tsunami, then you already have an effective plan for extreme space weather.
- GPS positioning and time services, LEO satellite and some terrestrial comms (HF, VHF radio) will be impacted, any functions relying on these will be degraded during the event.
- Transpower is the electricity sector coordinating entity, takes the industry technical/operational lead with government agencies (DPMC, NEMA, ODESC) during event response.
- Known historical phenomena. Last extreme event 1859, before grids existed. Growing scientific and engineering understanding of the HILP risk posed to modern interconnected systems and each affected asset owner, which must be addressed collaboratively to provide electricity to end consumers.
- Tight collaboration between scientific community and electricity participants required (Transpower close involvement since 2016 & Solar Tsunami Project 2019/20). Electricity Industry Space Weather Working Group established 2023, after science could provide answers to engineering questions. Goal to provide a coherent industry response and assurance to Government that the risk is adequately addressed and mitigated.
- Design level event is 1:100 with Transpower designing for 1:450 flooding, 1:2500 earthquake, 1:300 year wind

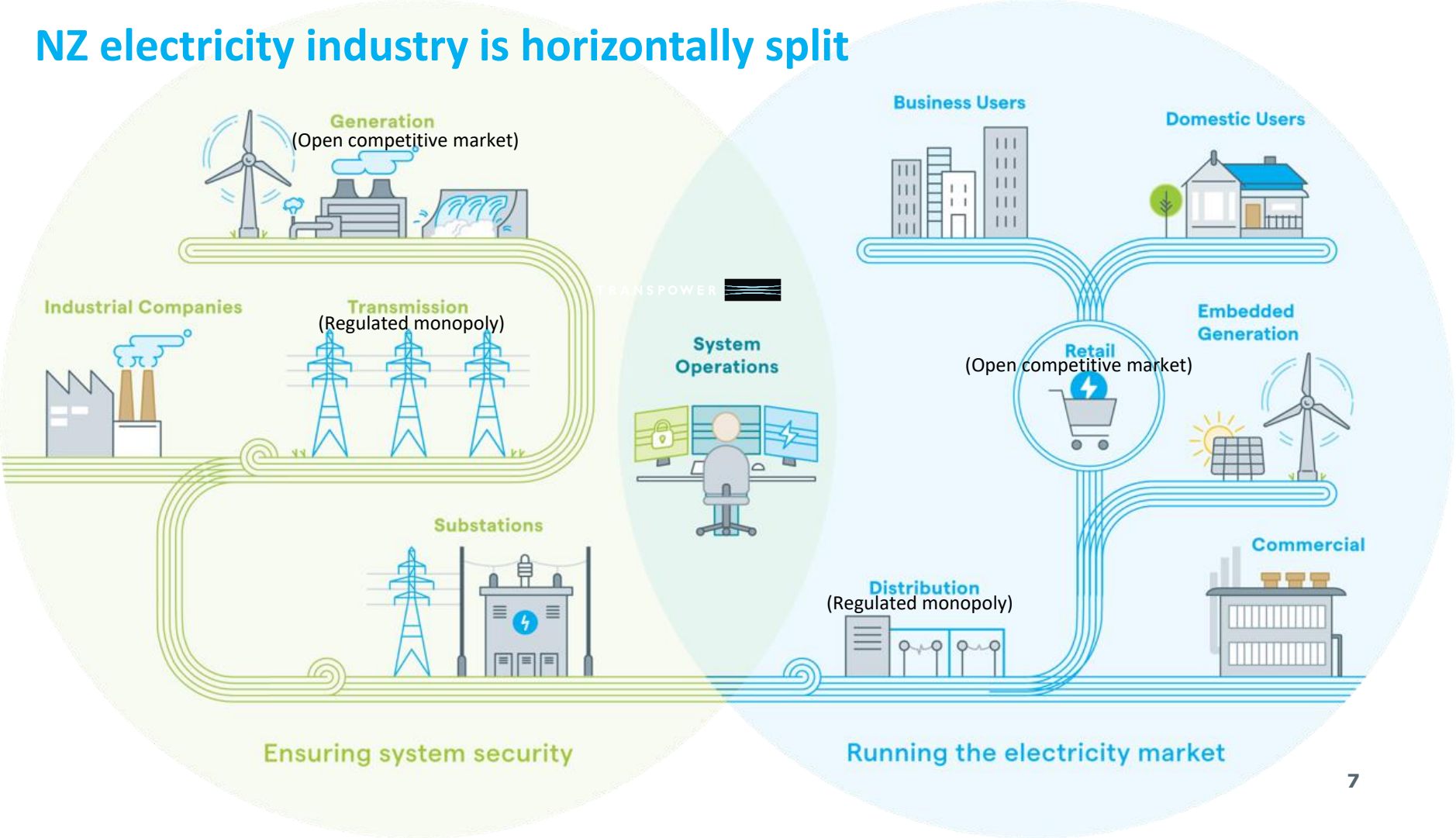
Country & Company Overview

Aotearoa, New Zealand

- Land area 220,000sqkm/108,000sqml
- Population 5.2M
- GDP NZ$262B/US$155B
- Seismically active, maritime, volcanic, flat lands to mountains (3,750m/12,500') fiords
- Rainfall 300mm/2,800mm pa
- Average Solar resource 11-14MJ/m2/day
- Average Wind 4-6m/s windfarm capacity factors 0.32-0.48
- Plan for many natural hazards earthquakes, tsunamis, volcanic, flooding, space weather

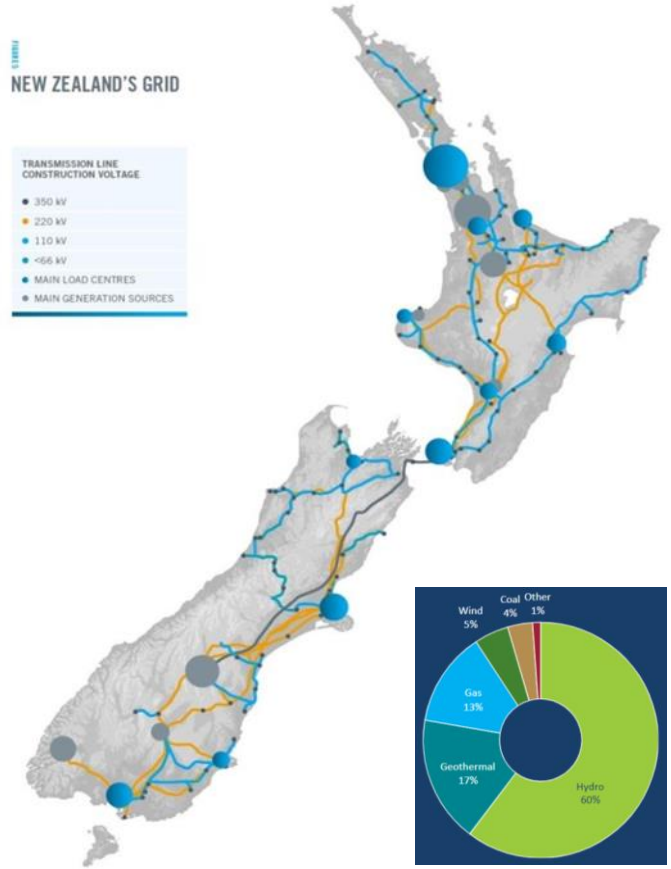


NZ electricity industry is horizontally split



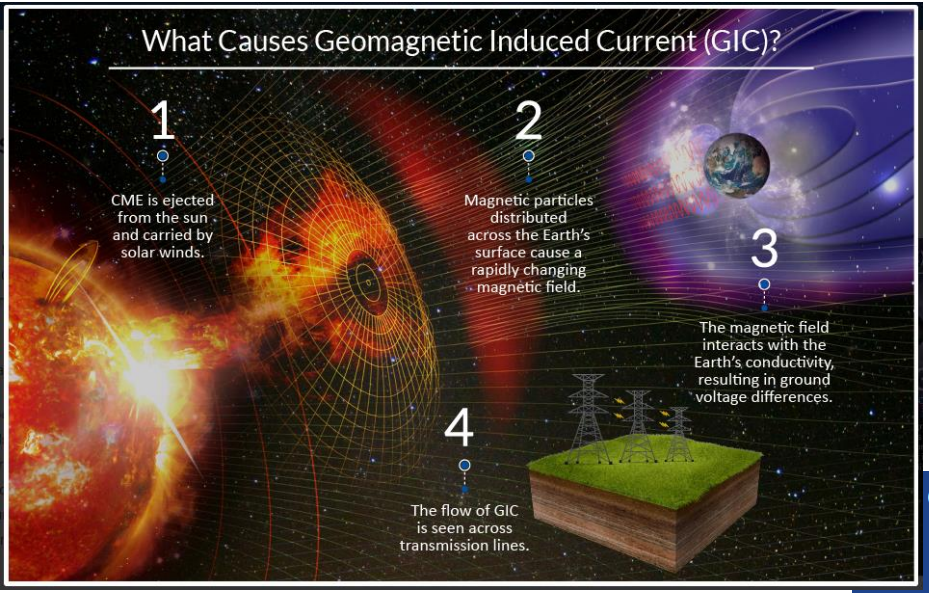
Transmission network

- NZ$4.9 billion regulated transmission assets
- Sole Transmission System Owner & Operator in New Zealand
- Approximately 11,000 kilometres of transmission lines
- 1,200MW HVDC Bi-Pole, 600km link
- 178 substations
- 27 distribution customers
- 10 large industrial direct-connect customers
- 6 large grid-connected generator customers
- Installed generation capacity 9,271 MW
- Peak demand 7,000MW,
- Annual generation 43,503 GWh
- 82% Renewable generation

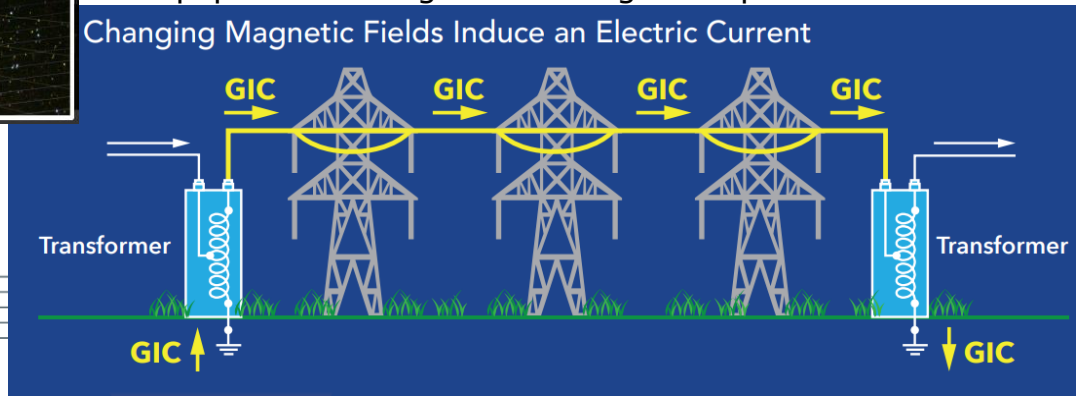


GIC Context & Risk

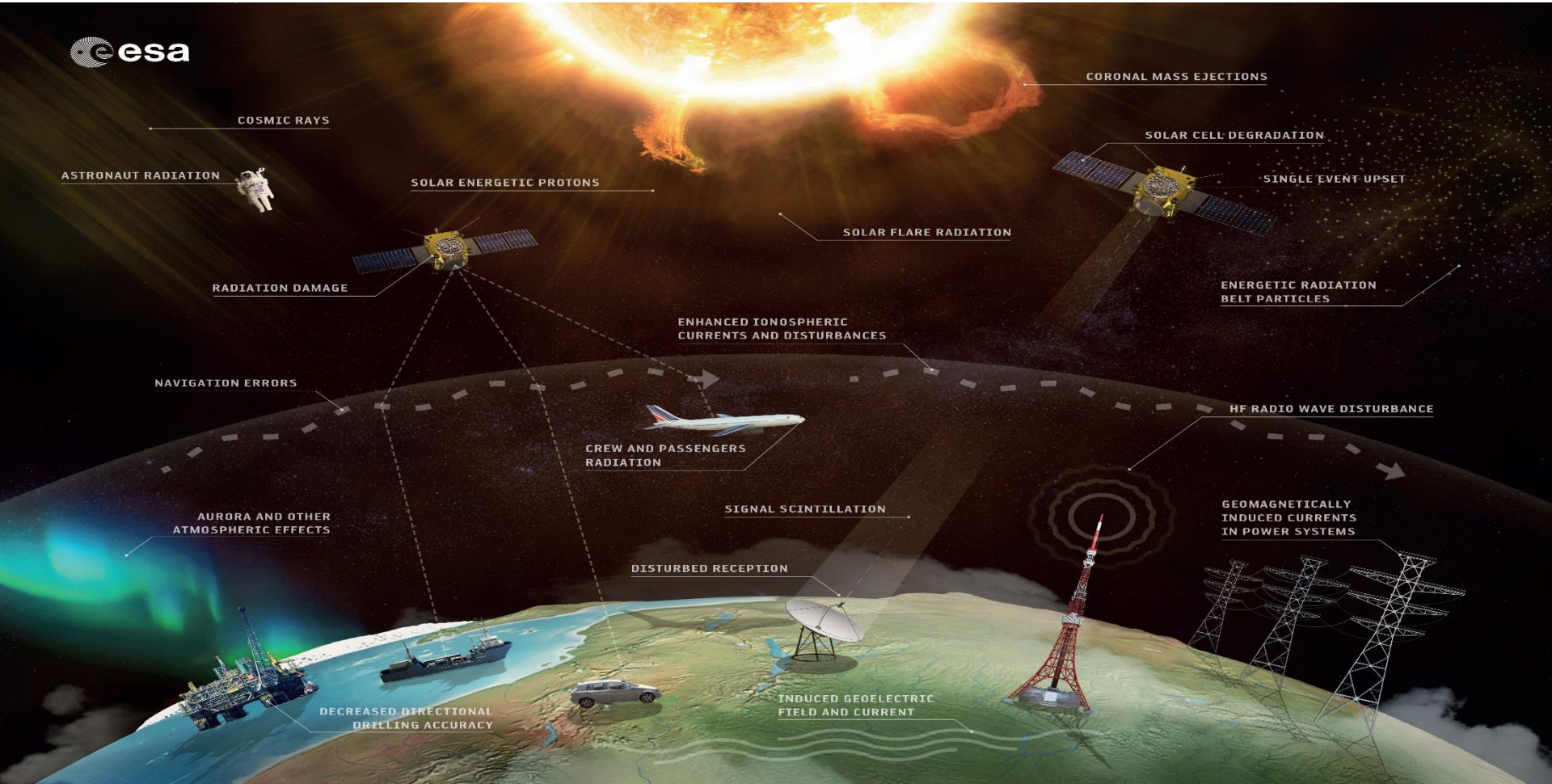
How does it interact with electricity network?



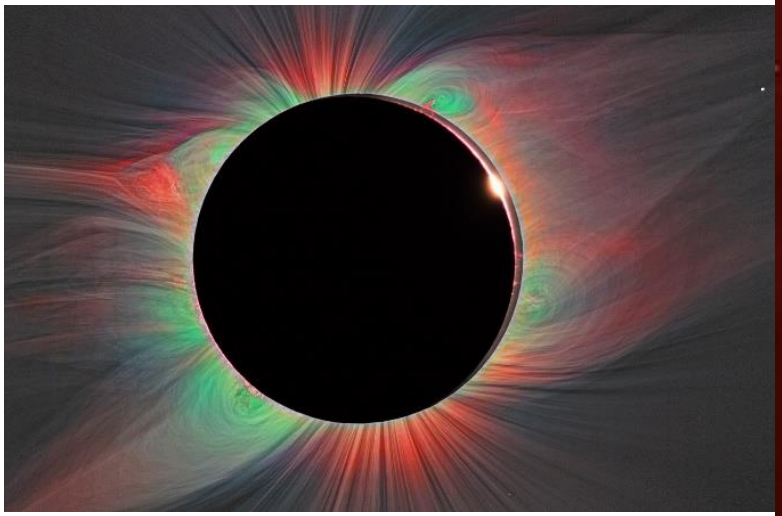
- A planet sized generator using Faradays law.
- An electric current produces a magnetic field
- The magnetic field produces a voltage in the ground
- Voltage differences (10-30V/km) between the ground points drives a current between them
- The current takes the path of least resistance either the ground or long metal connection like our transmission lines
- This is why it is mostly a generator and transmission issue (generators connected to ends of lines)
- Saturates transformers, heating, reactive power draw, equipment damage and voltage collapse

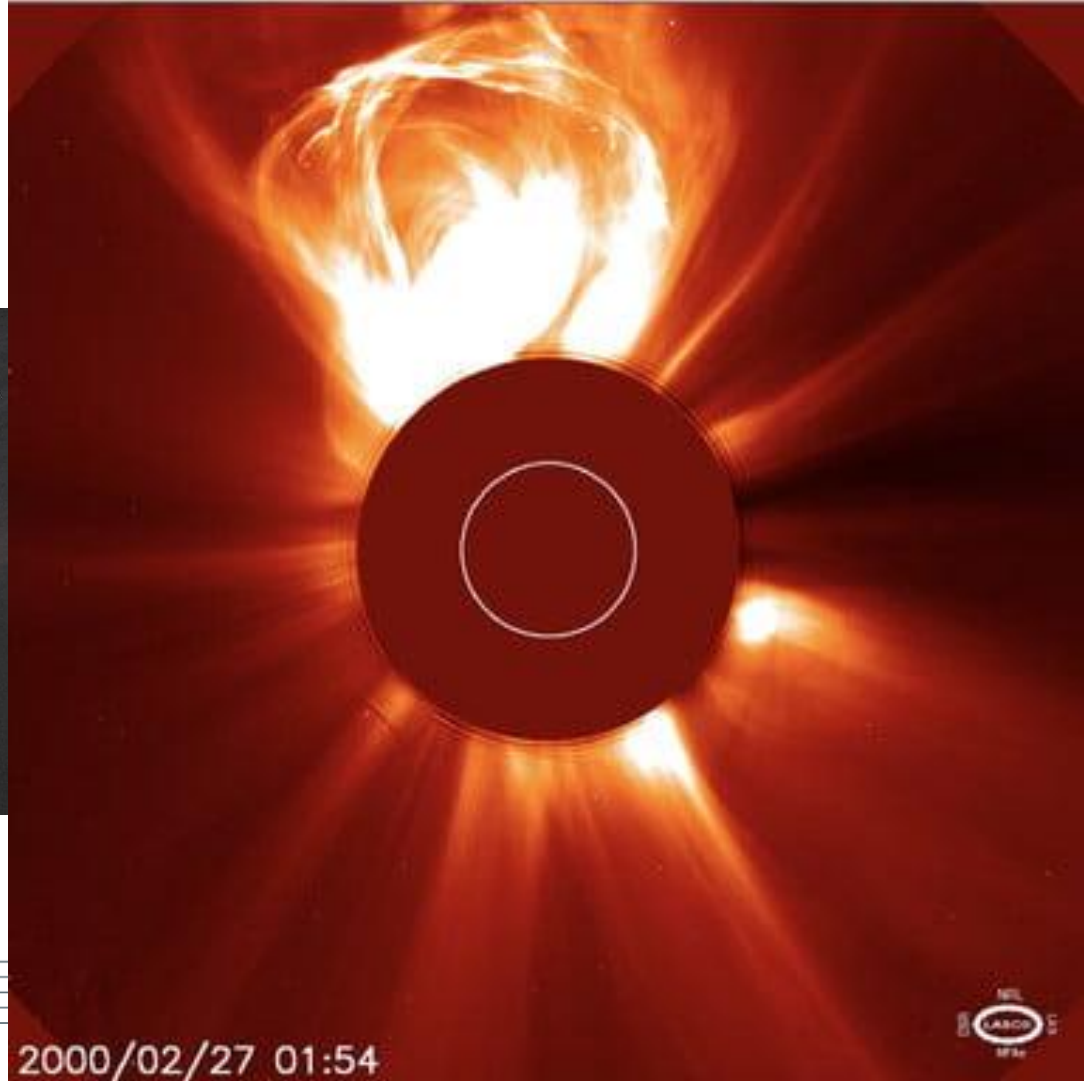


What is the impact on other infrastructure?



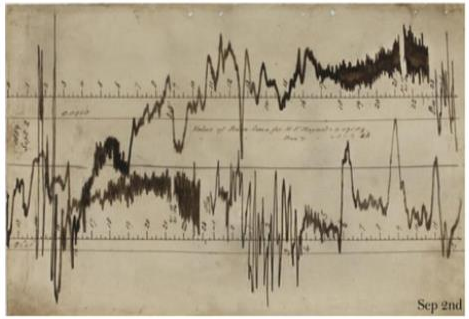
The physical threat





Environment @ the time

- Carrington event 1859
- Bulledale & Refton 1886/8
- Repair crew 1902 for the 1897 11kV 42km Buffalo-Niaggra



The Auroral Display in Boston.

Boston, Friday, Sept. 2.

There was another display of the Aurora last night, so brilliant that at about one o'clock ordinary print could be read by the light. The effect continued through this forenoon, considerably affecting the working of the telegraph lines. The auroral currents from east to west were so regular that the operators on the Eastern lines were able to hold communication and transmit messages over the line between this city and Portland, the usual batteries being discontinued from the wire. The same effects were exhibited upon the Cape Cod and other lines.

The New York Times

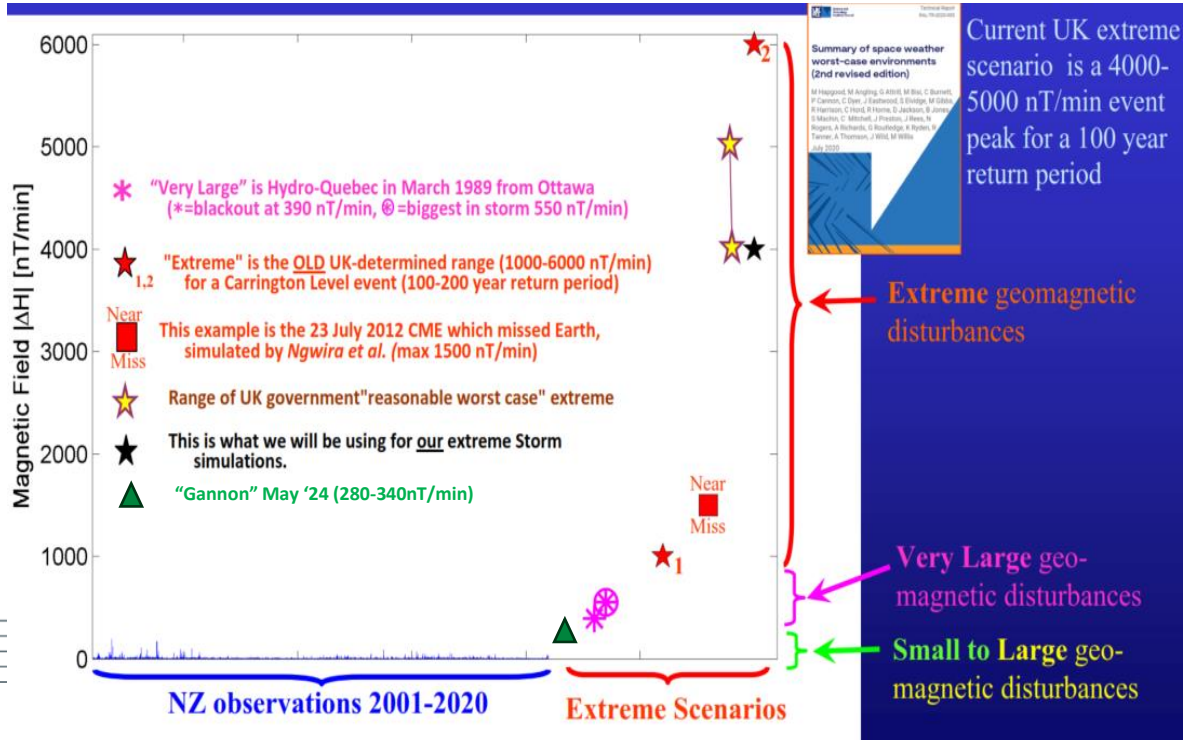
Published: September 3, 1859

Event magnitude and return period

- Solar storms one of the few global-scale natural catastrophes that impact interconnected systems.
- Other natural hazards we plan for floods 1:450, seismic 1:500-1:2500, wind 1:150-300, snow 1:150-500 (AS/NZS 1170 IL2-IL4)
- NERC Guidelines of 2013 & 2019 only assess impacts at 1:100 years, and is under done post Gannon
- CME return period reduced from 1:1200 year to 1:100-150 year
- Our "extreme storm" modelling based on UK study that suggests the 1:100-250 year return period is 1000 to 6000 nT/min; we selected 4000 nT/min.
- NOAA space weather predictions and real-time alerts are on a scale of G1-G5, with all events >350nT/min class as G5, .
- Not seen an Earth-directed extreme CME since "Carrington" event in 1859, but there has been extreme CMEs heading in other directions.

PROBABIITY OF OCCURING IN NEXT 50 YEARS

- Alpine fault 75%
- Extreme CME 64%
- Mt Taranaki eruption 30-50%
- Hikurangi fault 25%



NOAA geomagnetic storm scale

NZ Extreme event 4,000nT/min

Near miss 2012 1,500nT/min
Hydro Quebec 550nT/min
Gannon 390-420nT/min

Transpower mitigation plan initiates switching

Transpower mitigation plan monitors
Aurora visible from Christchurch

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
G 5	Extreme	**Power systems:** Widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** May experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** Pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).	Kp = 9	4 per cycle (4 days per cycle)
G 4	Severe	**Power systems:** Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** May experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** Induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	**Power systems:** Voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** Surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** Intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).	Kp = 7	200 per cycle (130 days per cycle)
G 2	Moderate	**Power systems:** High-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. **Spacecraft operations:** Corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).	Kp = 6	600 per cycle (360 days per cycle)
G 1	Minor	**Power systems:** Weak power grid fluctuations can occur. **Spacecraft operations:** Minor impact on satellite operations possible. **Other systems:** Migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).	Kp = 5	1700 per cycle (900 days per cycle)

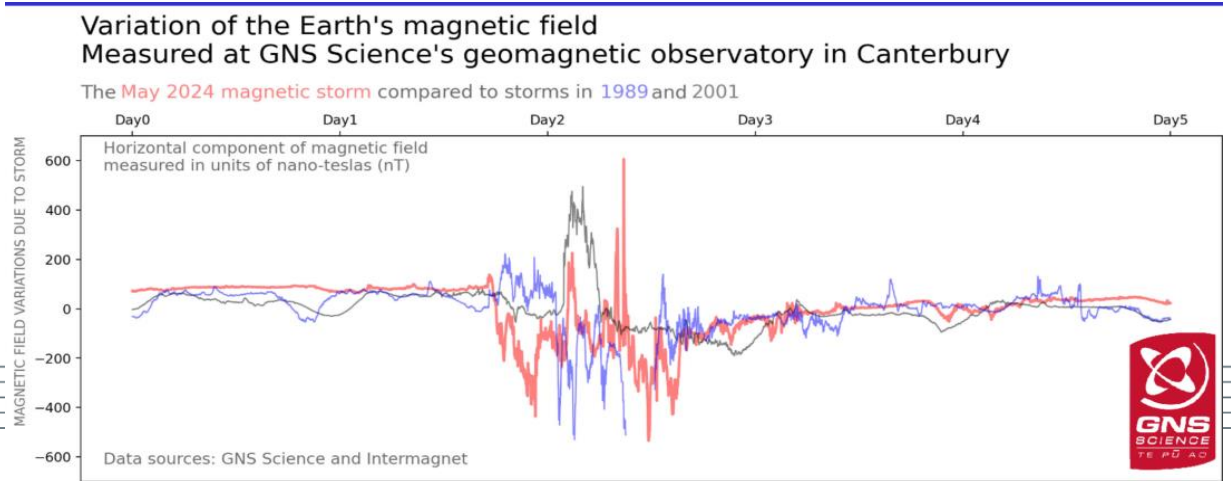
Recent damaging events

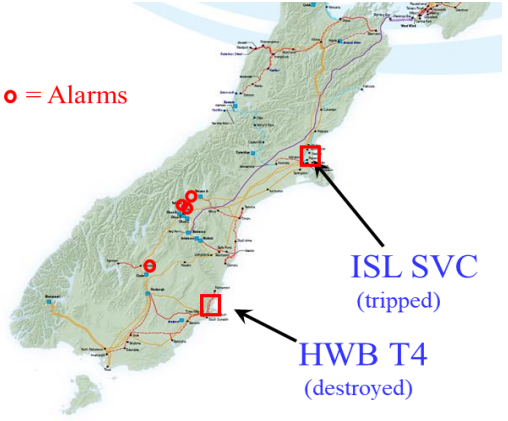
North America 13 March 1989

- CME 3-5 times smaller than an "extreme event"
- 1.5 minutes Hydro-Quebec system collapsed, transformers damaged

NZ 6th November 2001 14:53pm

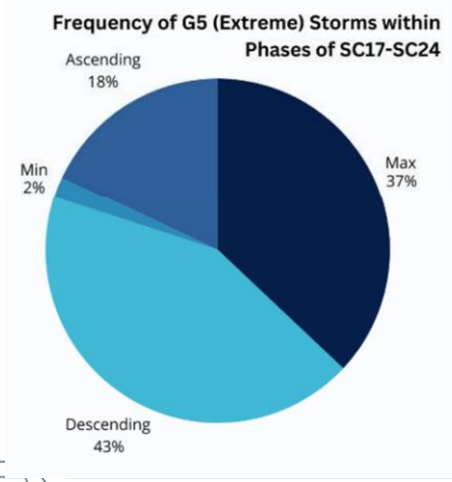
- CME 20-30 times smaller than an "extreme event"
- HWB T4 destroyed (unrepairable), ISL SVC tripped

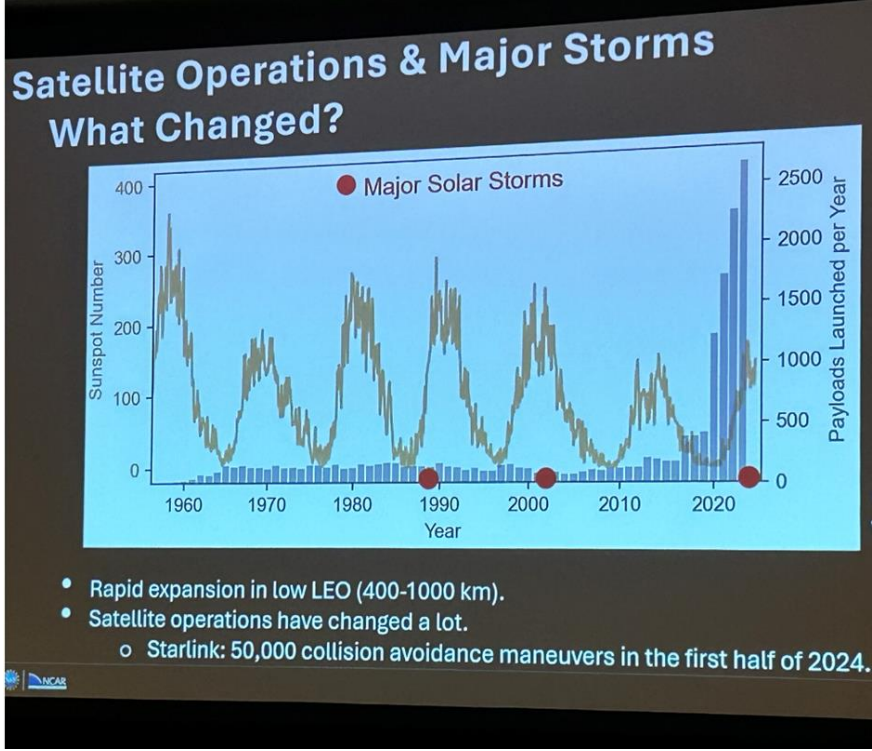




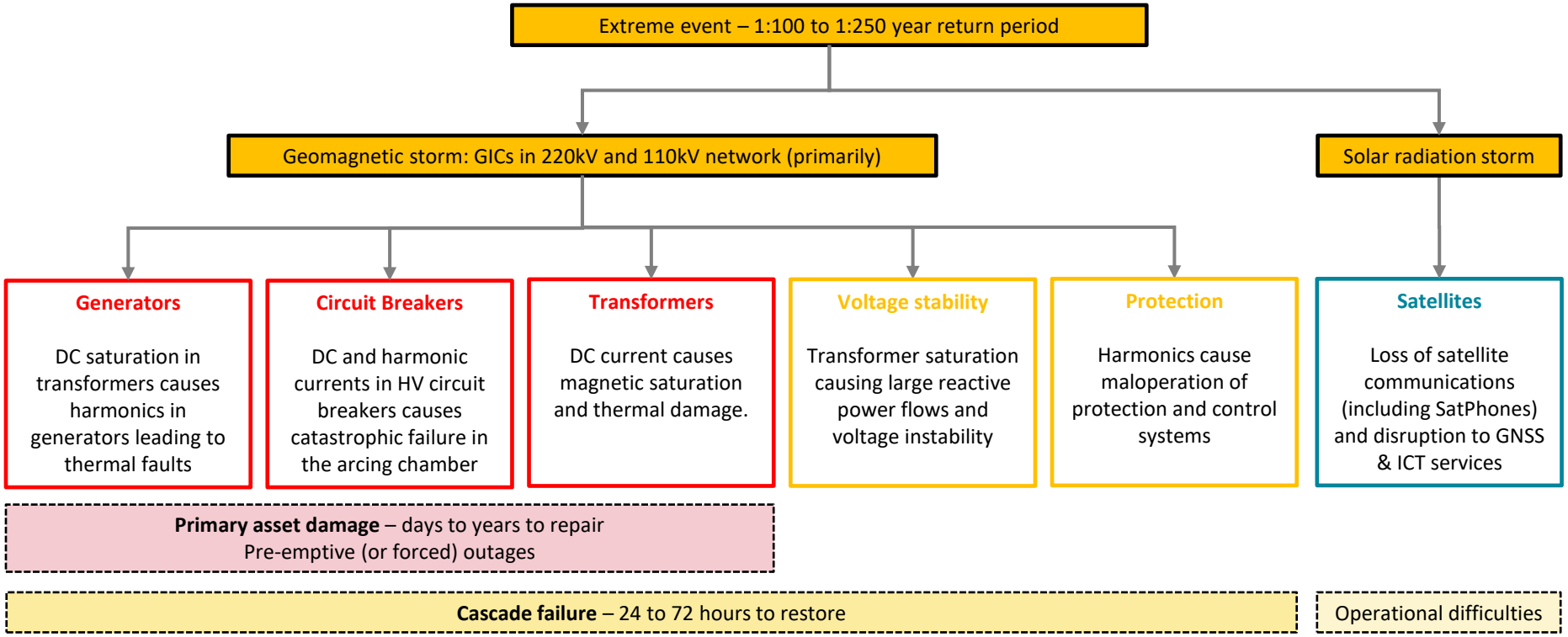
Changes overtime

- Sun has 11 year cycle
- Extreme storms can occur at anytime
- Most occurring descending phase
- Space is getting a lot busier
- Loss of time, position and sky is real



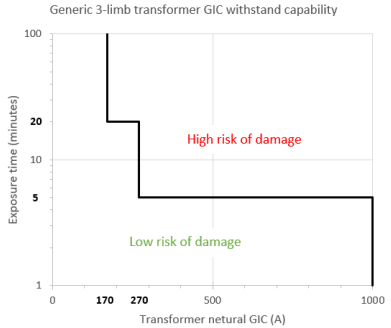


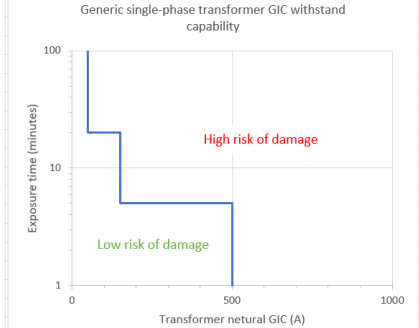
Risks to the electricity industry

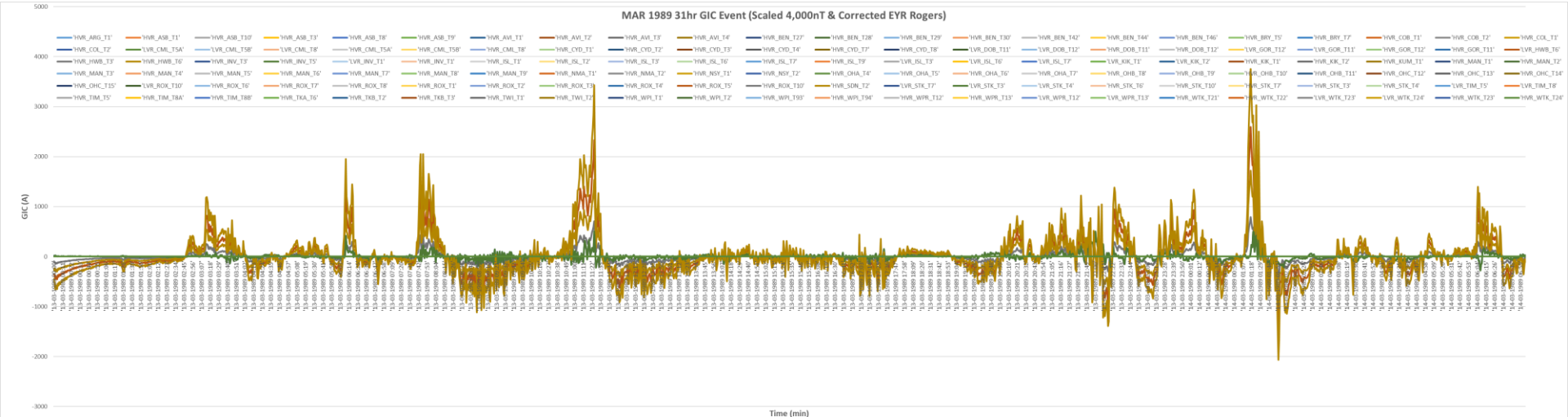


Model of NZ Power System

- All generator and transmission ccts, transformers, and earth grids
- 1989 Event scaled to 4,000nT/min with Rogers latitude correction
- GIC profile by unit, triaged IEEE C57 and our derived current limits







Ttransformer threat assessments

- Hitachi Energy, Dr Girgis & Mats Bernesjo undertook independent design checks, GIC magnetic assessment, design susceptibility, structural thermal impacts, winding thermal impacts.
- 27 units at risk of catastrophic failure

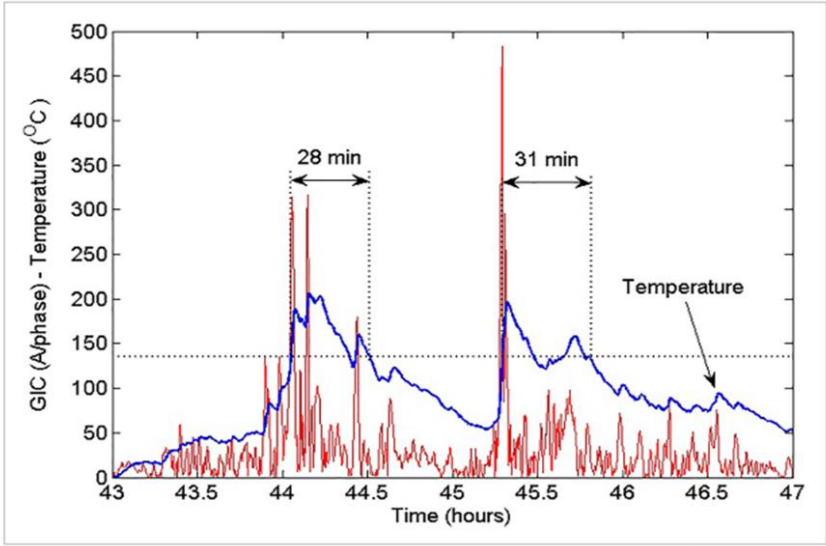
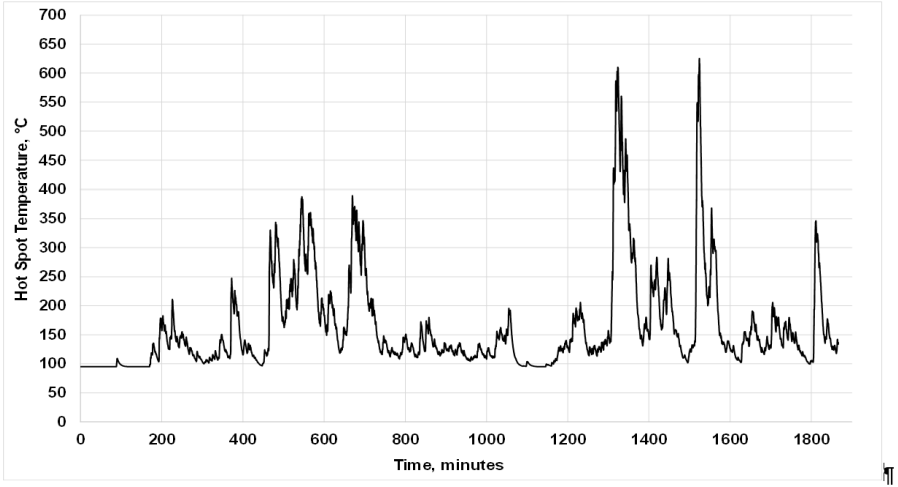
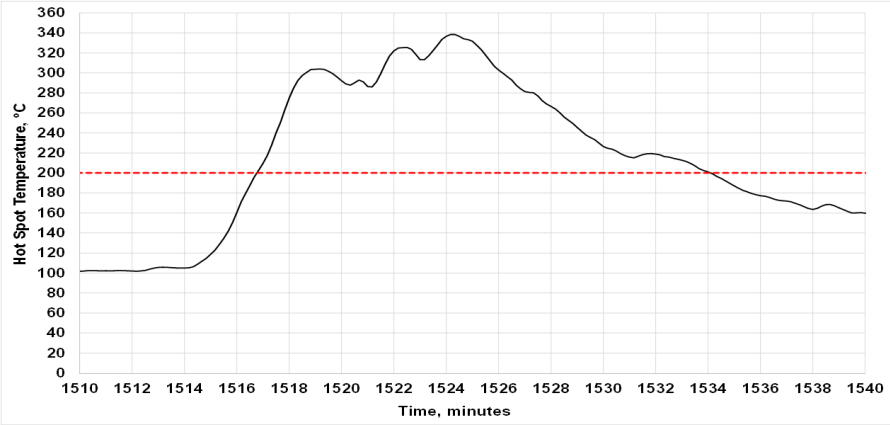


Figure 4 Open in figure viewer | PowerPoint

Example showing geomagnetically induced current (GIC)/temperature relationship. The Blue line indicates temperature and the red is the magnitude of GIC/phase. From Marti et al. (2013).



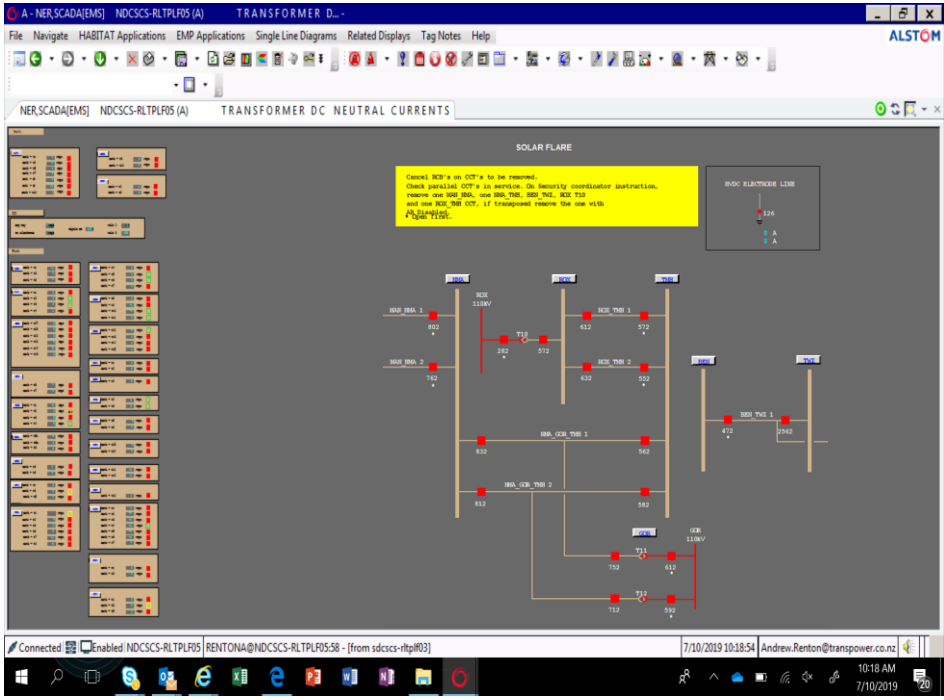
Figure·4·–·Calculated·Thermal·response·of·T6·Transformers·at·Halfway·Bush·to·GIC·Signature·of·Figure·2¶



Figure·6·–·Calculated·Hot·Spot·Temperature·of·Structural·parts·of·North·Makarewa·T1·&·T2·Transformers**¶

What have we and are we doing?

SCADA & GIC



- Original HVDC link installed 1965
- First 12 GIC monitors installed 1992 as part HVDC upgrade, expanded after 2001 event
- Monitor GIC currents at 72 TX over 29 sites country wide, based on initial modelling
- Adding 10 more TX at 7 sites HEN T1, T3 SFD T10, RDF T1 & T2, KAW T12, KIK T1, WIL T8, STK T1 & T2, based on results of solar tsunami modelling, 20+ years real time data

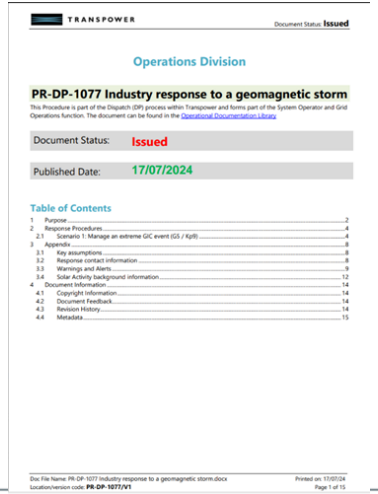
Joint testing DC Injection Testing

- Two injection campaigns 2023 & 2025
- 4 periods of 2hrs at 700A DC
- Monitoring multiple 3 phase transformers for GIC, vibration, audio and VLF radio
- Details of 1st and 2nd campaigns
- https://solartsunamis.otago.ac.nz/2023/01/first-injection-campaign/

Operational switching plan – predicted result

Using actual data to:

- Validated and published plan PR-DP-252 & PR-DP-1077
- Extrapolate to compare to historical record
- Compare to NERC & Carrington events
- Scenario using scaled 1989 event, winter peak demand, full security, objective minimise total system GIC and peak GIC in most at threat assets, by switching assets out of service



TRANSPOWER

Document Status: Issued

Operations Division

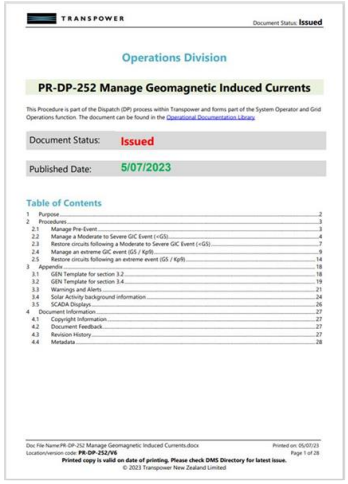
PR-DP-1077 Industry response to a geomagnetic storm

This Procedure is part of the Dispatch (DP) process within Transpower and forms part of the System Operator and Grid Operations function. The document can be found in the Operational Documentation Library

Document Status: Issued

Published Date: 17/07/2024

Table of Contents



TRANSPOWER

Document Status: Issued

Operations Division

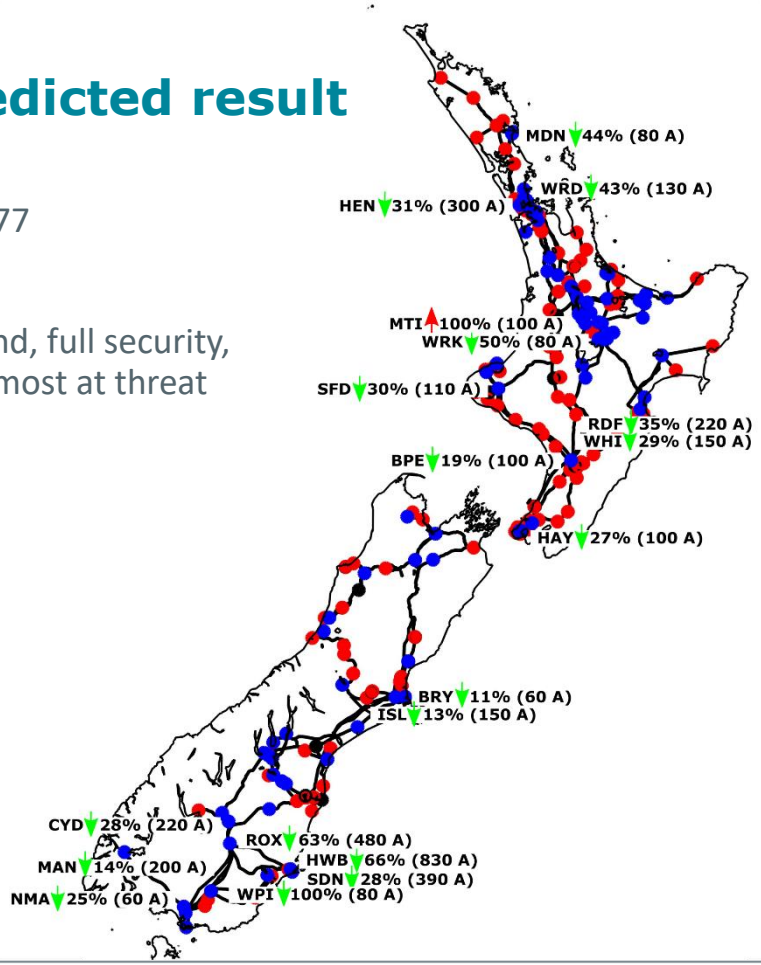
PR-DP-252 Manage Geomagnetic Induced Currents

This Procedure is part of the Dispatch (DP) process within Transpower and forms part of the System Operator and Grid Operations function. The document can be found in the Operational Documentation Library

Document Status: Issued

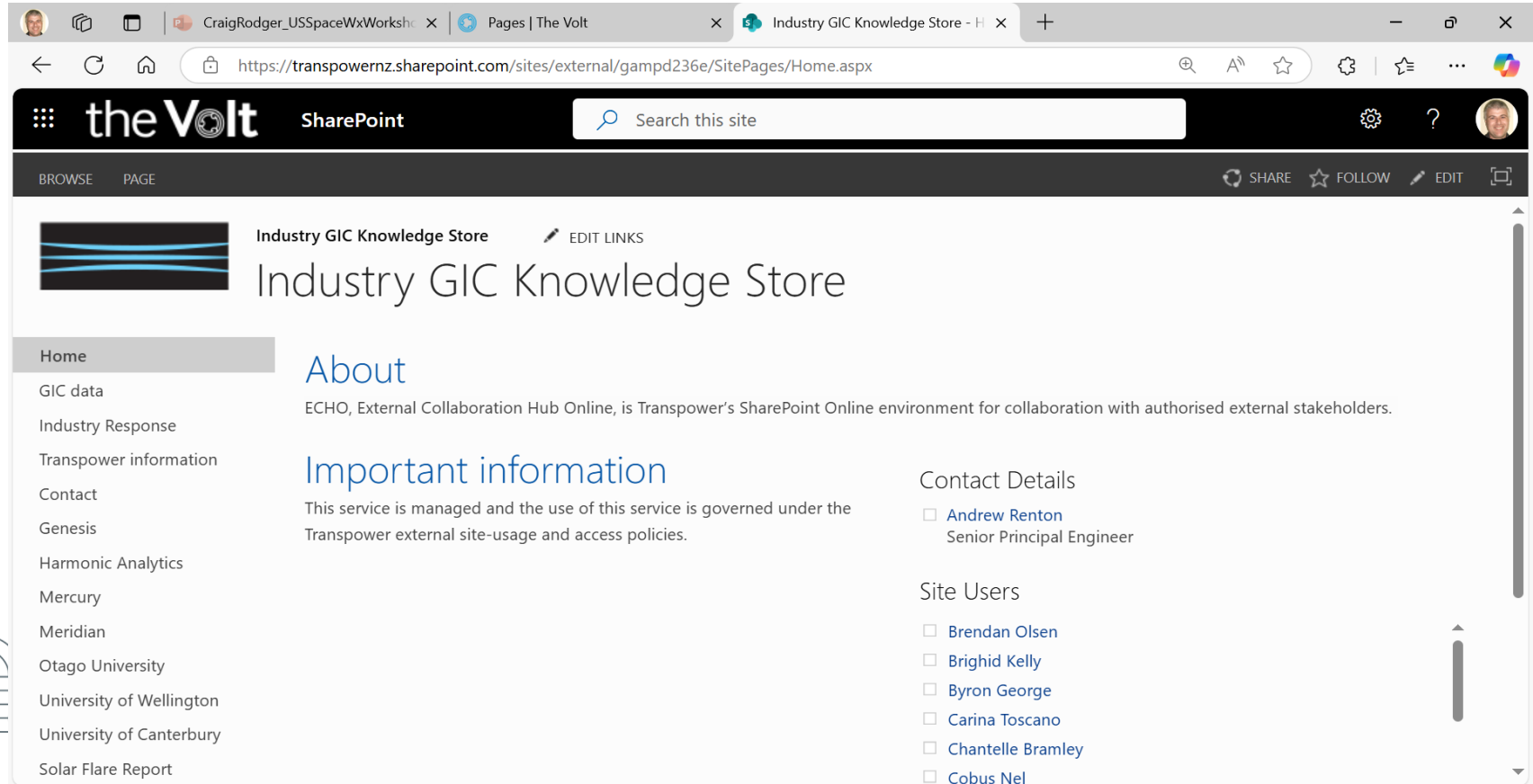
Published Date: 5/07/2023

Table of Contents



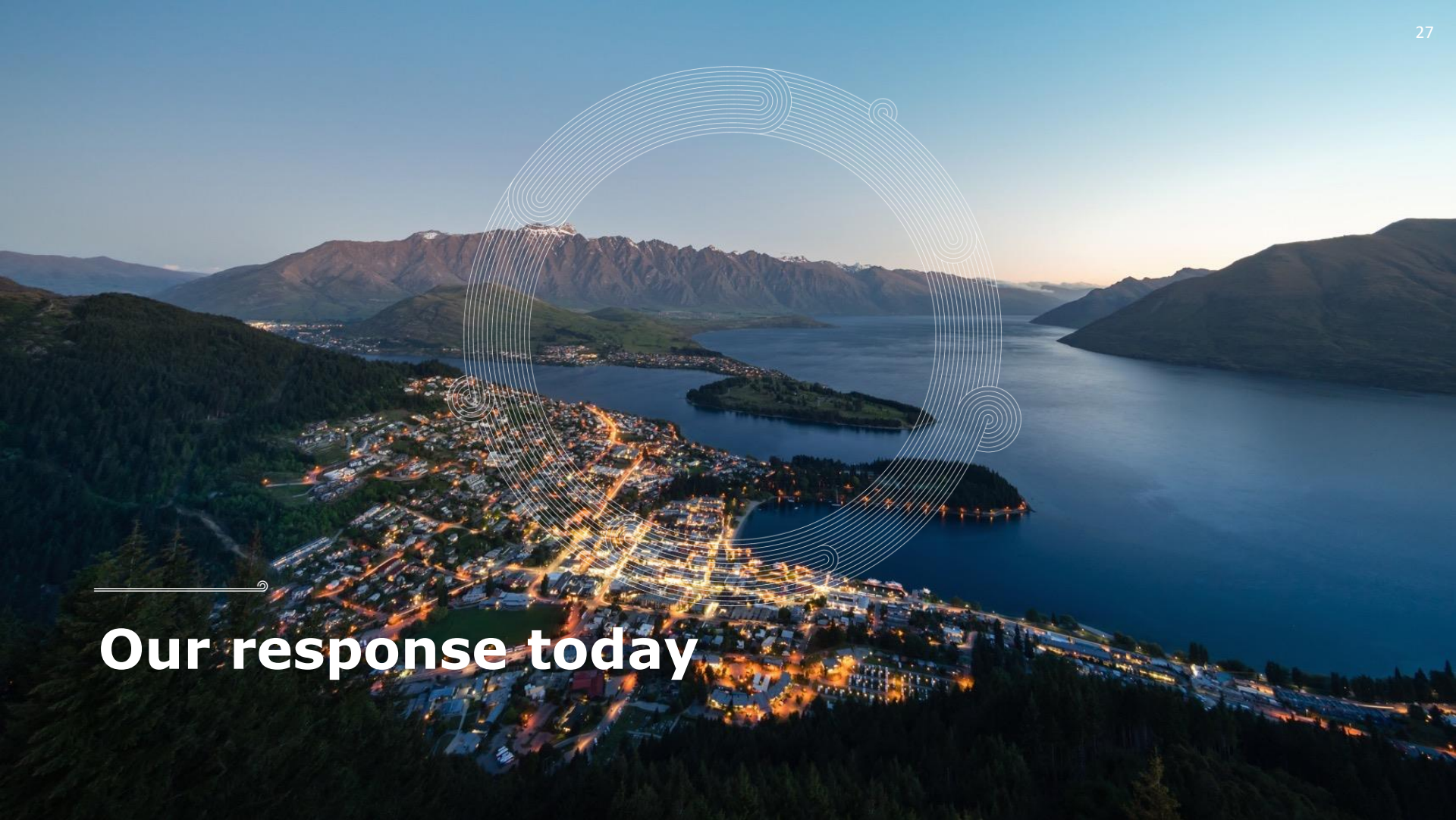
Information sharing & collaboration

- Development and hosting of shared industry knowledge basket for joint collaboration



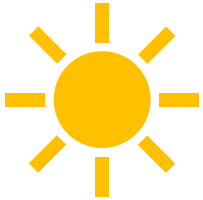
Operational situational awareness tools

- Developing displays for TX GIC, TX Temp, present and predicted solar wind/magnetic field change



Our response today

Possible event timeline



L1, SOHO, ACE, DSCOVR

1.5m km

Light 5s

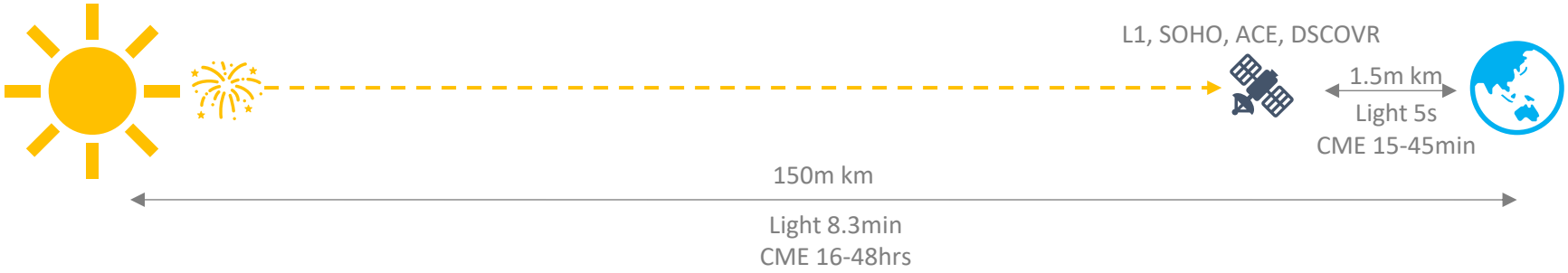
CME 15-45min

150m km

Light 8.3min

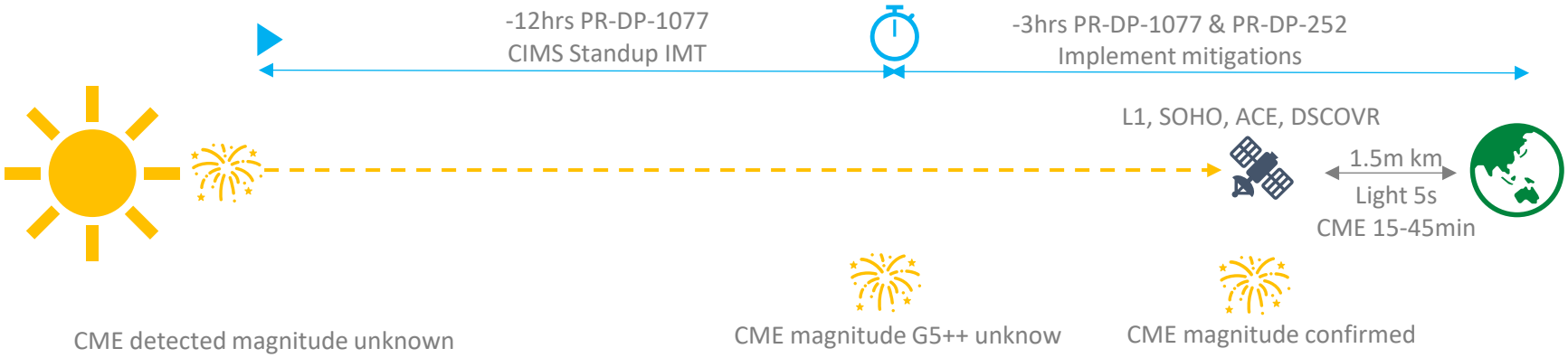
CME 16-48hrs

Possible event timeline



- When an event occurs scientists and NOAA will be aware of it within 10min, with WATCH notices issued of "G4 or Greater" (highest prediction possible)
- Effectively blind until L1 where first instruments are available to measure velocity, density, polarity to confirm magnitude is small G5 (Gannon 350-500nT/min) or Design Level G5 (4,000nT/min). NOAA will issue a WARNING notice at this point

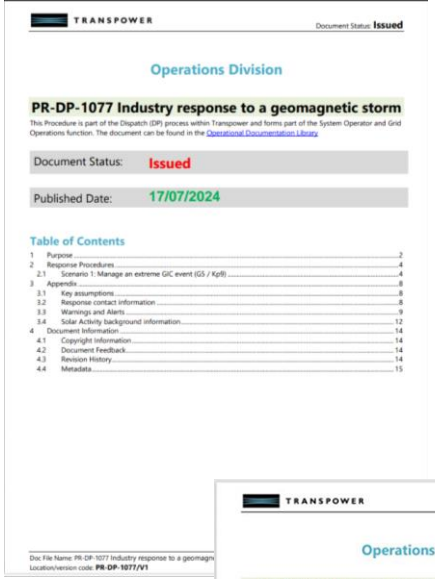
Possible event impact today



- When an event occurs scientists and NOAA will be aware of it within 10min, with WATCH notices issued of "G4 or Greater" (highest prediction possible)
- Effectively blind until L1 where first instruments are available to measure velocity, density, polarity to confirm magnitude is small G5 (Gannon 350-500nT/min) or Design Level G5 (4,000nT/min). NOAA will issue a WARNING notice at this point
- Confirmation of event occurs after it is practical to undertake any mitigations or to mange with lighter touch

Mitigation response plan

- Transpower have a procedure to "manage geomagnetically induced currents" (PR-DP-252), published to reduce magnitude GIC in transmission system. It covers monitoring space weather, outage recalls, calling GEN, and switching to reduce GICs.
- Asset owners generally plan to connect more assets so GIC is shared across more neutrals, lessening its effect – successful in up to moderate events, but in extreme events will put more assets at risks.
- Generators have now prepared their own business response plan. Outputs of these are input to Transpower's whole of industry (PR-DP-1077) and Transpower (PR-DP-252) response plans.
- The new joint industry response plan is published (PR-DP-1077). Includes event trigger, pre-impact coordination, identification of asset owner equipment removal levels, Government co-ordination, demand management and reference to restoration sequences.


TRANSPOWER

Document Status: Issued

Operations Division

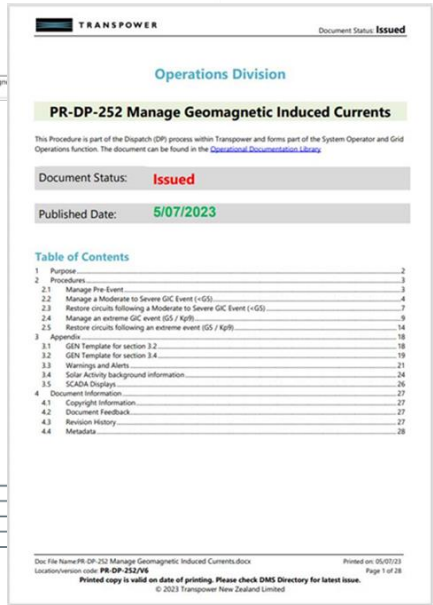
PR-DP-1077 Industry response to a geomagnetic storm

This Procedure is part of the Dispatch (DP) process within Transpower and forms part of the System Operator and Grid Operations function. The document can be found in the Operational Documentation Library.

Document Status: Issued

Published Date: 17/07/2024

Table of Contents


TRANSPOWER

Document Status: Issued

Operations Division

PR-DP-252 Manage Geomagnetic Induced Currents

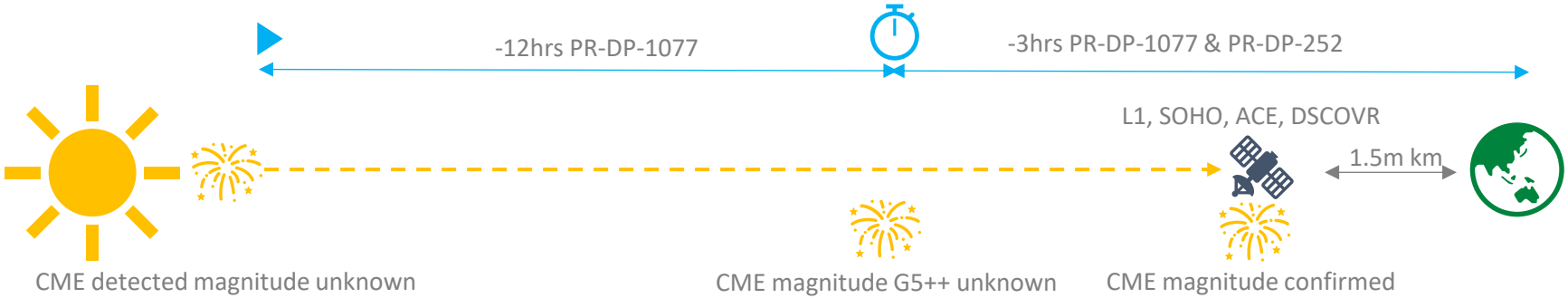
This Procedure is part of the Dispatch (DP) process within Transpower and forms part of the System Operator and Grid Operations function. The document can be found in the Operational Documentation Library.

Document Status: Issued

Published Date: 5/07/2023

Table of Contents

How an event would play out today



T-12 **Trigger event (WATA99) / Scientific community signal its big**

T-11 Industry conference held (Possible extreme event)

IMTs stood up

Customer Advice Notice (CAN) sent

T-10 IMT coordination meetings (every 2 hours)

Industry conference held (outline response plan)

T-9 CAN requesting assets made available, return outages

T-4 Advise NEMA of likely impacts

Recall assets from outage

Mobilise service providers / emergency generators / Tx cooling (fans/pumps)

T-3 Commence ramp down of at-risk geothermal generation

Demand management if required (GE)

T-2 **IMT coordination meeting (Go/No Go for Grid Emergency)**

T-2 Declare Grid Emergency

Switch out GIC circuits

Determine / communicate demand management

Single frequency keepers selected

Protect black start generation units

T-1 Shut down remaining at-risk generation

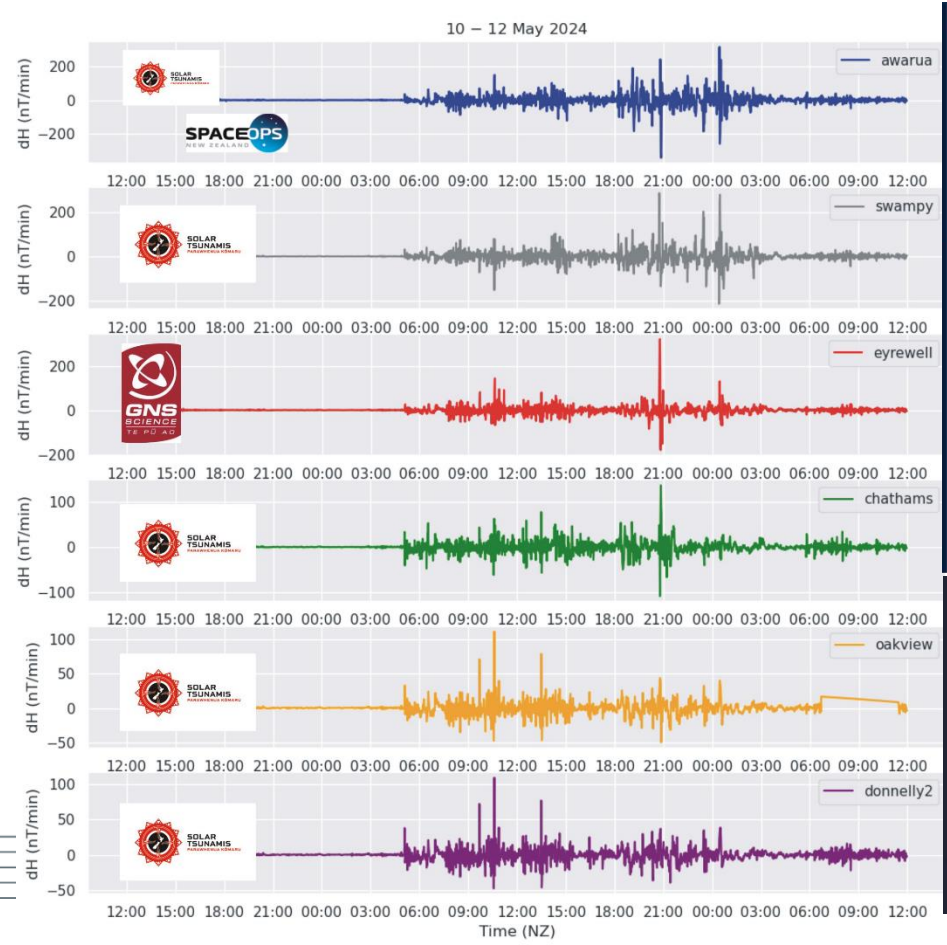
Demand management as required

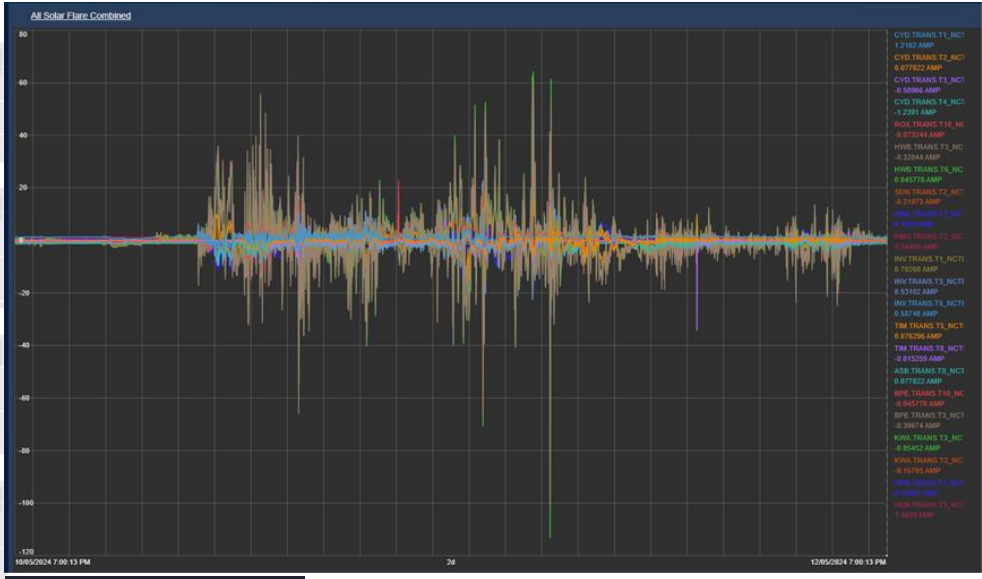
T-.5 **Storm passes L1 satellite / confirm how extreme storm will be**

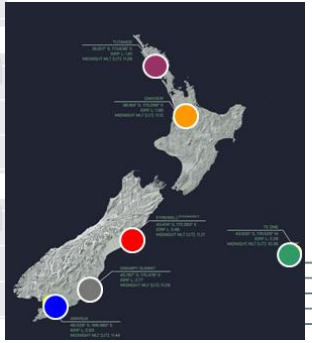
T=0 Storm hits – ongoing management of system, including demand management, responding to faults, until all clear given

Gannon Storm 10-13 May 2024

“Gannon” 10-12 May ‘24, Mag Field and GIC LEM monitoring results

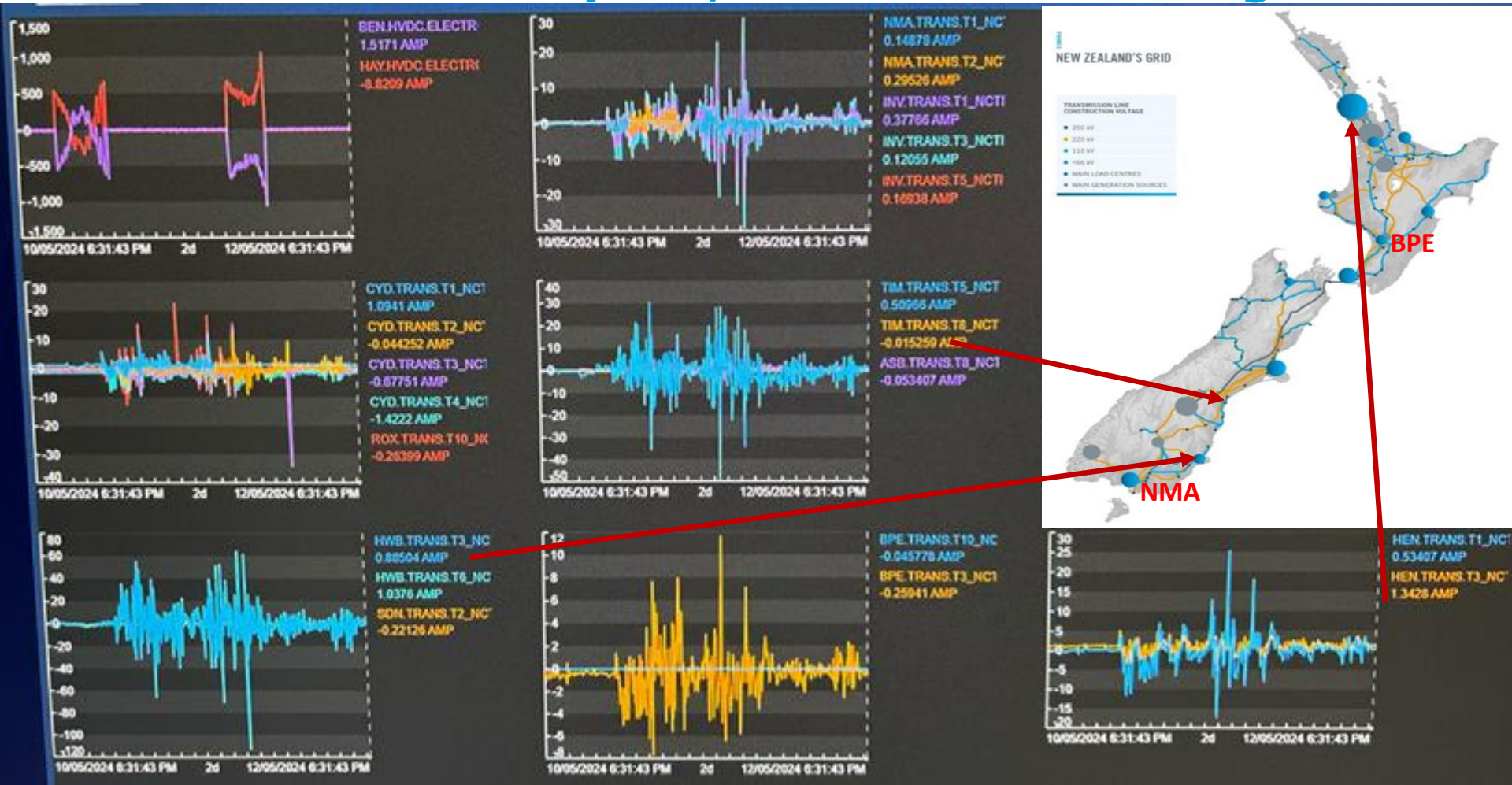






Site	Spike 1	Spike 2
Awarua	343 nT/min	318 nT/min
Swampy	287 nT/min	281 nT/min
Eyrewell	320 nT/min	130 nT/mi

“Gannon” 10-12 May ‘24, GIC LEM monitoring results

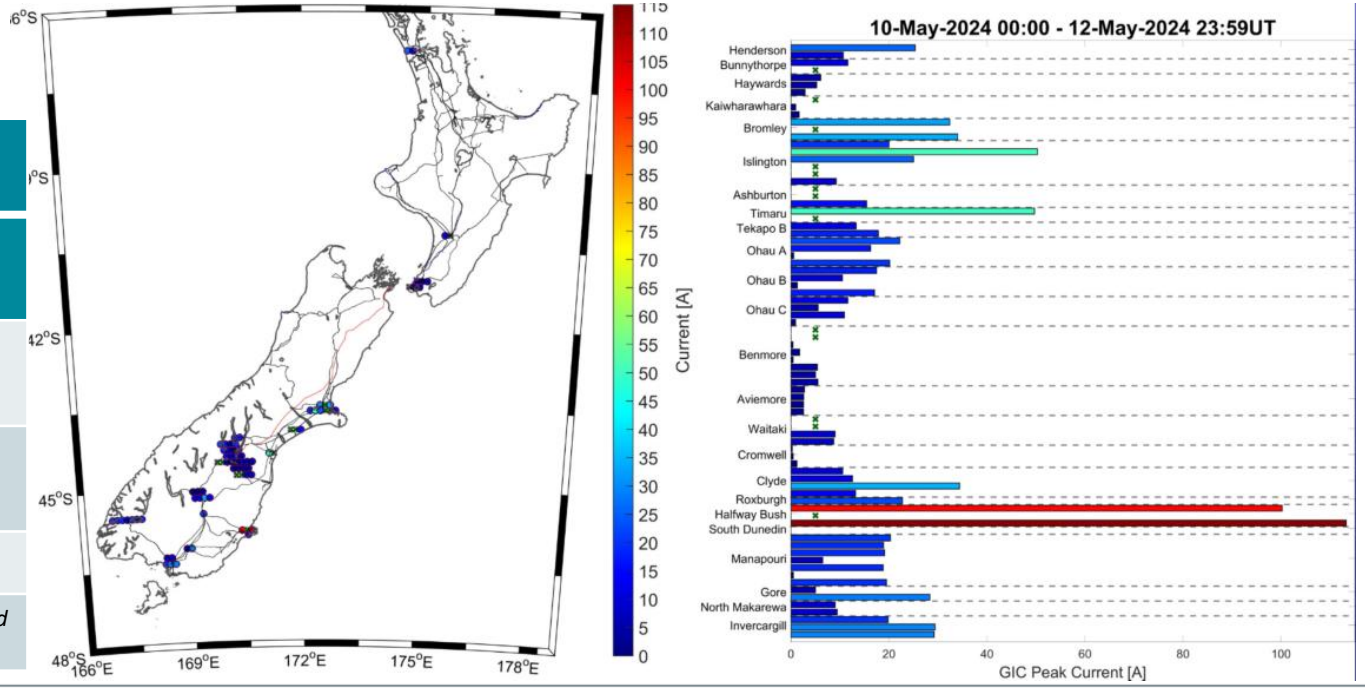


Peak GIC with switching plan implemented

- Work in Progress undertaking back calculation to see impact with/without switching plan & with/without SDN T2
- SDN T2 Tripped 05:28

HWB T6 GIC Neutral Current (A) (Calculated, *Actual measured*)		
System Config	SDN T2 In	SDN T2 Out
No mitigation	137A	211A
With mitigation	41A	103A
Actual	N/A	*113A*

Note T3 peaked at 100A, total site GIC 213A mitigated
Unmitigated site of approx. 430A



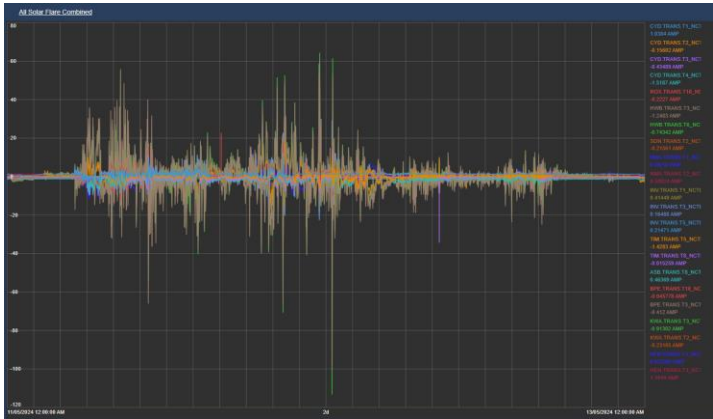
Operational response summary

Friday 10 May:

- 09:15: NEMA contact control room in relation to 'solar flare watch'. No action as only a 'watch' and trigger is 'warning' or 'alert'

Saturday 11 May:

- **04:53: First NOAA 'solar flare warning' (G2 – moderate) issued. More warnings and alerts follow**
- 05:28: South Dunedin transformer trips (turns out to be unrelated)
- **05:58: NOAA Alert K8-9**
- 06:19: Transformer GIC alarms trigger at several sites (sign of storm)
- More NOAA warnings and current alarms occur
- 09:00: Grid Emergency Notice (GEN) issued. Enable switching of circuits in SI
- **11:37: NOAA 'ALERT' (K9/G5 – extreme) issued**
- 12:01: Second GEN issued. Enable switching of circuits in NI
- 13:30: SO Industry briefing – inform industry
- **14:50: NOAA 'ALERT' (G5 – extreme) issued, more warnings and alerts follow**



Sunday 12 May:

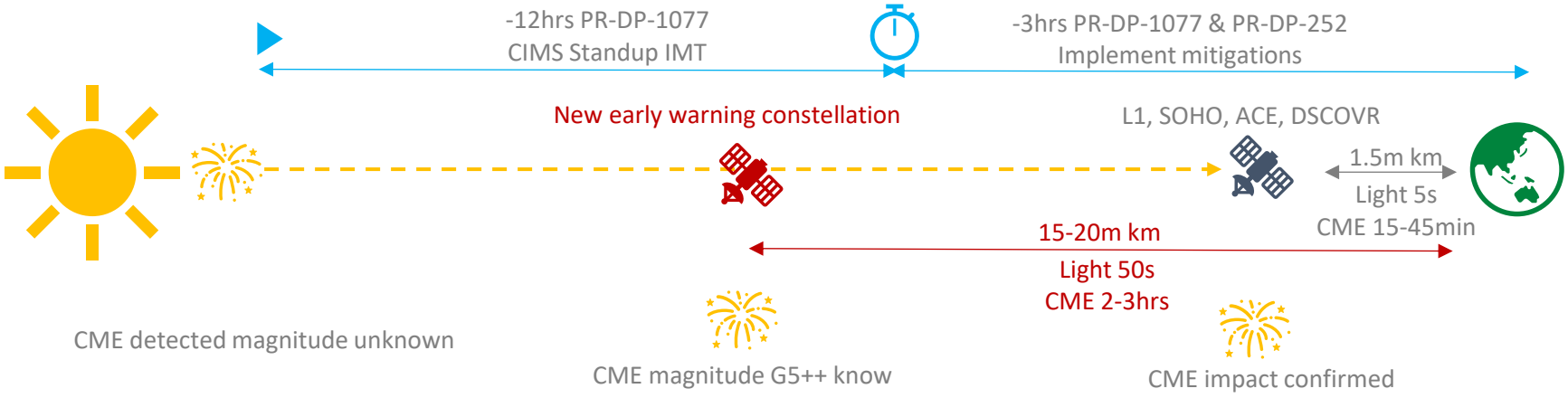
- Continue to monitor storm, after consultation with Otago Uni decide to end GENs on Monday morning 04:00

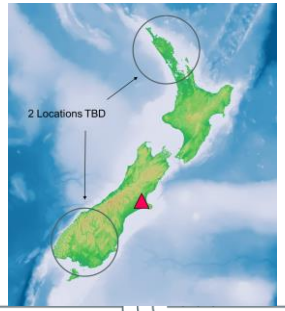
Monday 13 May:

- 04:00: GENs ended

Work to do & improvements

Improvements for event management 0-5 years





- Improved and permanent magnetometer array
- Supported 24/7/365 science advice

GIC blocking device

- Can be installed on transformer neutral to block GICs
- Currently prototypes only we have number 4 being installed
- Large footprint; not suitable for some sites (e.g. Manapouri)
- ATC Wisconsin reporting it has worked well for last 8 years (for small GICs to date).
- NZ$1.5-2M install per transformer.

Development of local/regional impacts for NEMA

Local Auckland Impact

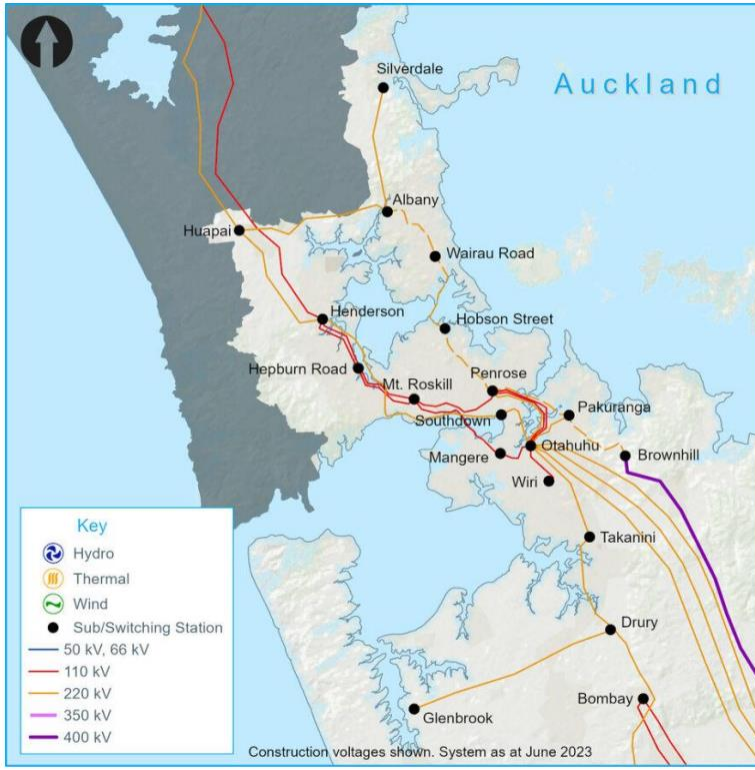
PR-DP-252 & PR-DP-1077
- BHL-WKM_A removed from service
- RDF-WRK_A removed from service

Sites that have elevated mean GIC >200-300A
- This level is higher than desired needs close and active monitoring and could cause loss of supply. Peak currents up to 550A
- Henderson 1ph (HEN 140MW), Glenbrook 3ph (GLN 110+80MW), Pakuranga 3ph (PAK 160MW) most susceptible sites,
- If loss of supply occurs then will remain off for duration of event 24-36hrs

Sites that have mean GIC <200-300A
- Rest of AKL sites 70-150A higher than preferred but manageable
- Should be of low risk e.g. Takanini, Penrose, Otahuhu, Wiri, Mangere etc with minimal chance of disruption

Installing additional sensors at OTA, GLN, HEN, power system studies to consider mitigations effectiveness

Even if Auckland sites fully available may have supply disruption should wider Grid impacts require response that reduces generation and therefore demand management required



TRANSPOWER

Q&A

We're for New Zealand. Tū mai Aotearoa.

Appendices