enabling renewable grids

Inertia & System Strength Measurement & Analytics

Partnering to improve the grid

EATON
Powering Business Worldwide

Decades of experience providing utilities with solutions to help **design, build and operate a smart, modern electrical grids**

Inertia & System Strength measurement solutions

Together providing utilities with solutions to navigate the global energy transition

reactive technologies

1st and only direct inertia management company enabling **renewable grids to help accelerate the clean energy transition**

Renewable power generation is increasing globally

Key drivers are:

- Decarbonization & Net Zero targets
- Rapidly falling costs of renewables
- Consumers' green demand

In 2021,

75%

of all new energy was **renewable**

The Challenge:
Maintain Grid Stability While Increasing Renewables

Transmission System Operators

- Grid Stability & Reliability
- Low Inertia
- Required Capacity & Ancillary Services
- Infrastructure Investment
  - new transmission or SCR’s?

Distribution Network Operators

- Voltage Stability
- System Strength
- Integration of DER
- Infrastructure Investment
  - replace/add power lines/feeders for increased protection?

Reactive Technologies Benefits

Achieve Net Zero

Get to net zero carbon through deep data insights into the power grid. With our cloud-computing software, you can monitor grid inertia in real-time and make accurate energy forecasts. These forecasts help you fast-track renewable energy rollouts on the grid, allowing you to build off traditional fossil fuel energy sources and build a renewable grid at a sustainable, reliable pace.

Minimize Risk

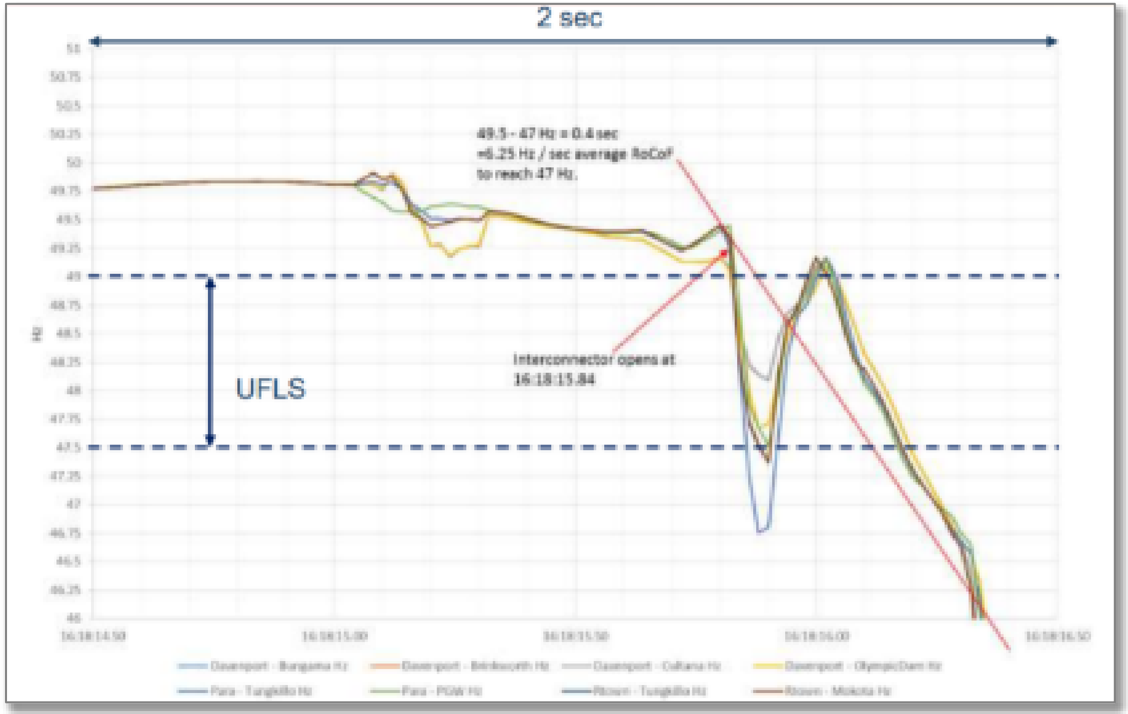
Our innovative Grid-Sonar technology gives you a 360° view of inertia for both traditional energy sources and renewable energy sources with 95% accuracy.
With this real-time data and grid visibility, you can confidently make critical decisions to maintain grid stability. Our algorithms will help you with energy demand forecasting and price risk management so you can plan for the future.

Asset Optimization

Gain grid insights and leverage grid visibility for maximum cost optimization.
By making accurate decisions about energy demand based on real-time data, you'll see huge cost savings. Our clients
are making six-figure cost savings thanks to the grid visibility gained through our innovative cloud-computing technology.

Inertia & Rate of Frequency Change

Rotational kinetic energy provided by spinning mass on Transmission or Distribution grids
Steam/gas turbines, synchronous motors/pumps etc.



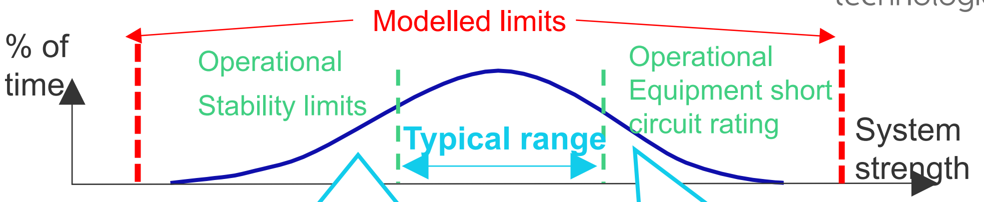
Inertia = Power Imbalance / RoCoF
High inertia systems have a more stable frequency

System Strength & Voltage Instability

"There are engineering challenges when integrating inverter-based resources into weak electric systems. More common challenges that planners and operators have had to face include:

- <u>**Transmission overloading:**</u> need for higher capacity transmission in the local area to accommodate higher penetrations of inverter-based resources
- <u>**Voltage profile or voltage deviation challenges:**</u> additional reactive power compensation or inverter-based controls to ensure acceptable voltage profiles across the system and sufficient reactive power available following major grid events
- <u>**Low short circuit ratio (SCR):**</u> no significant short circuit sources driving need to ensure sufficient levels of current for fault clearing and generator protection "

Source: NERC: Integrating Inverter Based Resources into Low Short Circuit Strength Systems



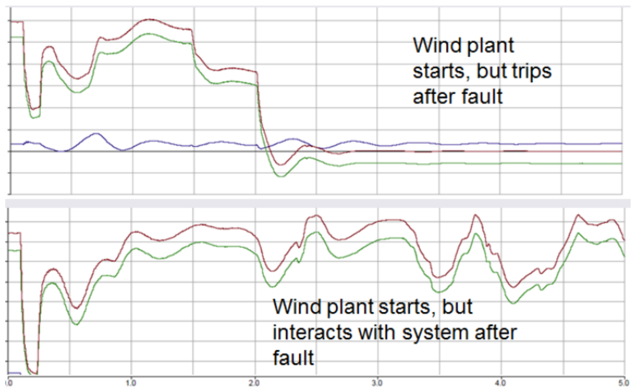
System strength too low

- Safety issue in case of short circuit as protection devices do detect faults and do not operate
- Voltage stability issues
- Power quality issues (harmonics)

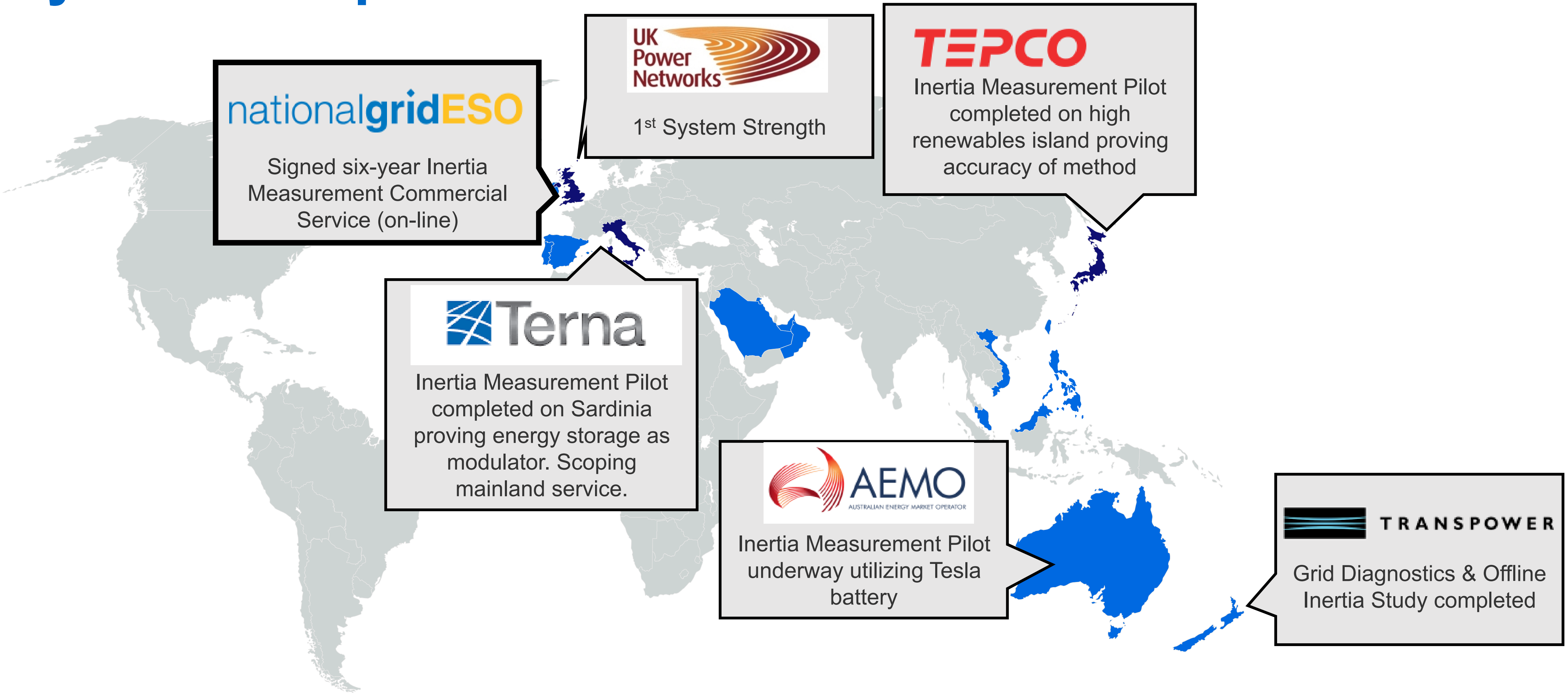
System Strength too high

- Fault level too high with risk of protection being underrated and not capable of interrupting fault currents

Control instability at wind plant connected to weak grid



Reactive has delivered on Inertia Services around the globe in
Key First Adopter Markets



Grid Operators Globally are facing the challenge of Low Inertia

Significant changes for the power system

Different generation physics	**Decrease in grid stability** Reduction of stabilizing physical properties, i.e., inertia and fault level
Intermittency	**Shorter reaction time scales** Real-time monitoring and fast flexibility solutions required to balance the grid
Decentralized generation	**Higher system complexity** Common models, accounting only for HV-connected plants, are insufficient
Increased need for management	**Significant higher costs** Increased need for measures to manage and stabilize the grid will increase cost

All of this puts significant restrictions on future additions of renewable energy

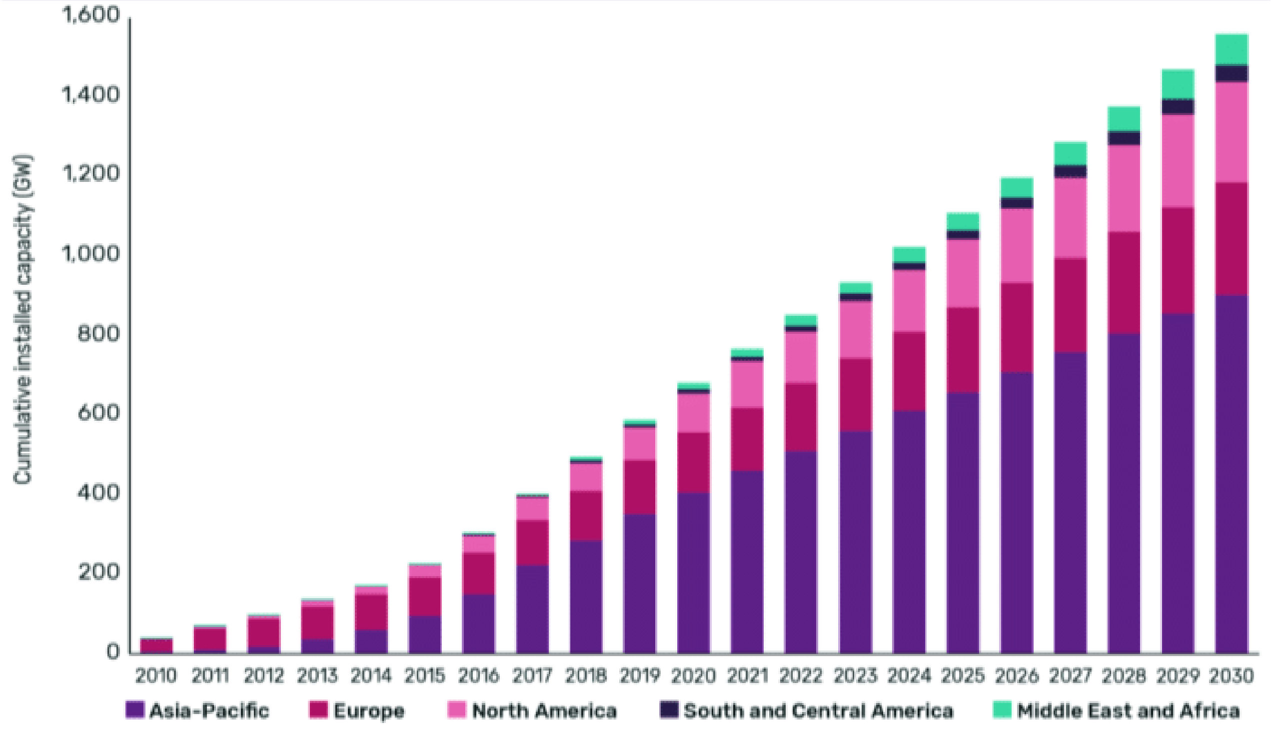
… are pushing grid operators to find solutions.

AEMO: "As the penetration of wind and solar on the system increases, operation of the system becomes significantly more complex. The **power system is being operated closer to its known limits** more frequently, with increasingly variable and uncertain supply and demand, and **declines in system strength and inertia**."

nationalgridESO: "Zero carbon operation of the electricity system means a **fundamental change to how our system was designed to operate**; integrating newer technologies right across the system… **using new smart digital systems** to manage and control the system in real-time."

Terna: "Innovation and digitization, required to cope with the **increased complexity of the system**, are one of the two enabling factors of our strategy and we plan to devote around EUR 900 million to these initiatives…this represents a paradigm shift: **from Watts to Bytes**."

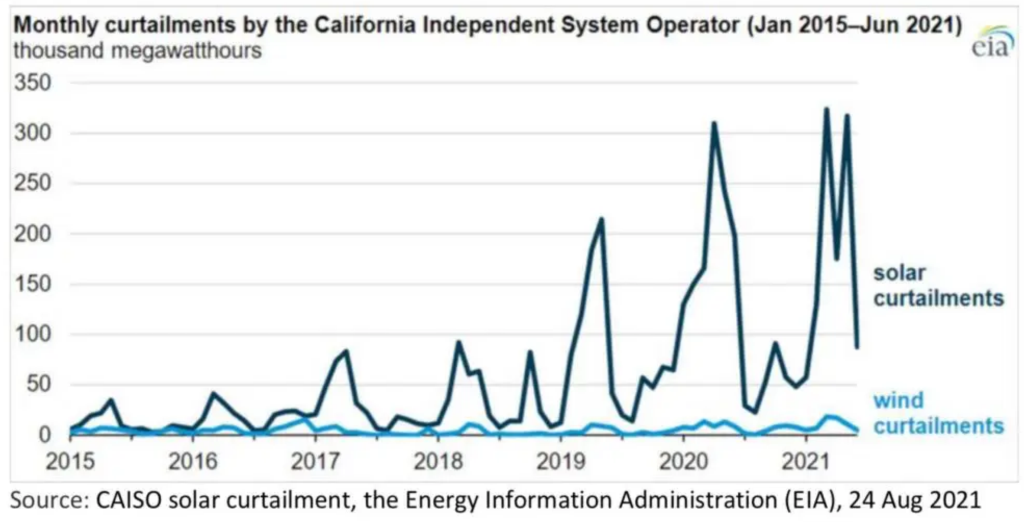
Increasing deployments of renewable energy…
drives greater and greater curtailment



Cumulative installed Solar PV capacity [GW_p]

Source: GlobalData Power Intelligence Center

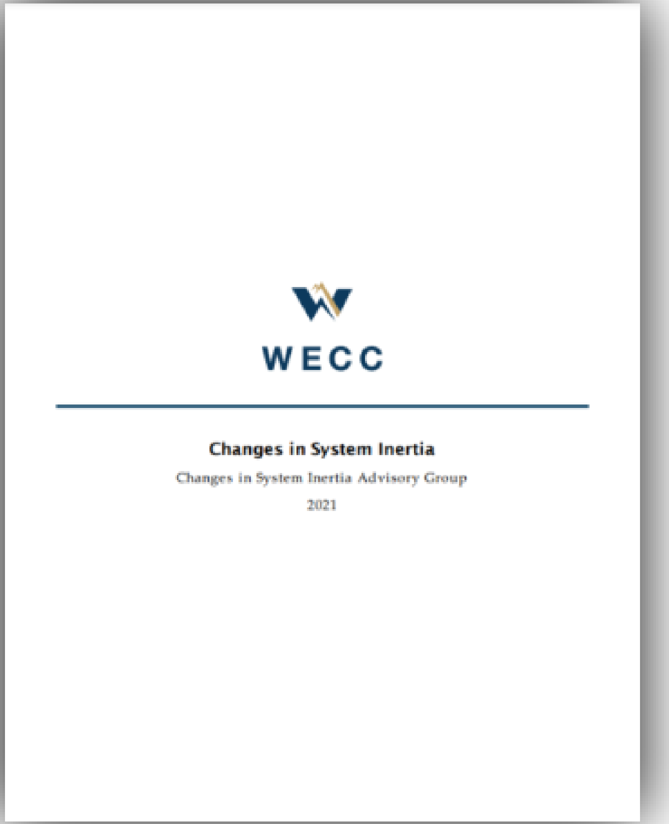
Loss $$ Curtailments



CAISO

WECC – Changes in System Inertia

WECC have recently published a report into declining inertia levels and the need to monitor & manage inertia more closely



WECC

Changes in System Inertia

Changes in System Inertia Advisory Group

2021

"Recommendation 1: Planning Coordinators, Transmission Planners, Balancing Authorities, and Reliability Coordinators **should monitor system inertia** and **frequency response**, especially under low inertia conditions. "

Source: WECC Changes in System Inertia Advisory Group 2021
https://www.wecc.org/Reliability/Changes%20in%20System%20Inertia%20(Final).pdf

PJM Challenges

PJM - Energy Transition in PJM: Frameworks for Analysis Dec. 15, 2021

… as the penetration of renewable resources increases, there is an overall decline in essential reliability services.

Localized issues associated with system strength ("weak grid") will have to be mitigated early into the fuel-mix transition.

PJM – Annual Planning Report – March 8, 2022 – Regulatory Driver

IBR resources currently do not supply the full range of reliability attributes – inertia, voltage control, stability, ramping and short-circuit current – that conventional, directly synchronized generators provide. Planners and operators must consider these factors as older conventional generators – coal-fired ones in particular – continue to retire.

PJM – Annual Planning Report – March 8, 2022

Targeted reliability studies will build on 2022 scenario study results in order to evaluate generation and transmission reliability attributes, such as reactive control, stability, system inertia and frequency control, and short-circuit **impacts, to ensure grid reliability**.

The ability of new, natural gas-fired generating units to replace reliability attributes (inertia, voltage support, frequency response, short-circuit current, etc.) will depend significantly on their location. Operability issues can arise in areas where sufficient levels of those attributes are not readily accessible.

Inertia Measurement & Analytics Solution

A paradigm shift in the Measurement & Analytics of Grid Stability

Grid-Sonar™ - Active “SONAR” for the Grid

Modulator

Reactive XMUs

Grid Metrix Cloud SaaS

Unique Stability Information
(Transmission, Distribution)

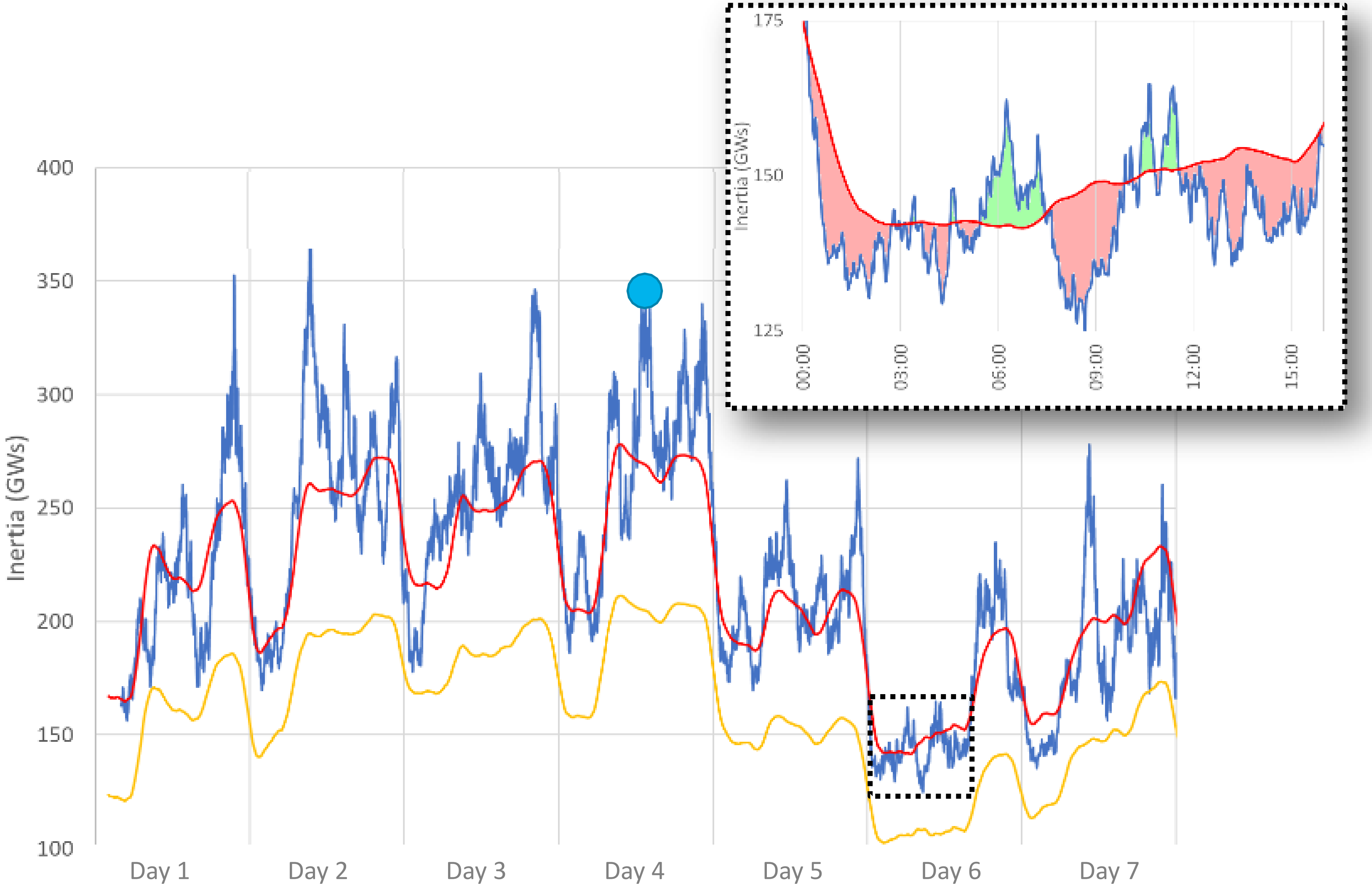
- Long Term Asset Planning
- Real-time Optimisation
- Grid Management Applications
- Grid Simulation Modelling

Signal transmitted via power grid

Data transmitted via secure IP link

Highly accurate real-time data streamed to the control room

Breakthrough: Direct Inertia Measurement



1 Sum inertia constants

- Inertia follows demand curve closely but under-reports level of inertia (so potential for over-spend on contingencies)

Model demand side

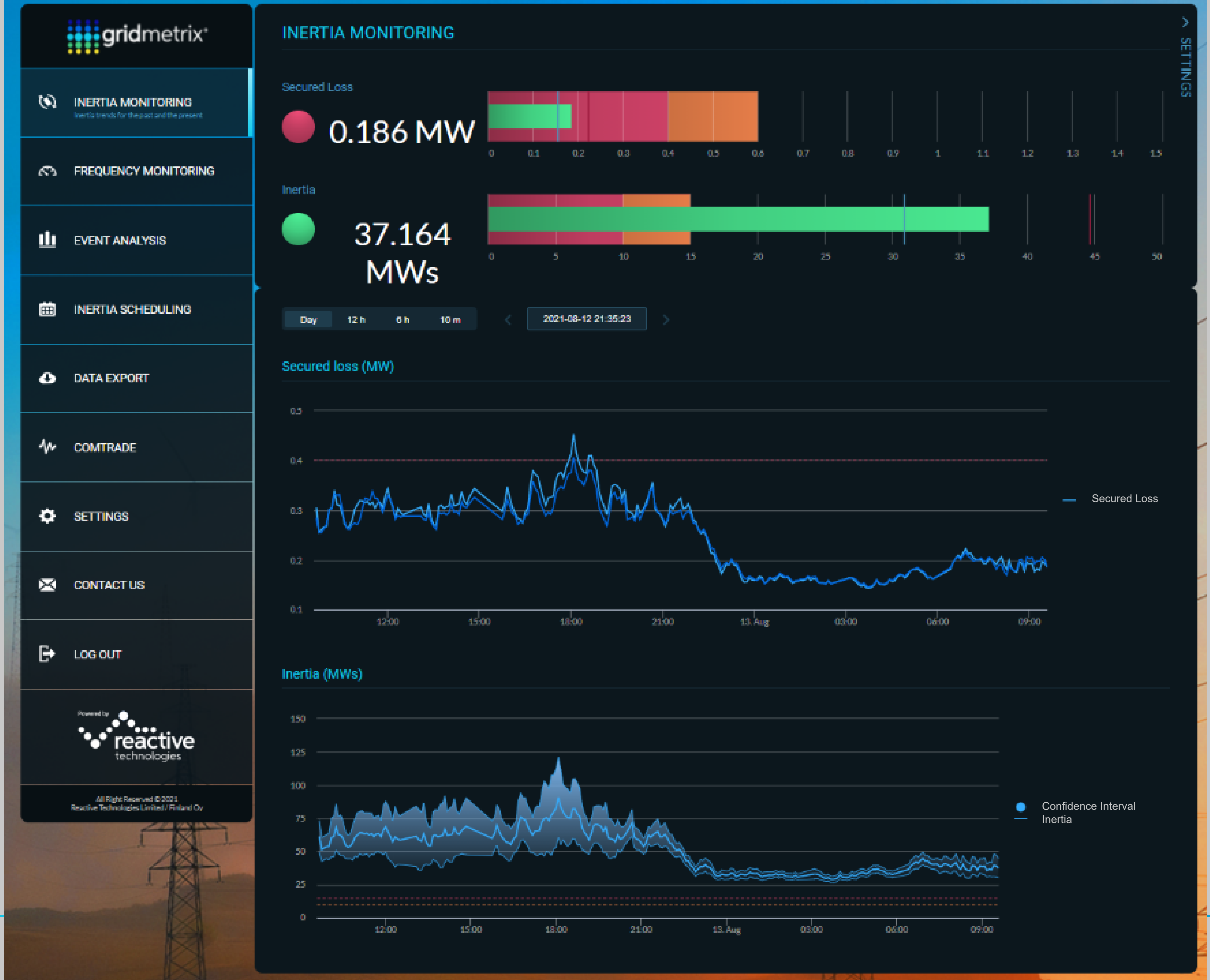
- 'Scaling' factor added to provide static view of real inertia level though inherent inaccuracy

2 Measure during frequency event

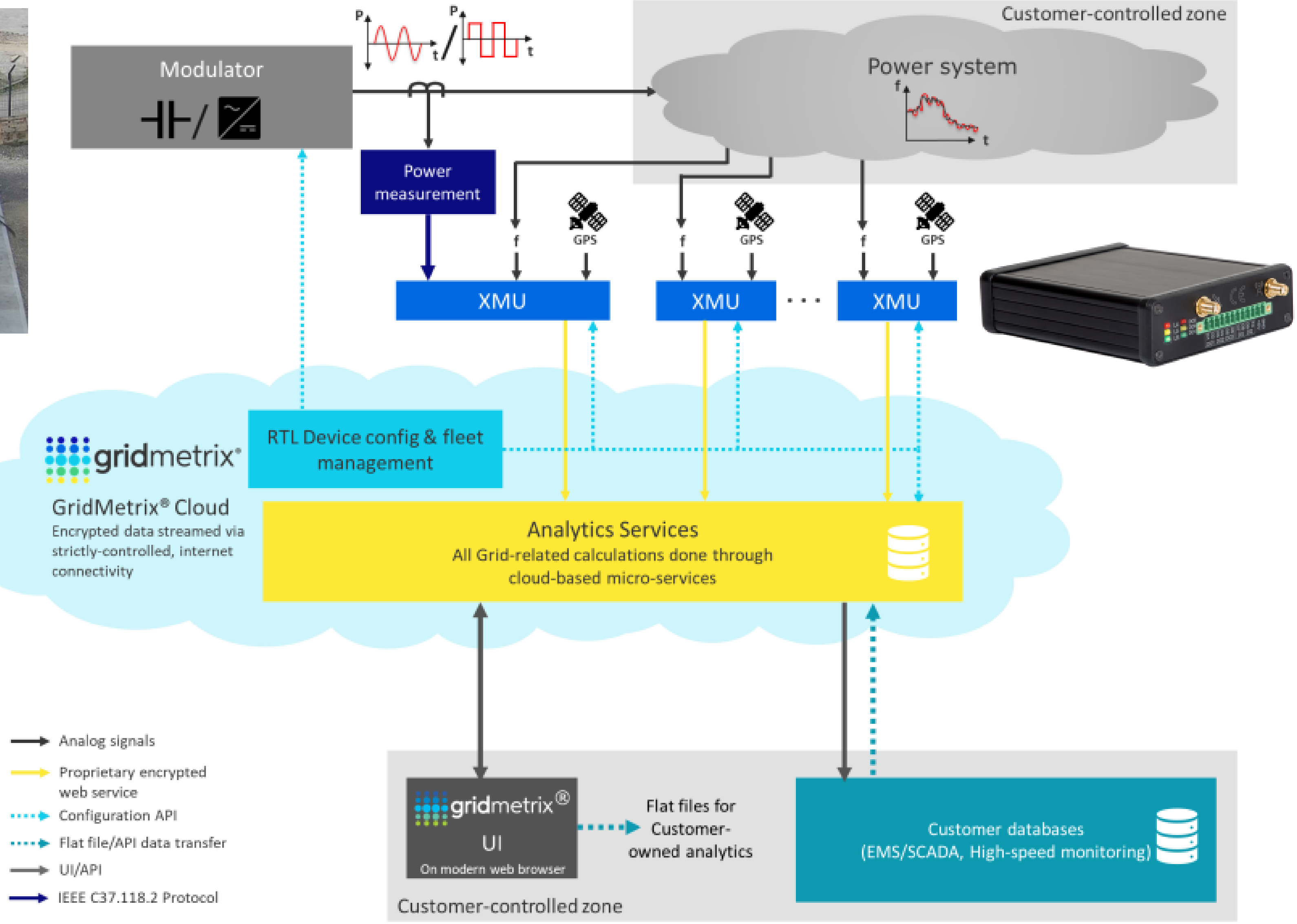
- Single value during the week a considerable distance from modelled values

4 Active power injection

- Continuous value given, aligns with large frequency event
- Shows volatility of inertia and error in models during low inertia times
- Further validated with Terna & Tepco case studies

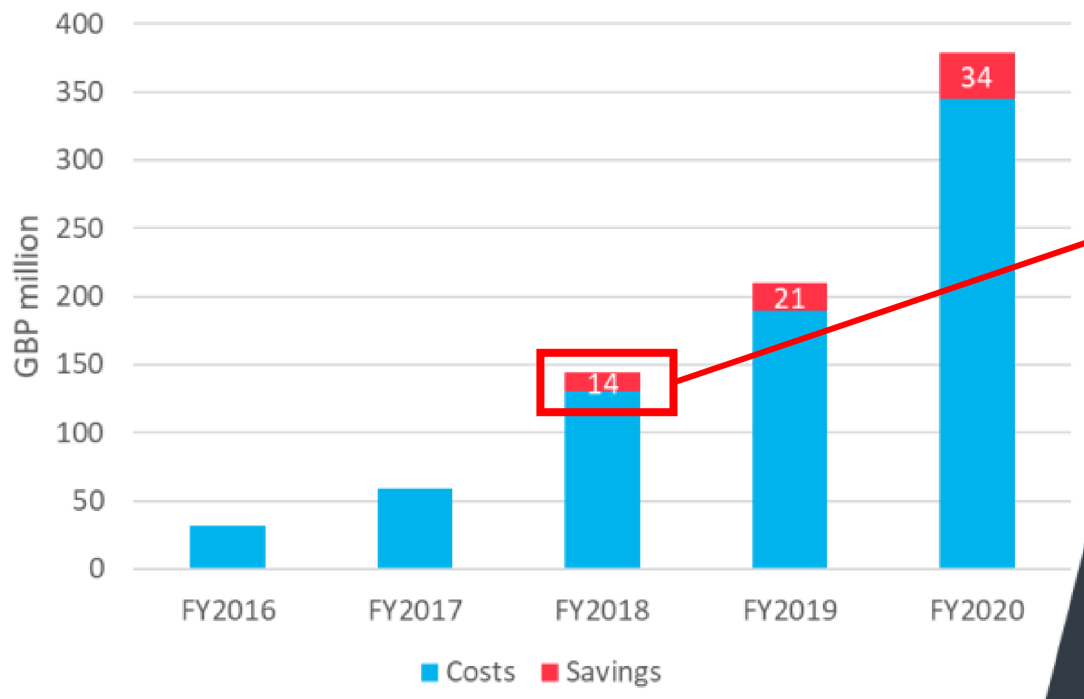

gridmetrix
INERTIA MONITORING
FREQUENCY MONITORING
EVENT ANALYSIS
INERTIA SCHEDULING
DATA EXPORT
COMTRADE
SETTINGS
CONTACT US
LOG OUT
Powered by reactive technologies
INERTIA MONITORING
Secured Loss
0.186 MW
Inertia
37.164 MWs
Day
12 h
6 h
10 m
2021-08-12 21:35:23
Secured loss (MW)
Secured Loss
Inertia (MWs)
Confidence Interval
Inertia
SETTINGS

GridMetrix® Architecture in the UK



Inertia measurement benefits National Grid ESO, UK

Cost of managing decreasing inertia in the UK [GBP M]



Source: ESO Cost of Managing RoCoF

Fintan Slye
Director, UK System Operator at National Grid ESO

"Inertia will become much more important in the years to come, I think today it is taken for granted…
Inertia is at the heart of everything we do"

nationalgridESO

UK Customers save

$19.6M/yr

On managing inertia (10% of total cost)

We will save

$96.5M

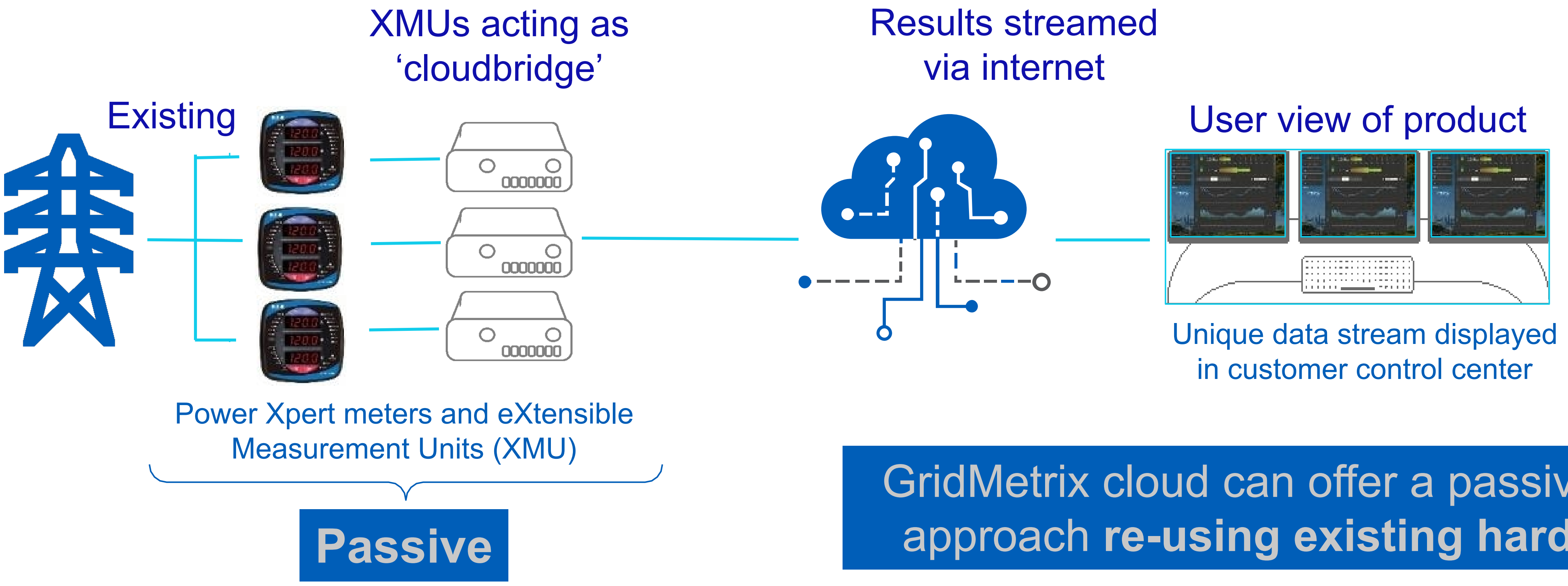
Over the 5-year contract lifetime

enabling renewable grids

System Strength Measurement & Analytics Solution

Passive measurement: System strength entry service

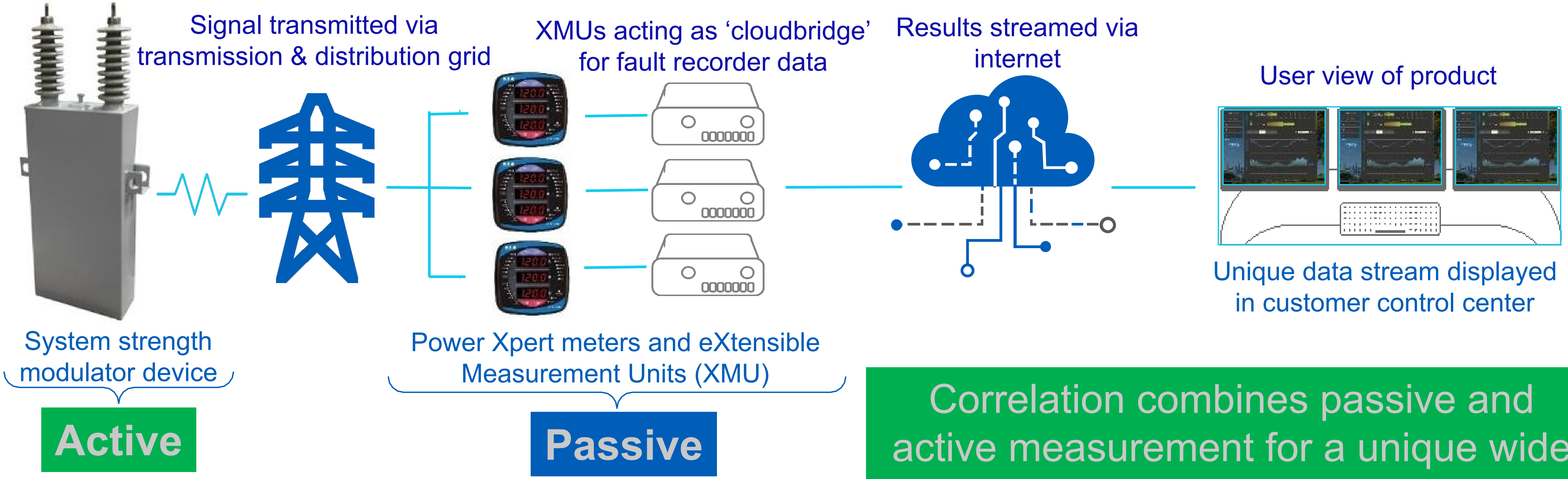
- **Passive** method for planning (i.e. asset replacement when system strength is high)
- Active & correlation can be used for real time Active Network Management for high renewables, advanced grids



GridMetrix cloud can offer a passive-only approach **re-using existing hardware**

Active & Correlation: Unrivalled accuracy

- **Active** system strength measurements face cost/benefit challenge of covering entire network
- **Correlation** IP enables network-wide high accuracy system strength measurements at a fraction of the cost



Correlation combines passive and active measurement for a unique wide and accurate view of system strength

System strength roadmap
Scales with increasing need for accurate data

	Description	Provide SS data stream	High accuracy	Read frequency	Full coverage	Enables ANM
Current modeling approach	Asset & operation data used to simulate system strength	✗	✗		✓	✗
Passive Method	Re-use of existing DFR measurement units	✓	Acceptable near-real time measurements	Limited, on natural events, infrequent	✓	
Measured active, primary plant approach	Expensive measurement device installed	✓	✓	On-demand ✓	✗	✓
Correlation Method	Active measurements made at 11kV & correlated across radial network	✓	✓	✓		✓

reactive technologies

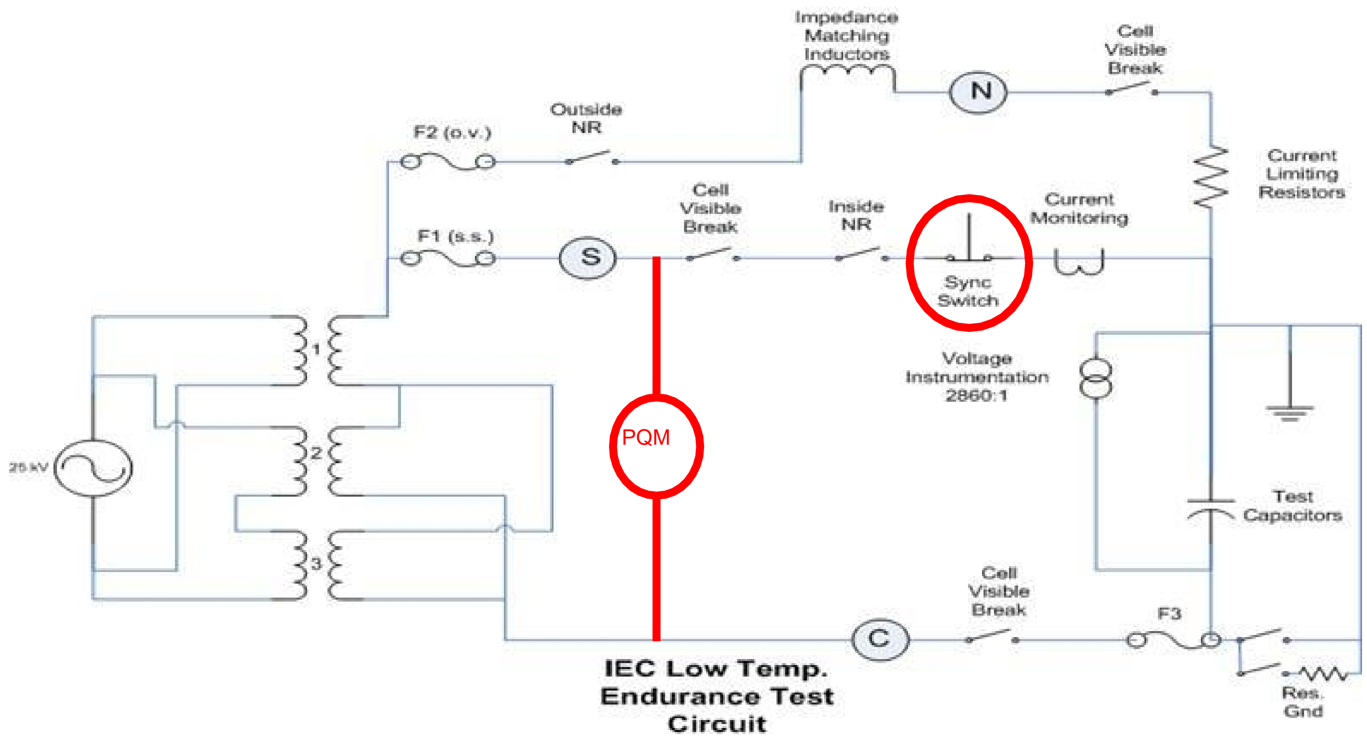
enabling renewable grids

EATON

System Strength Lab Testing

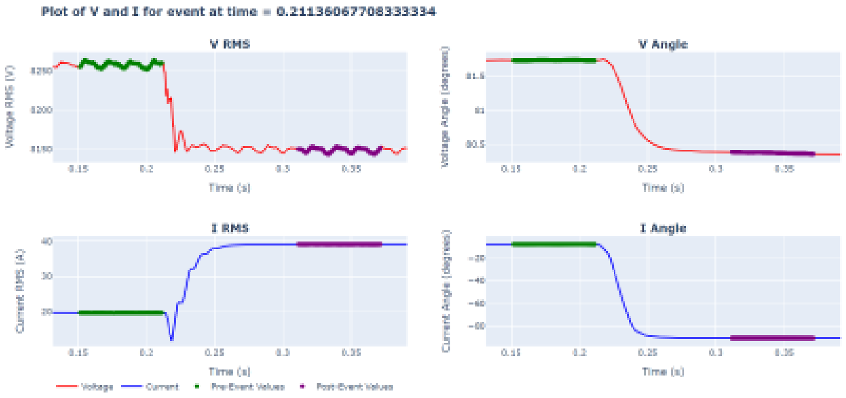
Lab test of Inductor Switching

- voltage perturbation produced by inductor switching during capacitor overvoltage test
- PQM recording single phase voltage and currents as comtrade files
- Automatic event detection
- Calculates RMS quantities, tracks the voltage and current angles during the event.
- Very low system strength lab setup
- Results validation via measured lab impedances and modelling

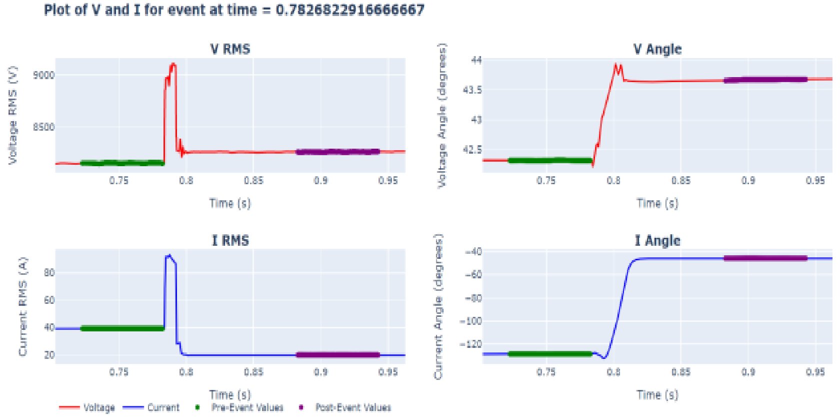


Pre-Event Voltage Data

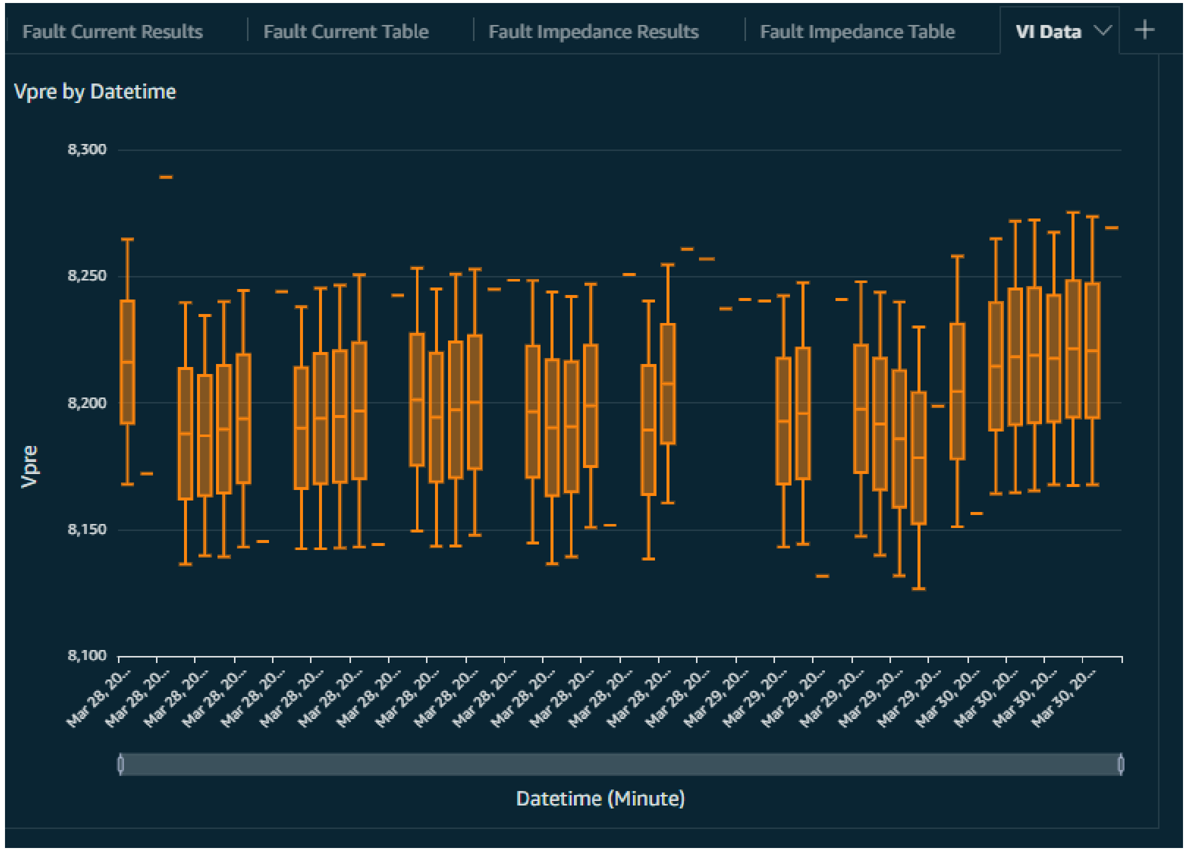
Inductor Switch In Event



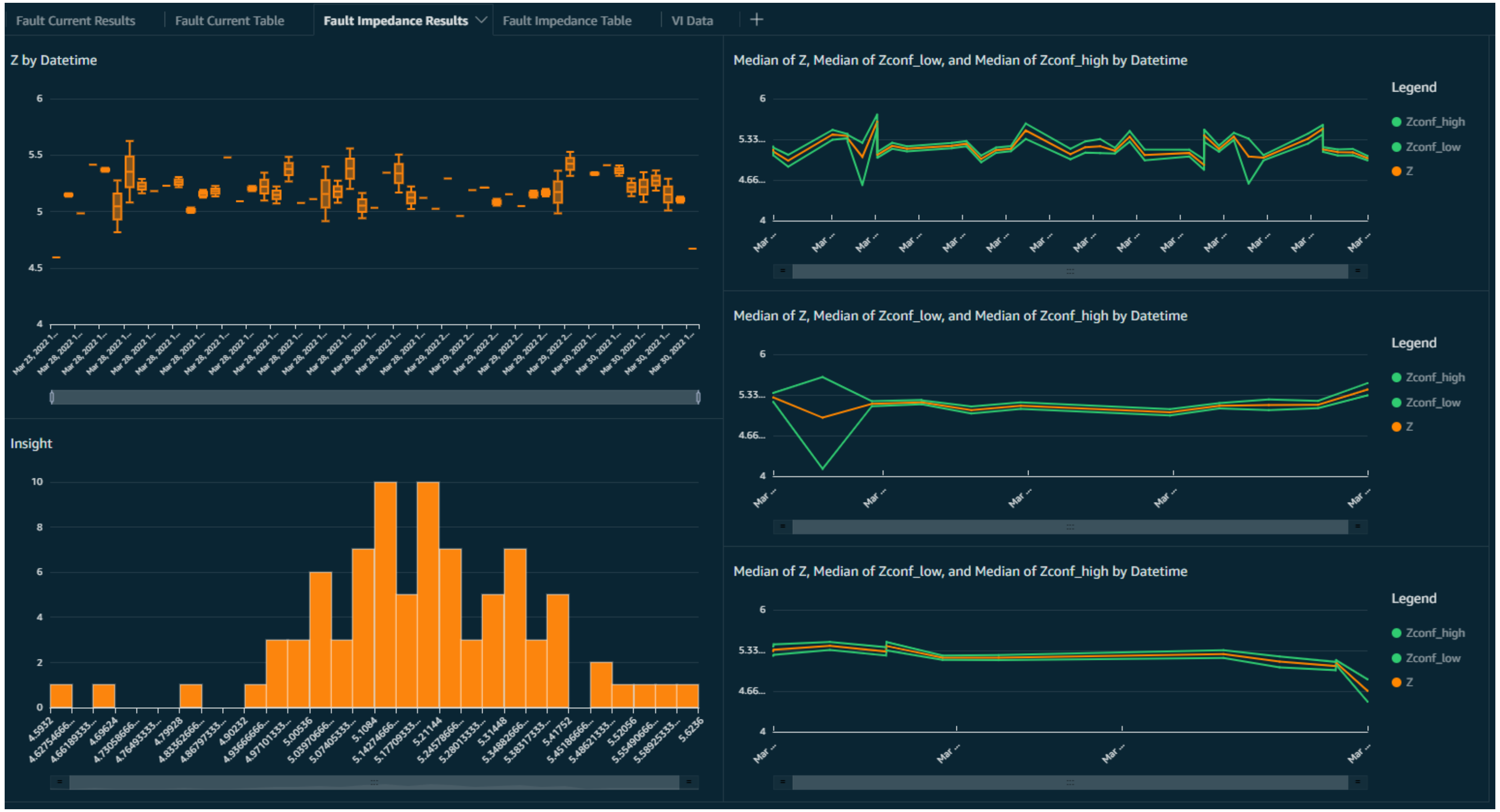
Inductor Switch Out Event



Voltage variation before the inductor switching events



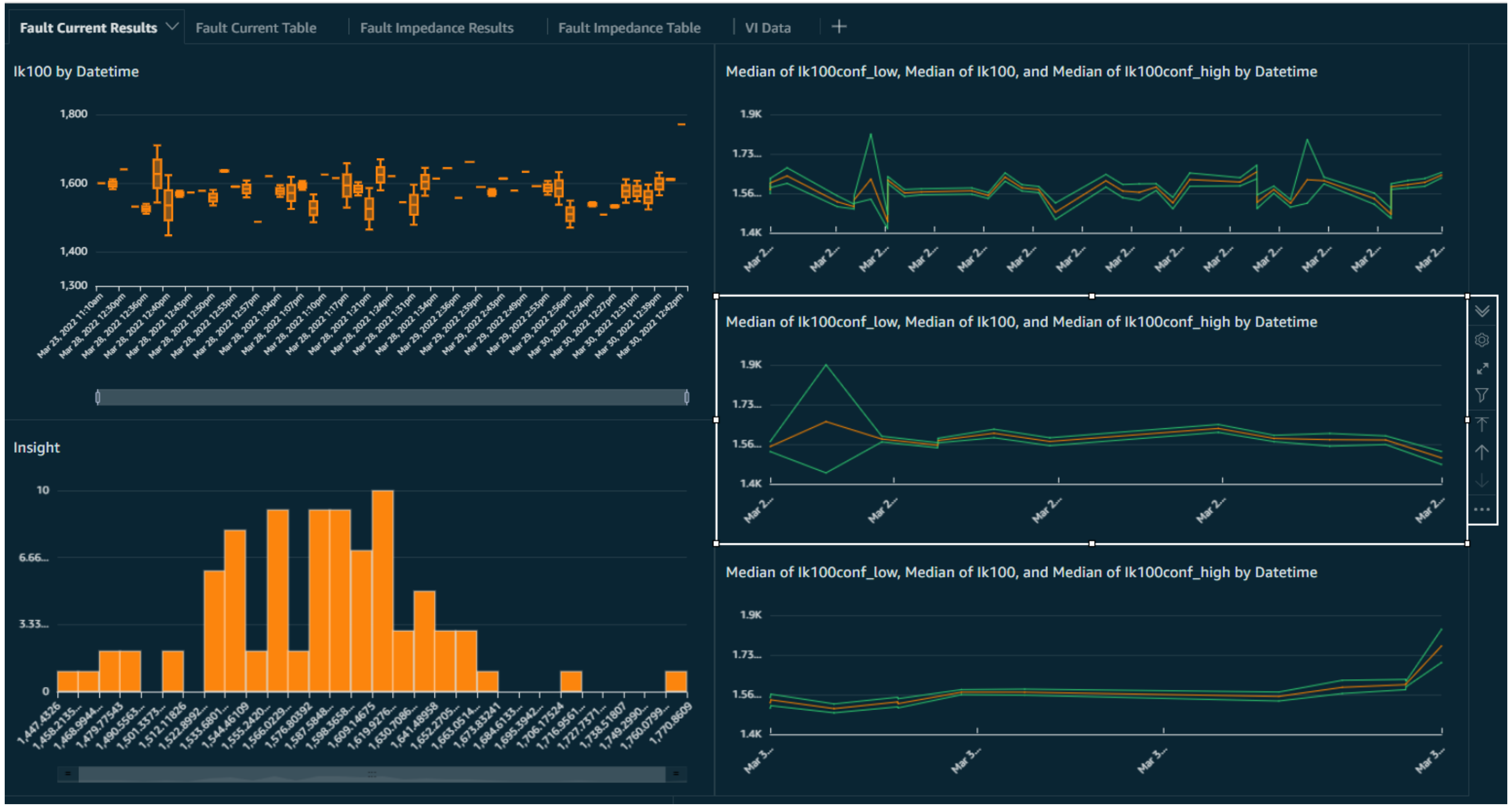
Results UI – Fault Impedance



- Fault impedance measurements directly from the grid
- Fault impedance histogram
- Fault impedance variations during 3 different time periods together with confidence intervals

*confidence intervals are based the variation of quantities during a 3 fundamental cycles period

Results UI – Fault Current



- Steady state fault current measurements directly from the grid
- Steady state fault current histogram
- Steady state fault current variations during 3 different time periods together with confidence intervals

*confidence intervals are based the variation of quantities during a 3 fundamental cycles period

Results UI

Fault impedance and confidence interval

Fault Current Results | Fault Current Table | Fault Impedance Results | **Fault Impedance Table**

Median of Z, Median of Zconf_high, and Median of Zconf_low by Datetime

Datetime	Z	Zconf_low	Zconf_high
Mar 28, 2022 12pm	5.19	5.1465	5.2369
Mar 28, 2022 1pm	5.1648	5.1028	5.228
Mar 29, 2022 2pm	5.1841	5.1136	5.2294
Mar 30, 2022 12pm	5.2914	5.2311	5.3487

Fault current and confidence interval

Fault Current Results | **Fault Current Table** | Fault Impedance Results | Fault Impedance Table

Median of Ik100, Median of Ik100conf_low, and Median of Ik100conf_high by Datetime

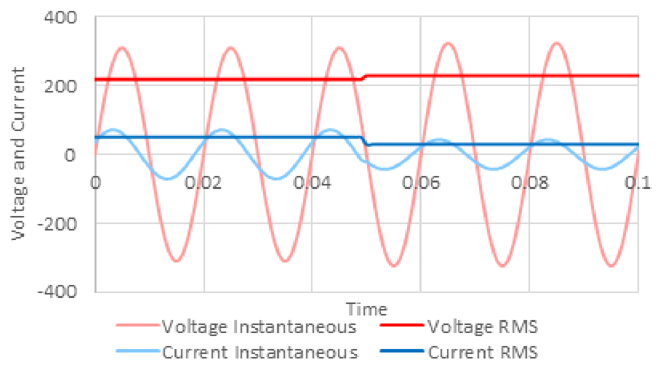
Datetime	Ik100	Ik100conf_low	Ik100conf_high
Mar 28, 2022 12pm	1,577.7006	1,562.2993	1,590.6332
Mar 28, 2022 1pm	1,594.1023	1,569.5906	1,611.4839
Mar 29, 2022 2pm	1,588.2955	1,572.159	1,600.1022
Mar 30, 2022 12pm	1,555.3984	1,538.7709	1,577.1009

- Low error measurement of fault impedance and fault current
- Good confidence even in a very low strength grid
- Results validated via lab power systems models

System strength measurement without models!

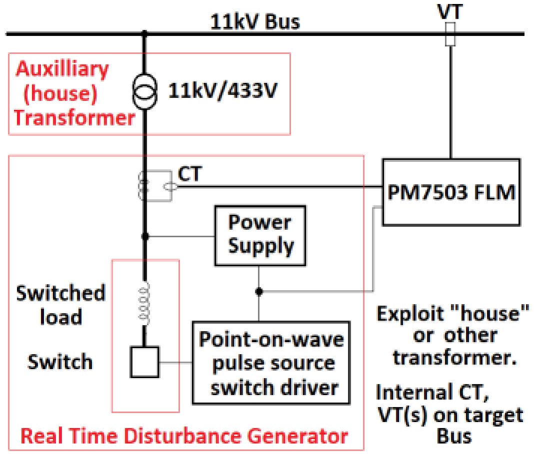
System Strength Measurement Method
UK Power Networks

Passive Measurement



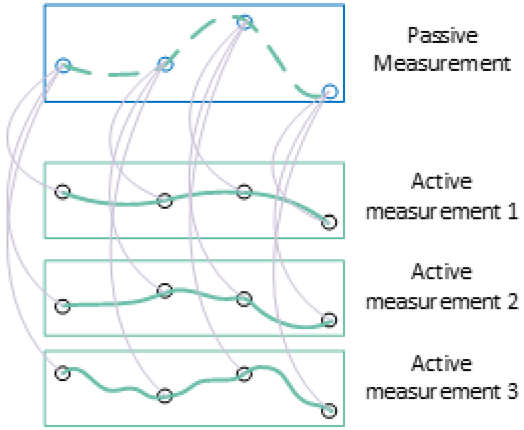
- SS measured from small natural voltage events
- Standard COMTRADE recording
- Power measurement devices
- Estimate short circuit impendence during event using Thevenin equivalent at measurement point

Active Measurement



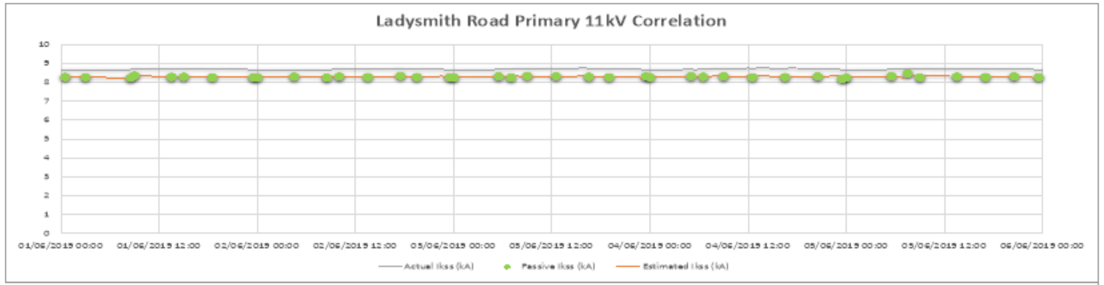
- SS measured from small created voltage events
- Event created by reactor at low voltage
- Event measured by power meter at high voltage
- Automated calculation of SS performed in real time whenever a near-nominal event is recorded.

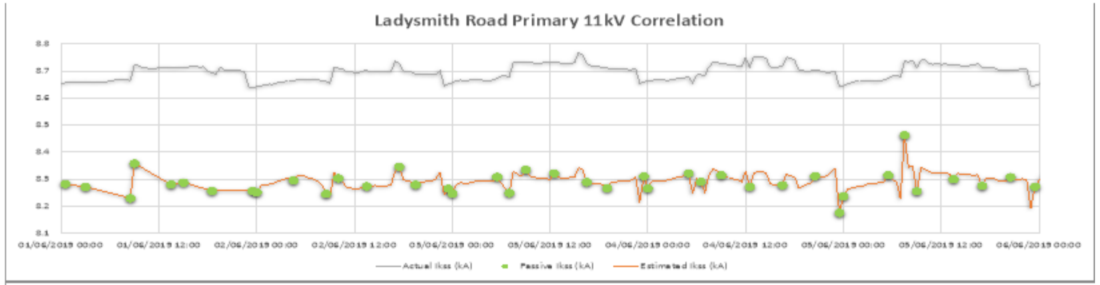
Correlation

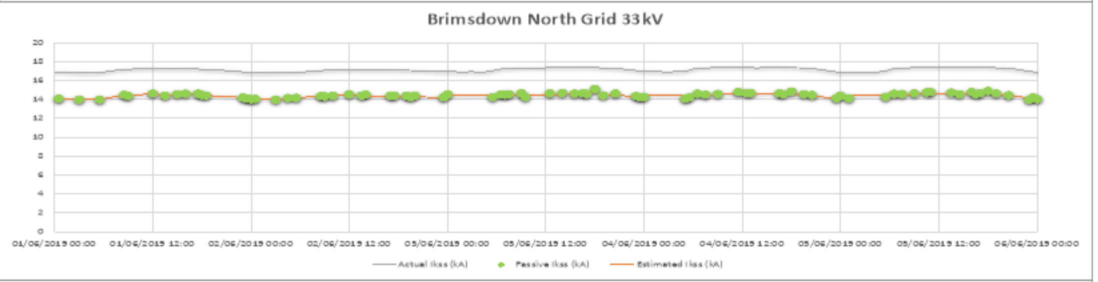


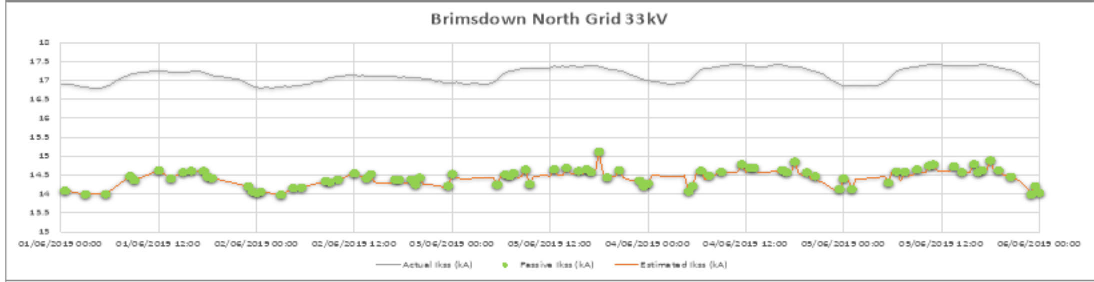
- Combines benefits of active and passive measurements
- Linear regression model to interpolate between passive events using high accuracy active measurements
- SS mapped from few measurement points to many nodes across the network

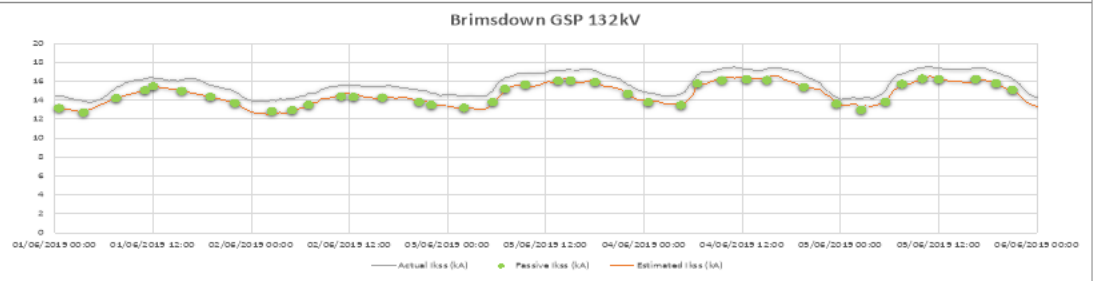
UKPN Studies Show High Accuracy from Reactive's method

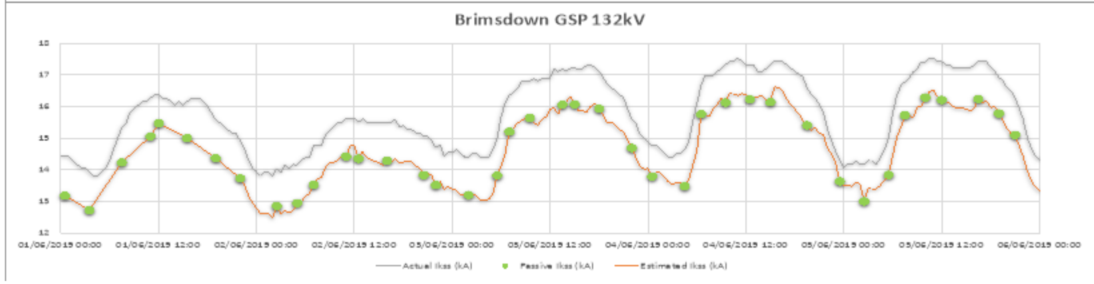












Accuracy is in line with level needed to make reinforcement decisions:

11kV mean error : ~6%

33kV error: ~16%

132kV error: ~7%

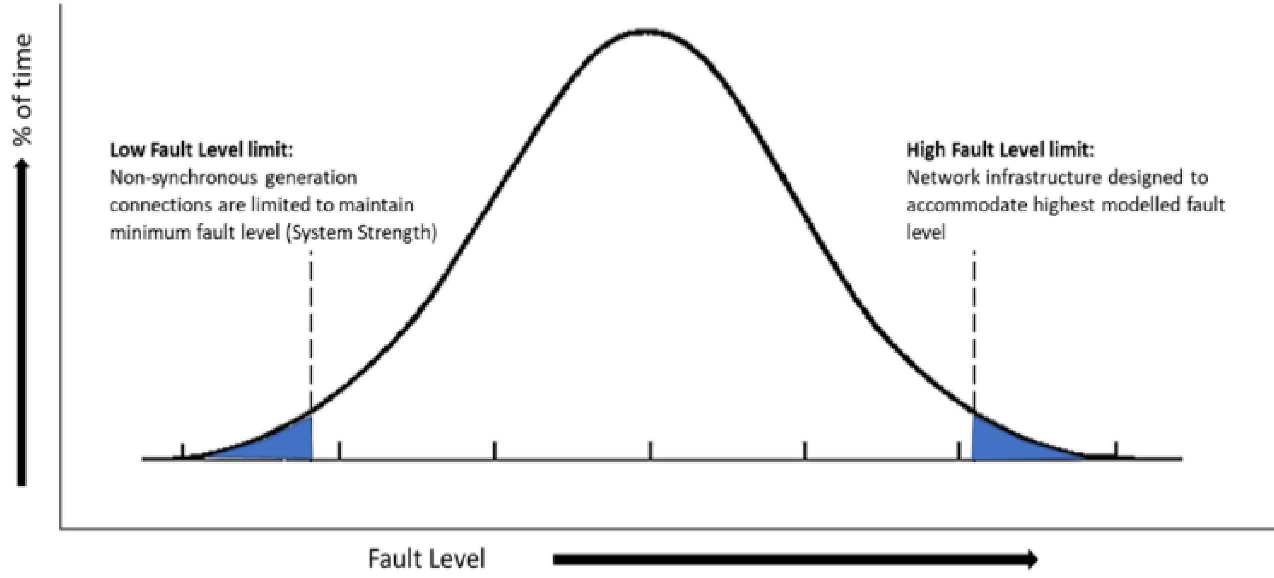
System strength monitoring benefits
UK Power Networks

- Avoided/deferred network reinforcement: only upgrade the network when necessary
  High system strength
- Introducing interruptible connections to customers: Manage generation against fault level constraints
  Low system strength
- Improved system security and health & safety: Meet the reliability targets set by regulators
- Power quality improvement: Run the grid interconnected; minimize equipment failure and customer minutes lost
- Validate existing network models: Ensure that models remain as close to system reality to support improved decision making

UKPN can save

$400K

per sub, 90 subs = $36M

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