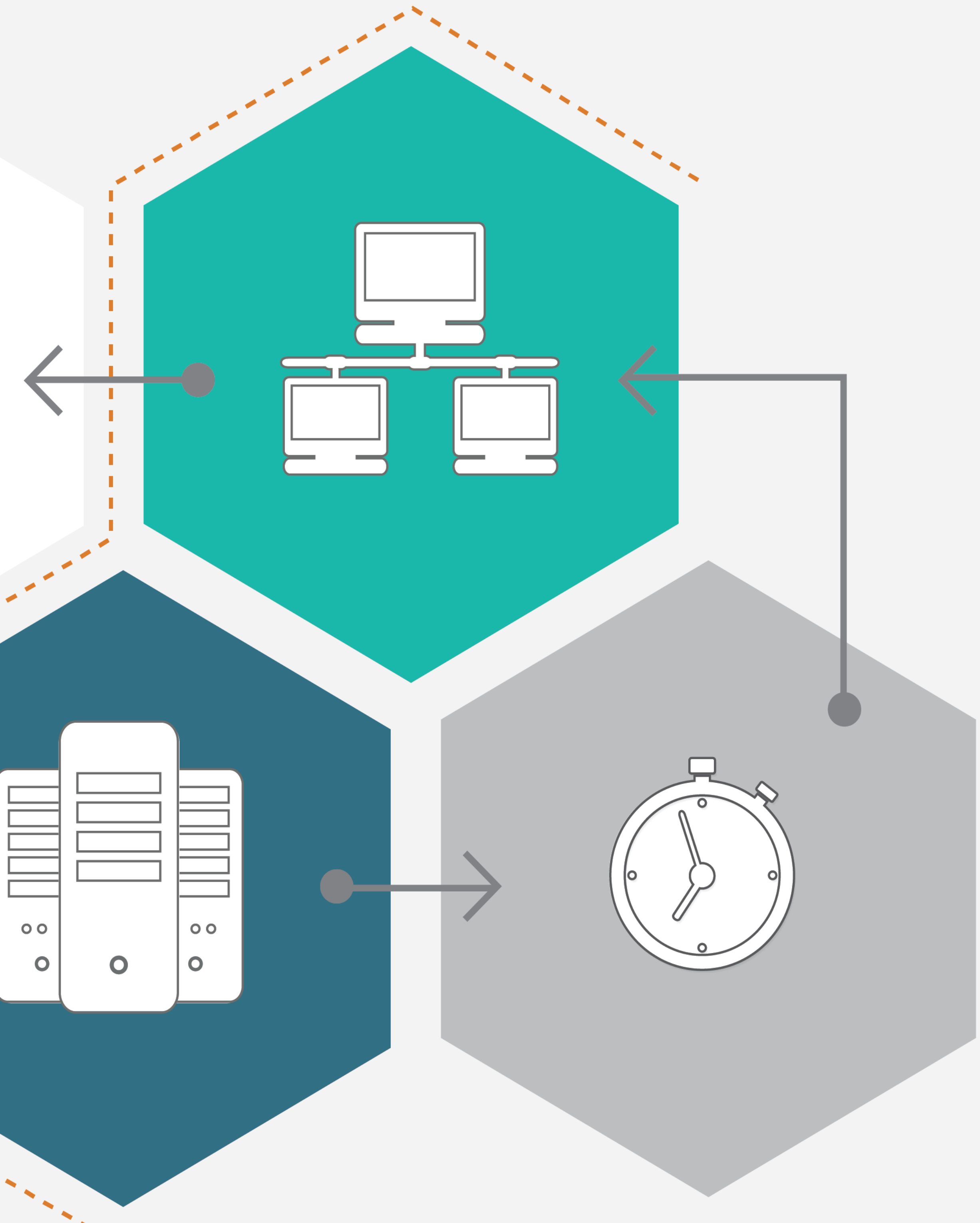
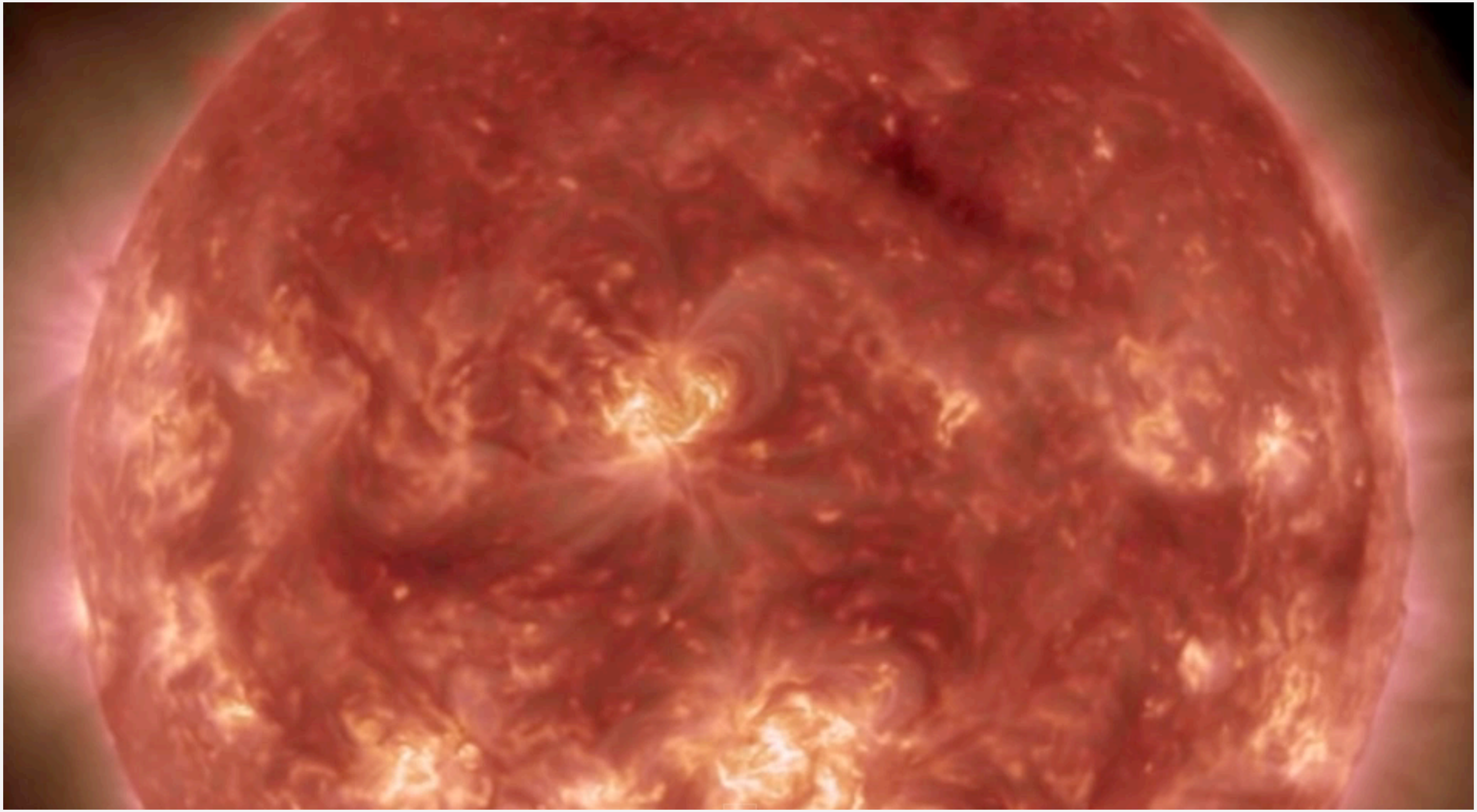


PingThings

PredictiveGrid™

GMD/GIC detection explorations via PMU’s



the data

Provider	Sensor	Notes	Data Rate
USGS	magnetometers	3 locations: Virginia, Colorado, and Washington	1 Hz
SCADA	transformers	Several transformers and types	0.25 - 0.5Hz
NOAA	SWPC	multiple sensors and satellites	varies
ATC & others	PMU	multi-terabytes of data, multiple PMU's, multiple vendors	30-60Hz

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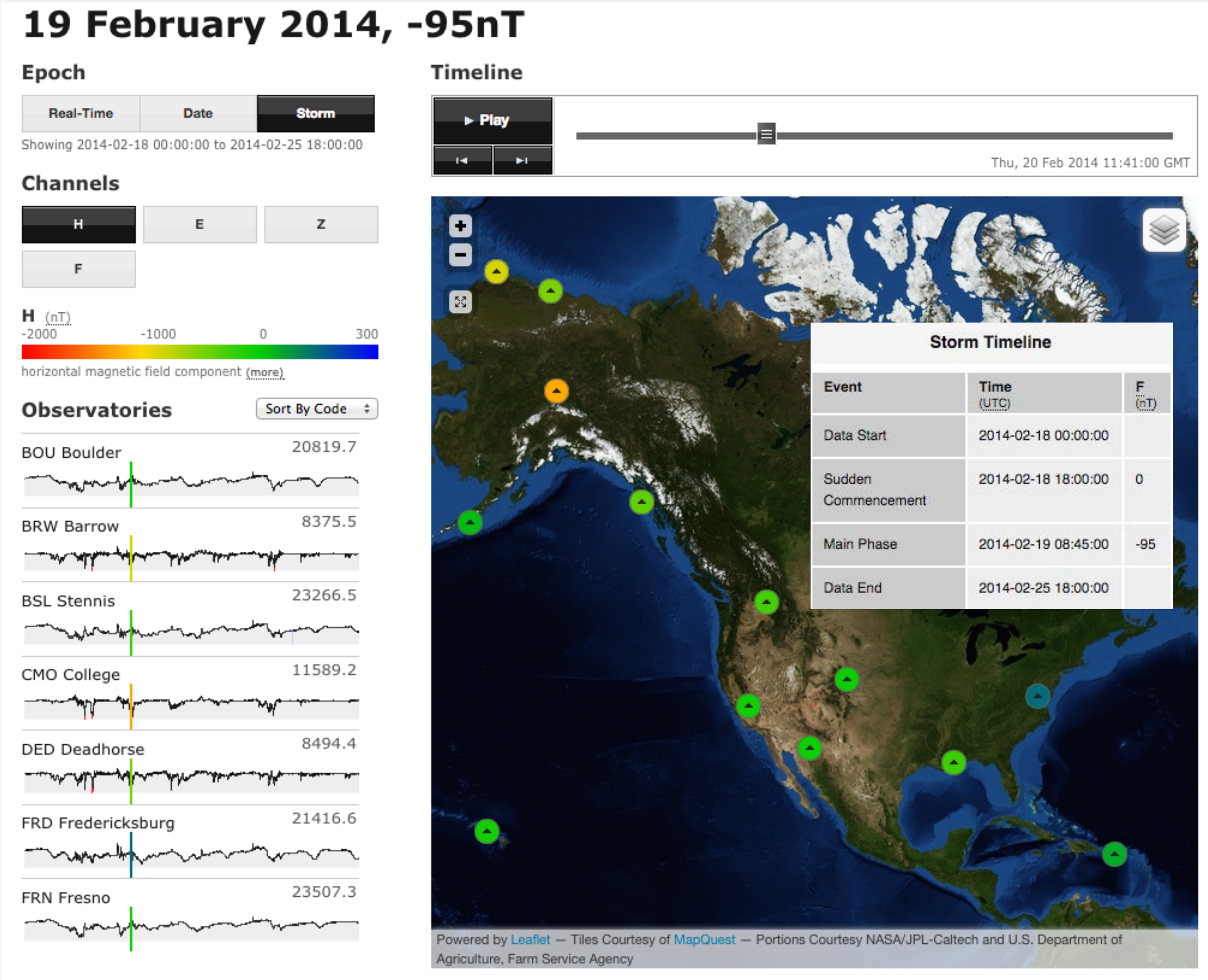
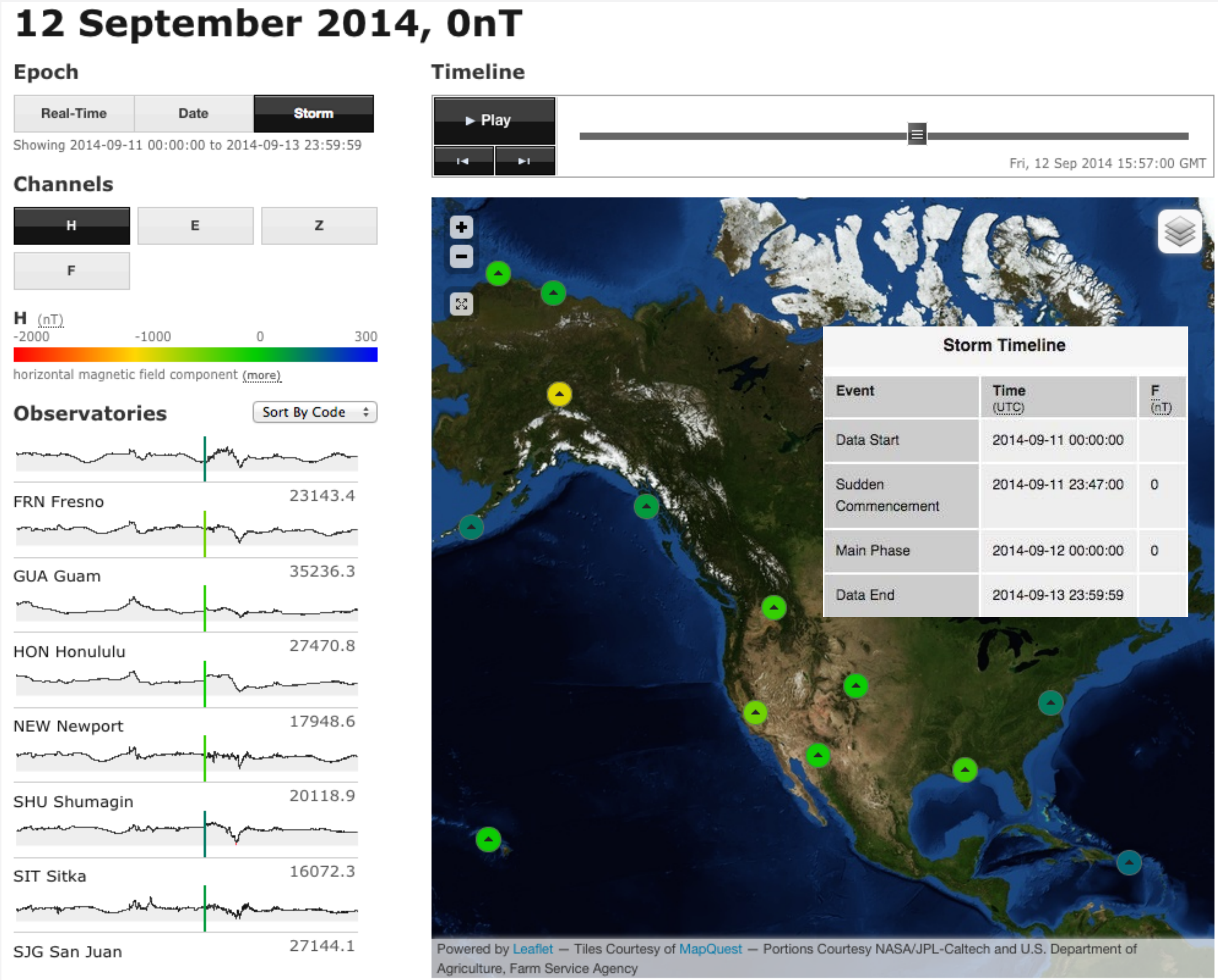
Geomagnetic Storm



Geomagnetic Storm



KP Index (SWPC)

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
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	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)

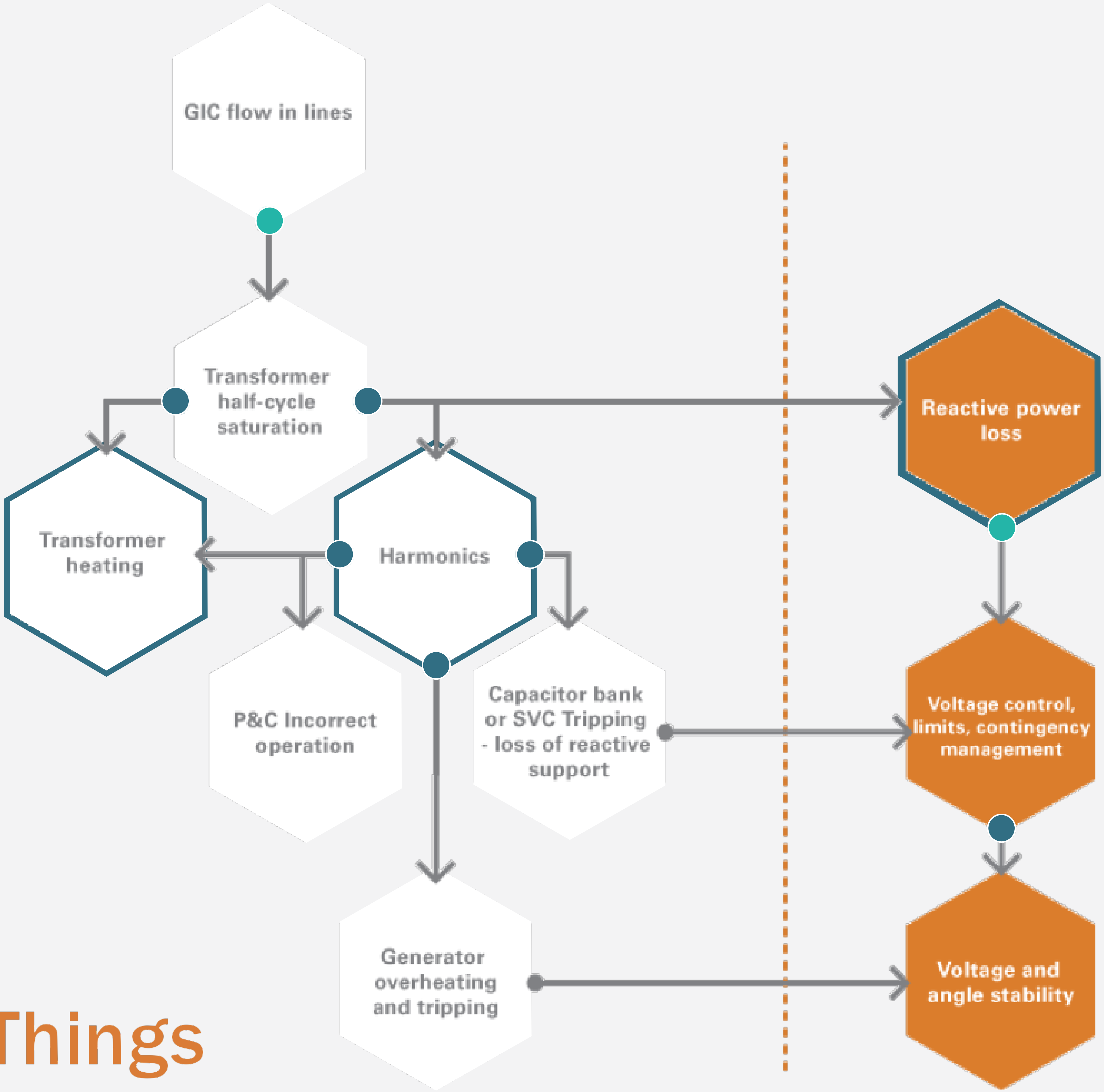
it doesn’t happen that often… but

- We are losing our shield 10 times faster then previously estimated as reported by ESA SWARM satellites
  - Measurements made over the past six months confirm the general trend of the field’s weakening, with the most dramatic declines over the Western Hemisphere
  - The latest measurements also confirm the movement of magnetic North towards Siberia.
- Solar minimum and solar maximums have little to do with Coronal Mass Ejections, Plasma filaments, ejecta etc.

the knowns

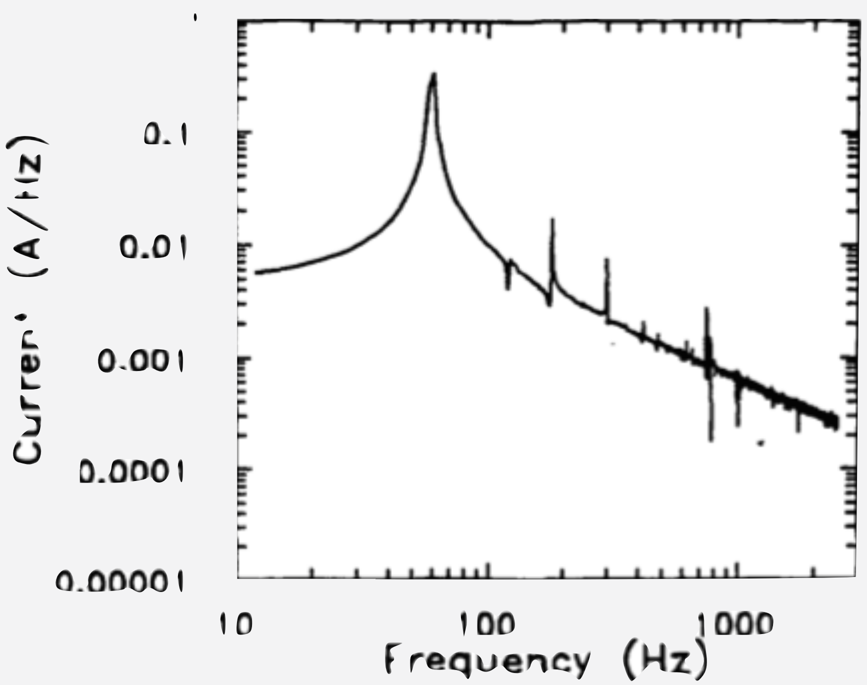
GIC Current Flow that can be measured by sensors

- GIC Current Causes:
  - Half cycle saturation which causes
    - Reactive power of VAR consumption increase
    - Harmonics
    - Possible mechanical vibrations
    - Audible noise

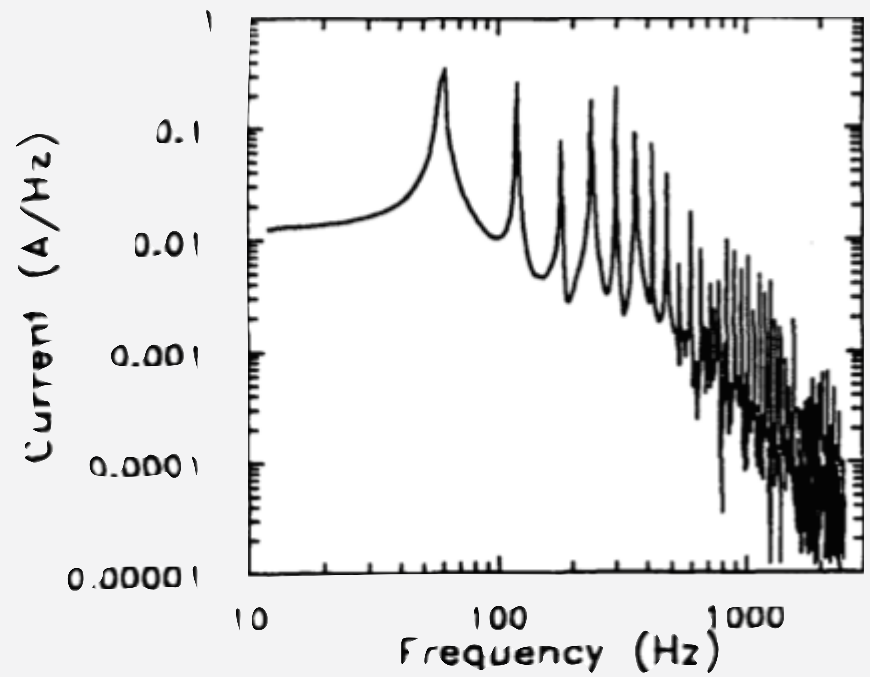

GIC flow in lines
Transformer half-cycle saturation
Transformer heating
Harmonics
Reactive power loss
P&C Incorrect operation
Capacitor bank or SVC Tripping - loss of reactive support
Voltage control, limits, contingency management
Generator overheating and tripping
Voltage and angle stability

PingThings

harmonics



a. Primary Current With No Dc Excitation



b. Primary Current With 5.5-A Dc Excitation

Impact of Quasi-DC Currents on Three-Phase Distribution Transformer Installations

Oak Ridge National Laboratory, Martin Marietta

BW MCCONNELL, PR BARNES, FM TESCHE, DA SCHAFER,

June 1992

harmonics

Single Phase AC/DC Excitation of a Model 3 phase Distribution Transformer 30kVA, 230V/230V, Dyn (Ref. Fig.3-1)

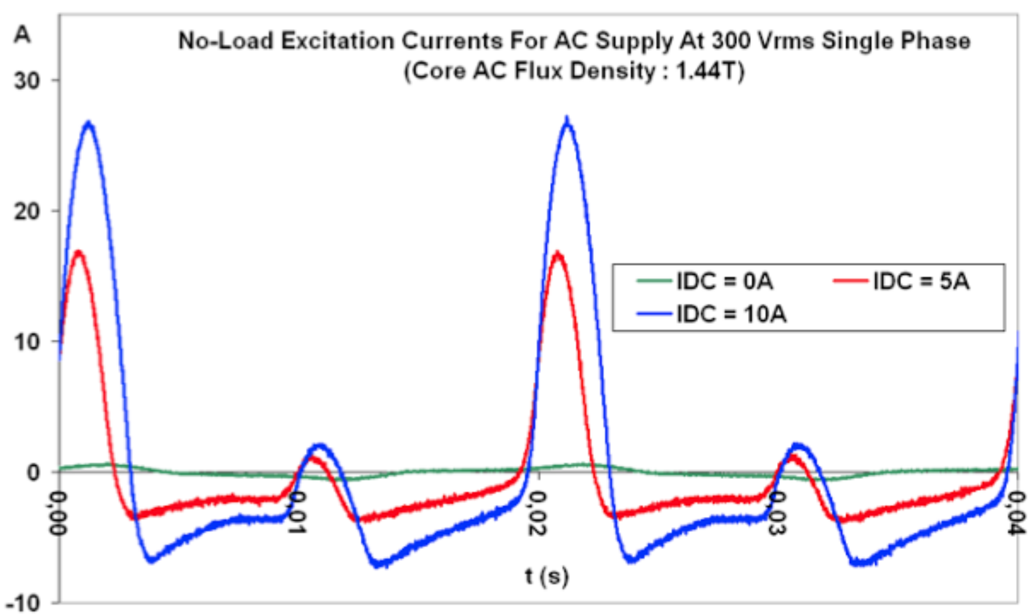


Fig 3-3: Waves of excitation currents from the AC source (single phase supply) for varying levels of DC excitation

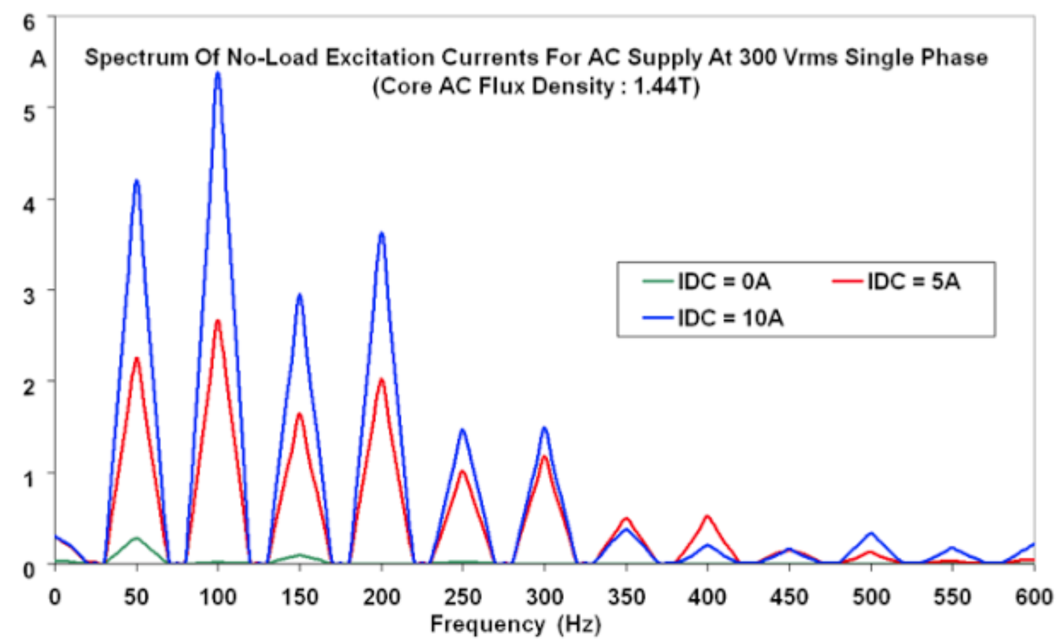
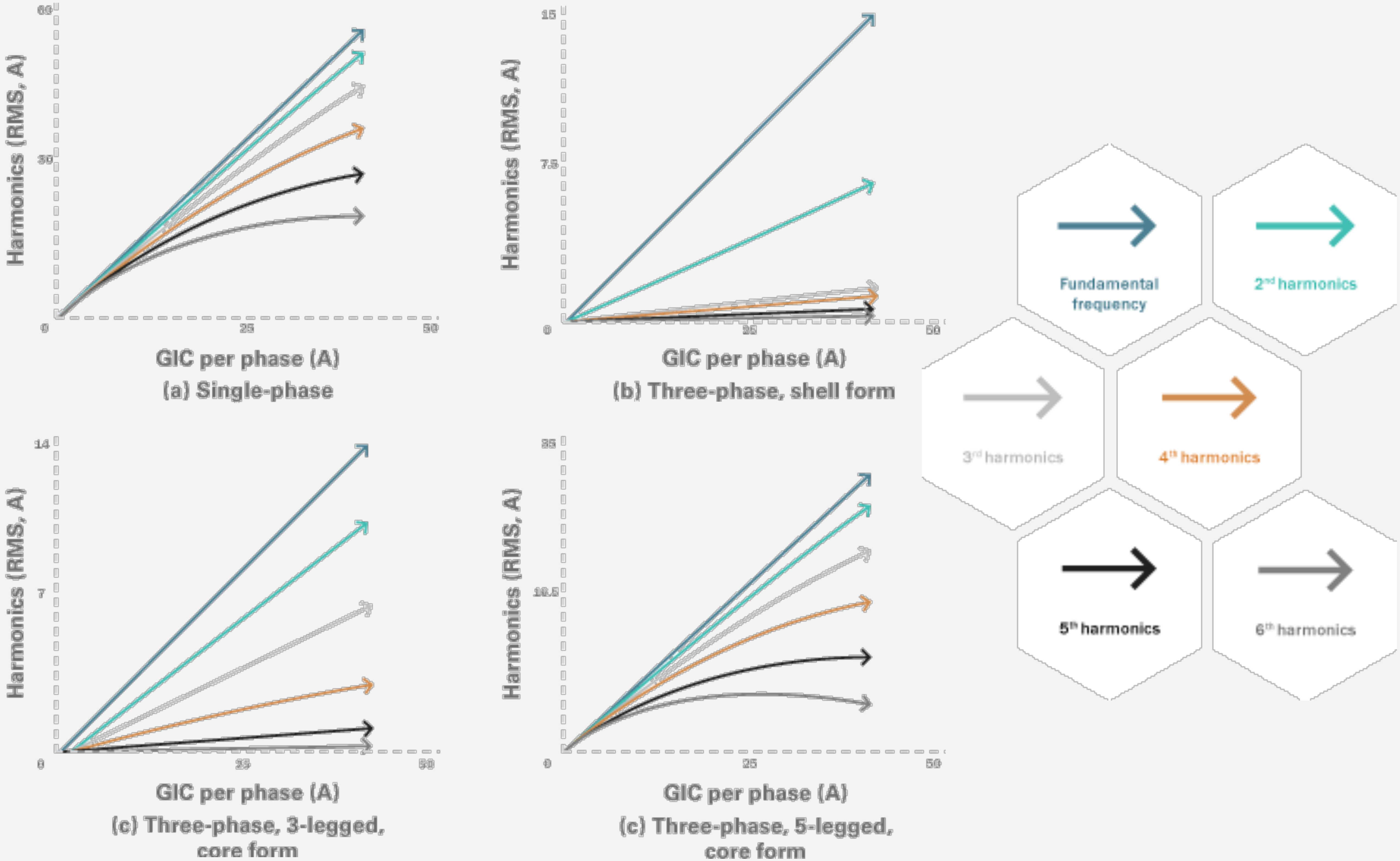


Fig 3-4: Spectrum of excitation currents from the AC source (single phase supply) for varying levels of DC excitation

Behaviour of transformers under DC/GIC excitation: Phenomenon,Impact on design/design evaluation process and Modeling aspects in support of Design

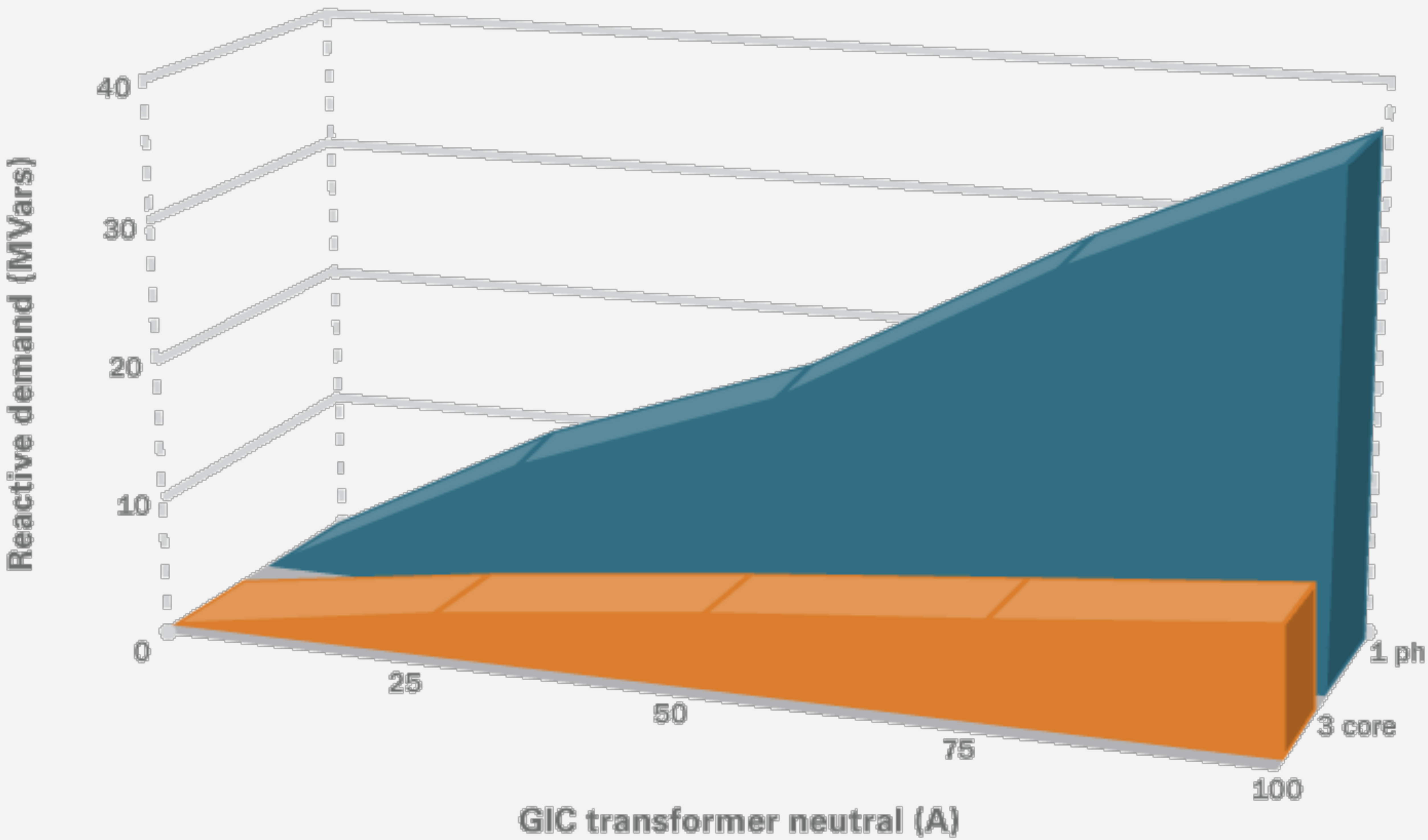
T. NGNEGUEU*, F. MARKETOS, F. DEVAUXJ. BALDAUF, J. OLIVEIRA

CIGRE 2012

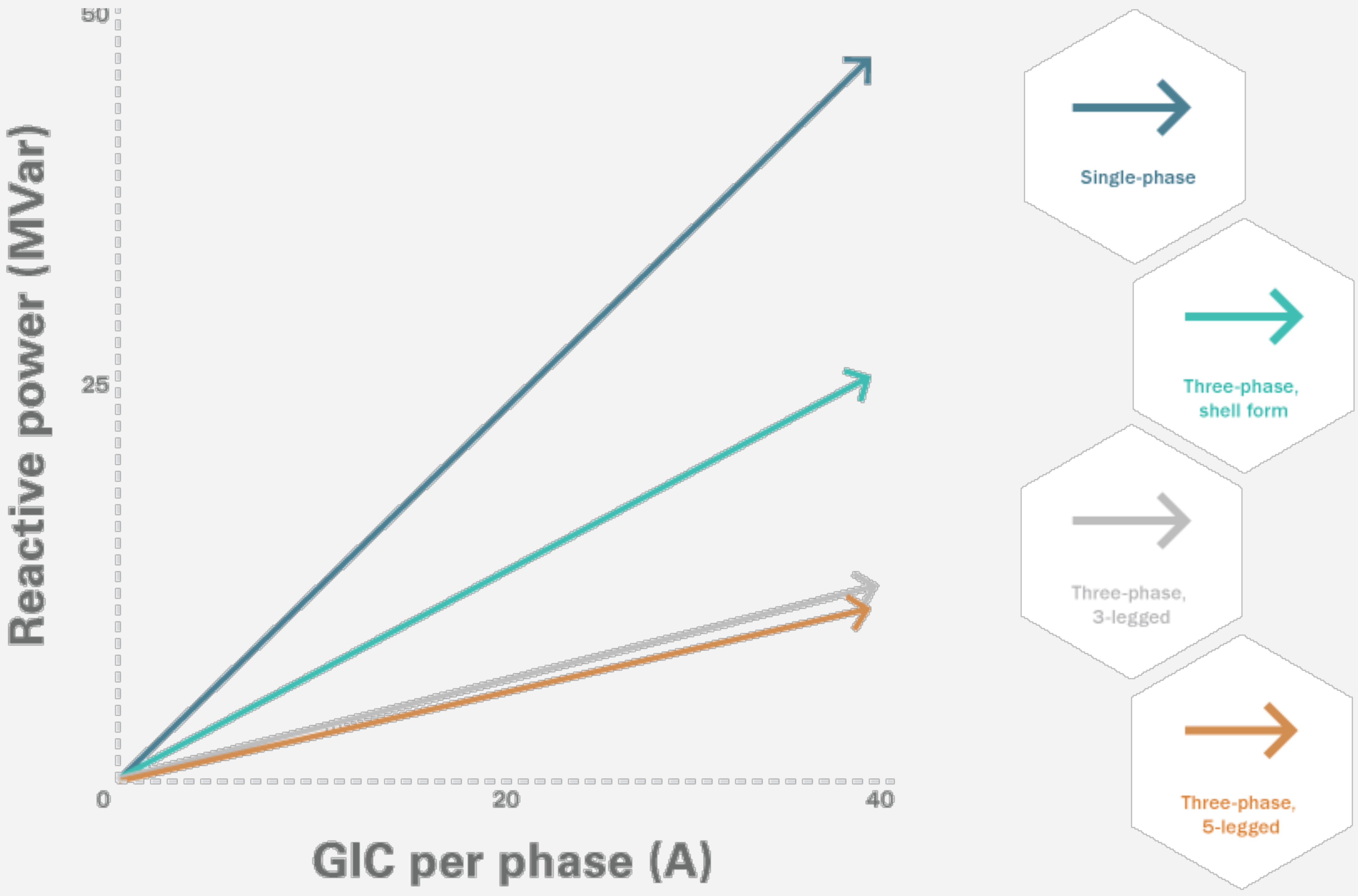

Harmonics (RMS, A)
GIC per phase (A)
(a) Single-phase
Harmonics (RMS, A)
GIC per phase (A)
(b) Three-phase, shell form
Harmonics (RMS, A)
GIC per phase (A)
(c) Three-phase, 3-legged, core form
Harmonics (RMS, A)
GIC per phase (A)
(c) Three-phase, 5-legged, core form
Fundamental frequency
2nd harmonics
3rd harmonics
4th harmonics
5th harmonics
6th harmonics

PingThings

Transformer reactive demand



PingThings

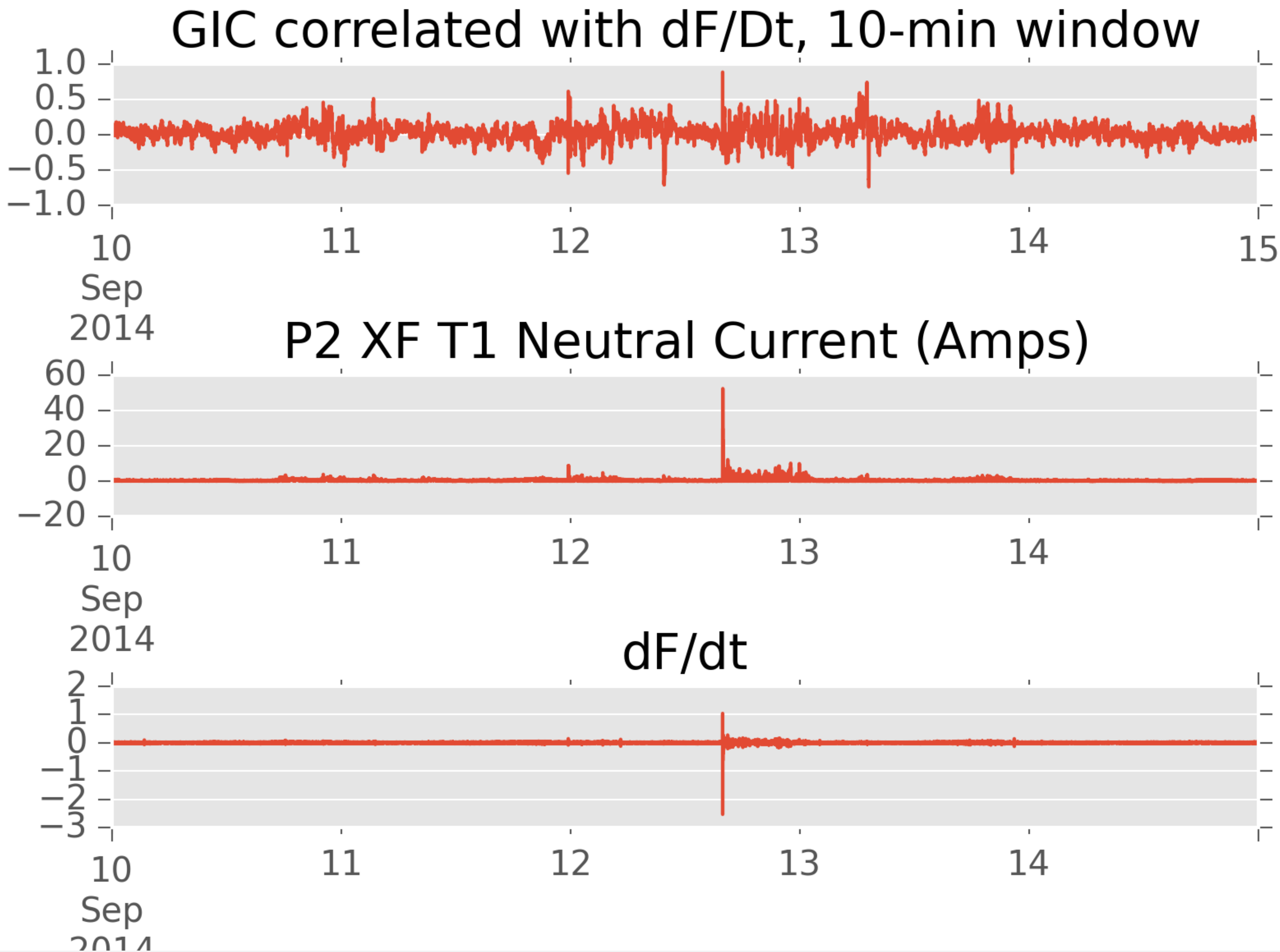


50
25
0
Reactive power (MVar)
20
40
GIC per phase (A)
Single-phase
Three-phase, shell form
Three-phase, 3-legged
Three-phase, 5-legged

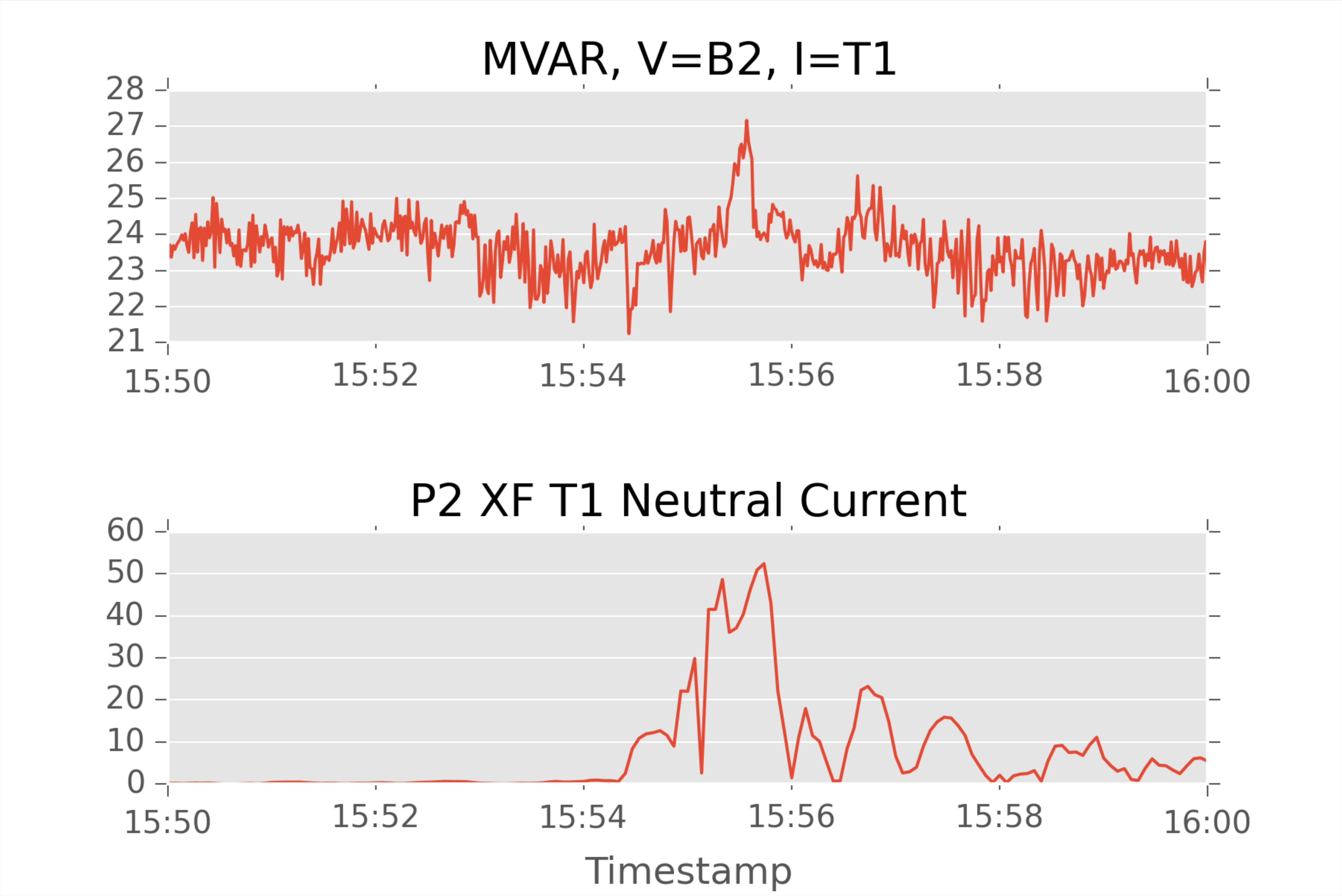
the findings to date

- PMU match to magnetometer
- PMU with SCADA “ground truth”
- PMU GIC detection (standalone)

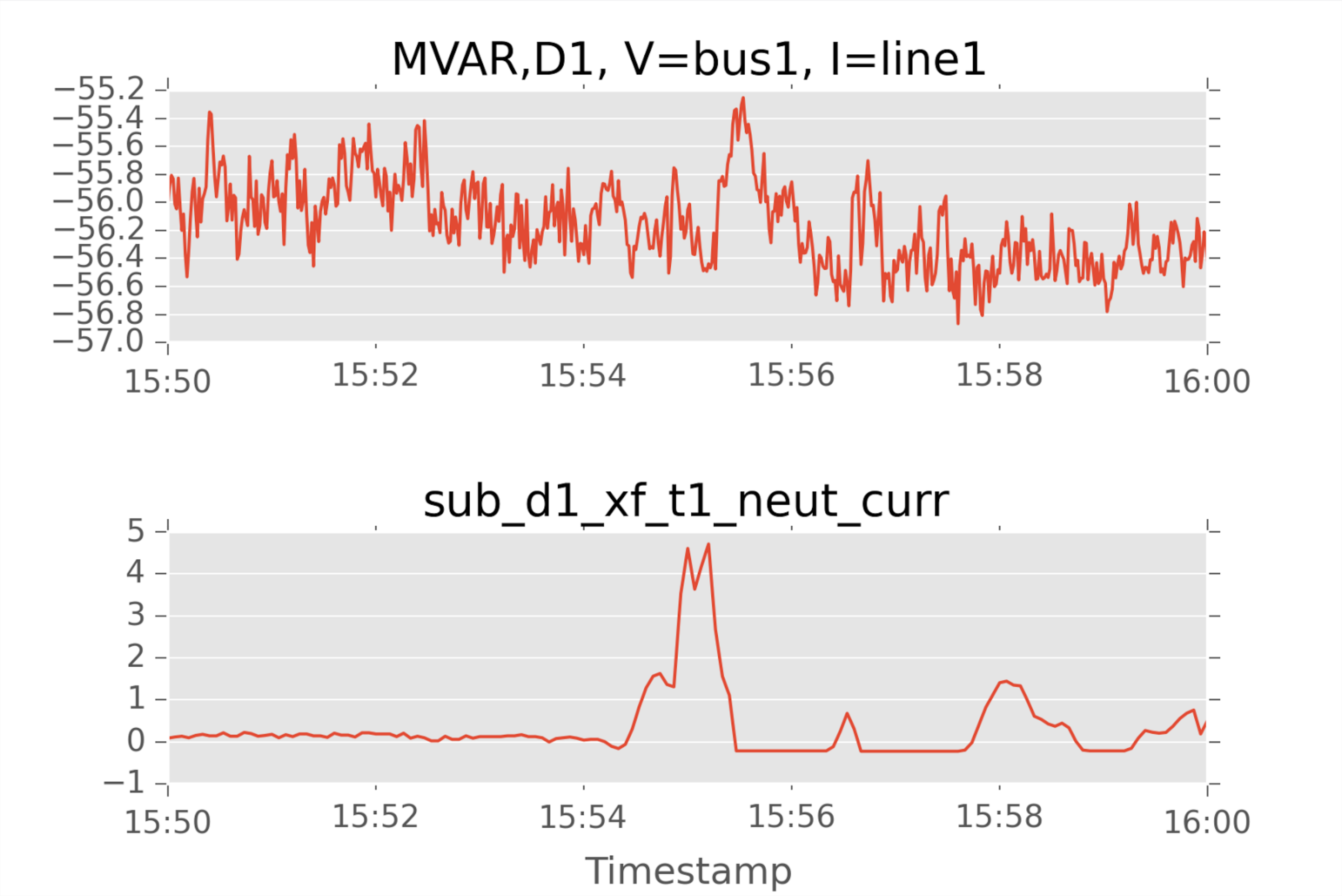
GMD and GIC Correlations



PMU detection, MVAR



PMU detection, MVAR



Summary

- Analyzing over 2 terabytes of data from three partners for past 4 weeks
- 40+ PMU's, multiple manufacturers
- Focused on 2 of the most recent storms Feb 19th and Sept 12 2014 (multiple days pre and post storm)
- Correlated GMD with GIC on transformers via magnetometers of UGSG
- Have identified multiple artifacts on PMU's during time window that need further investigation
- Clearly correlated MVAR consumption with GIC and storm rate of change

the road forward…

- open dialogue
- more partners
  - we will buy the beer
- more data
  - higher sampling rates for harmonics
  - wider array of PMU types/ manufacturers
- more events (they will happen)