WESTERN POWER DISTRIBUTION INNOVATION TEAM

BALANCING ACT CONFERENCE

ONE GREAT GEORGE STREET

20TH JUNE 2019

NIGEL TURVEY

WPD - DSO & FUTURE NETWORKS MANAGER

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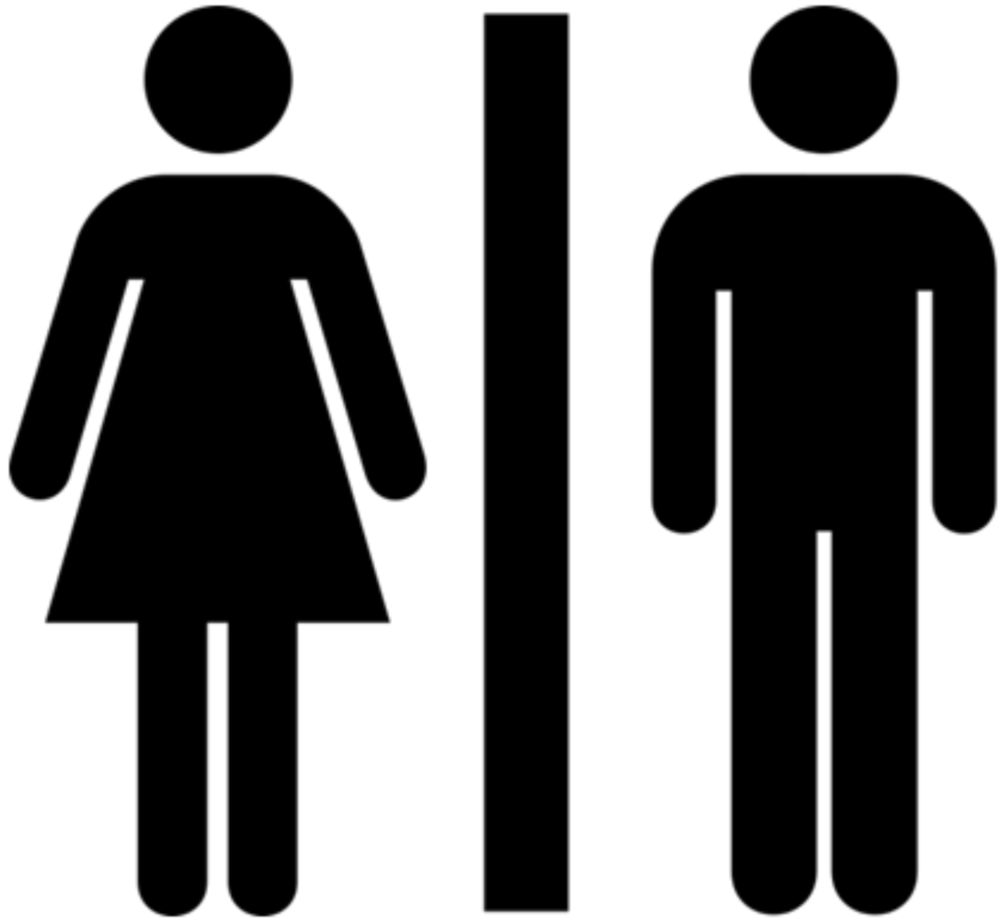
HOUSEKEEPING



INNOVATION OBJECTIVES

The objectives of WPD’s innovation programme are to:

- Develop new *smart* techniques that will accommodate increased load, storage and generation (Distributed Energy Resources – DER) at lower costs/quicker connections than conventional reinforcement.
- Facilitate regional and local energy markets; including local flexibility services.
- Improve business performance against one or more of our core goals of safety, customer service, reliability, the environment or cost effectiveness.
- Ensure solutions are compatible with the existing network.
- Deliver solutions so that they become business as usual.
- Provide long term, whole system outcomes and value for money for consumers.
- Assist the UK to reduce carbon emissions and combat climate change.

AGENDA

10.10 – Network Equilibrium

11.00 – Primary Networks Power Quality Analysis

11.30 – Refreshments

11.50 – Technical Panel Session

12.30 – Lunch & Networking

13.30 – EDGE-FCLi

14.00 – Virtual Statcom

14.30 – Refreshments

14.45 – Losses Investigation

15.15 – New Projects

15.30 – Close

WESTERN POWER DISTRIBUTION INNOVATION TEAM

NETWORK EQUILIBRIUM

BALANCING ACT CONFERENCE

20TH JUNE 2019

YIANGO MAVROCOSTANTI
WPD - INNOVATION & LOW CARBON NETWORKS ENGINEER

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OUTLINE

- Introduction to the Network Equilibrium Project
- Project Objectives
- Equilibrium technologies
  - What is the problem?
  - Design, Testing and Trials
  - Key learning
- Summary

NETWORK EQUILIBRIUM – AN OVERVIEW

Project Budget:

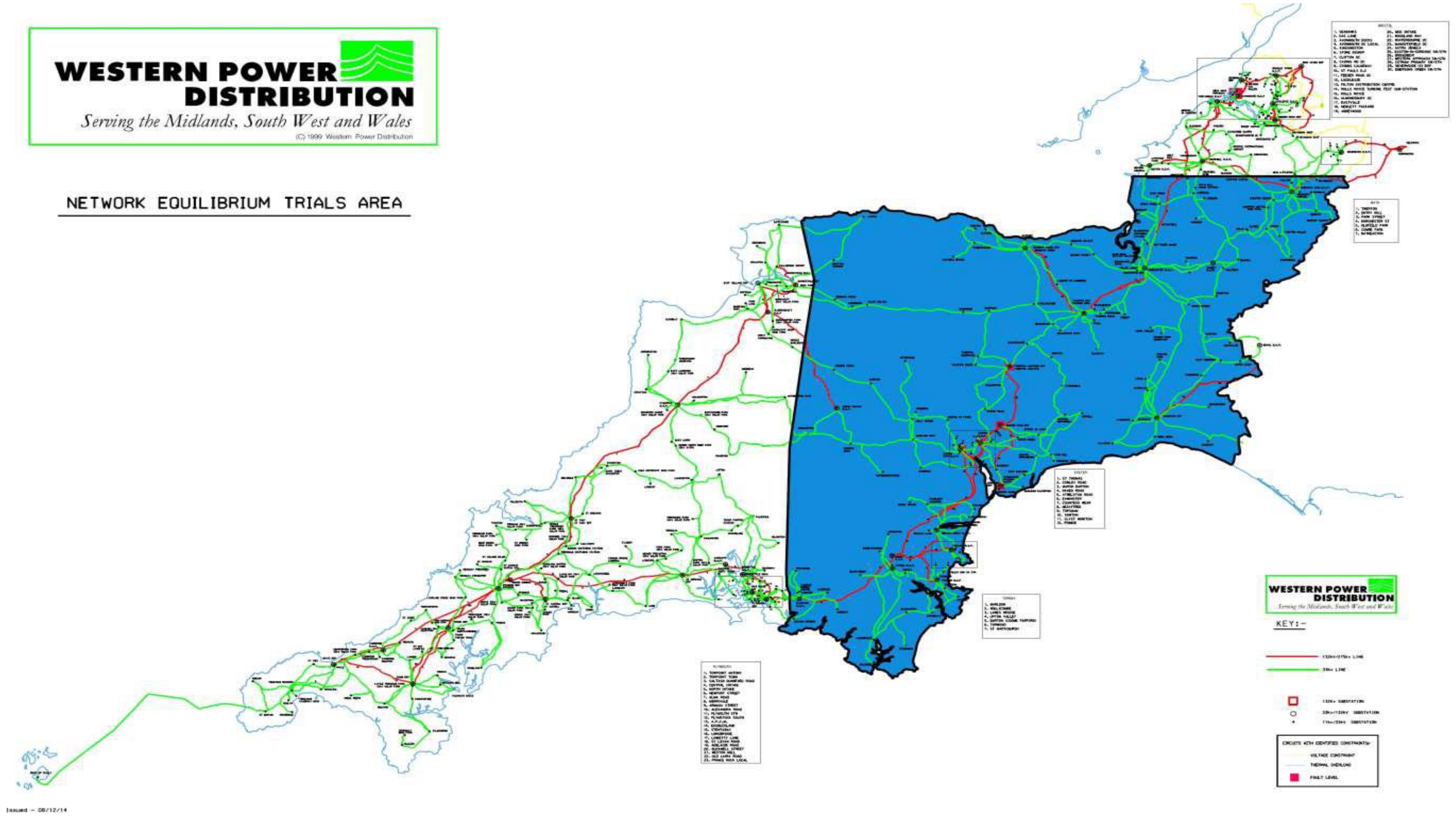
£13m Tier 2 project.

Project area:

Part of WPD's South West Network.

Duration:

March 2015 – June 2019.



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PROJECT OBJECTIVES

Improve network planning using advanced tools

Optimise network voltage profiles

Control and balance network power flows

RELEASE NETWORK CAPACITY TO ALLOW MORE DISTRIBUTED GENERATION (DG) AND LOW CARBON TECHNOLOGIES TO CONNECT

PROJECT METHODS

EVA Enhanced Voltage Assessment	SVO System Voltage Optimisation	FPL Flexible Power Link
• **Voltage Limits Assessment** to investigate potential amendment of statutory voltage limits. • **Advanced Planning Tool** to improve network planning.	• Centralised, real-time voltage control system to optimise the voltage profiles on 33kV and 11kV networks.	• Back-to-back voltage source converter installed between two previously unconnected Bulk Supply Points.

ENHANCED VOLTAGE ASSESSMENT (EVA)

What is the problem we want to solve?

Statutory voltage limits on the GB system can be a technical barrier when trying to connect DG to the distribution network

ENHANCED VOLTAGE ASSESSMENT (EVA)

What are the solutions we explored?

Voltage Limits Assessment Study

Can UK voltage limits be widened to release capacity?

Advanced Planning Tool

Quantify network capacity and plan for SVO and FPL technologies

VOLTAGE LIMITS ASSESSMENT (VLA) WORK

- Questionnaires were circulated to DNOs, TSOs, manufacturers, consultants etc.
- Completed review of industry standards, specifications and codes
- Workshop to discuss findings with DNOs

VOLTAGE LIMITS ASSESSMENT (VLA) CONCLUSIONS

- General support for making amendments to the voltage limits
- Existing equipment standards and specifications **would not** hinder increases up to ±10%
- Further assessment required to assess impact on reactive power absorption and fault levels

ADVANCED PLANNING TOOL (APT) WORK

Create new network models and simulate VLA

Produce SVO plug-in to optimise substation target voltages

Produce FPL plug-in to balance demand and generation

ADVANCED PLANNING TOOL (APT) CONCLUSIONS

VLA Simulations

- The results of the power system studies showed that:
  1. 11kV network voltage limits could be extended to ±8%
  2. 33kV network voltage limits could be extended to ±10%

- Similar to EN 50160, duration at the extents of the limits should only be permitted for short periods of time

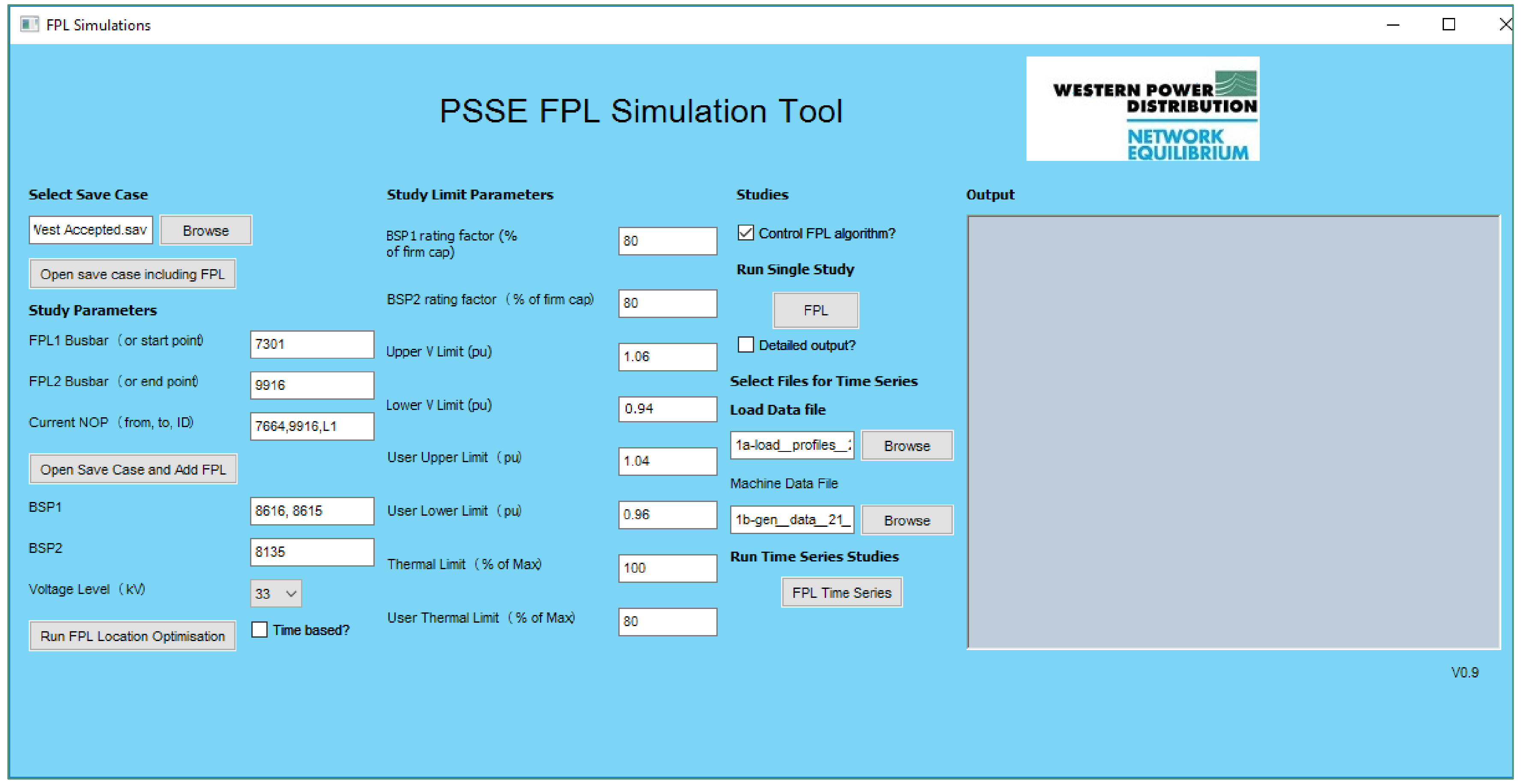
- Significant capacity could be released at the majority of trial substations

Bulk Supply Point	Average Capacity Released (MW)
Bowhays Cross	33.80
Bridgwater	124.53
Exeter City	0.00
Exeter Main	17.51
Paignton	0.00
Radstock	0.00
Taunton	66.49
Tiverton	0.00

Primary Substation	Average Capacity Released (MW)
Colley Lane	0.00
Dunkeswell	0.34
Lydeard St Lawrence	0.32
Marsh Green	2.65
Millfield	5.57
Nether Stowey	0.44
Tiverton Moorhayes	4.06
Waterlake	2.66

ADVANCED PLANNING TOOL (APT) CONCLUSIONS

SVO/FPL Simulations



- PSS/E plug-ins were developed as part of the APT to simulate the FPL and SVO.
- The plug-ins were scripted using Python with a Graphical User Interface for selecting options and outputs.
- It was verified from the trials that the plug-ins provided a conservative view of the expected operation of the technologies.
- SVO capacity release of 210MVA.
- FPL capacity release of 20MVA.

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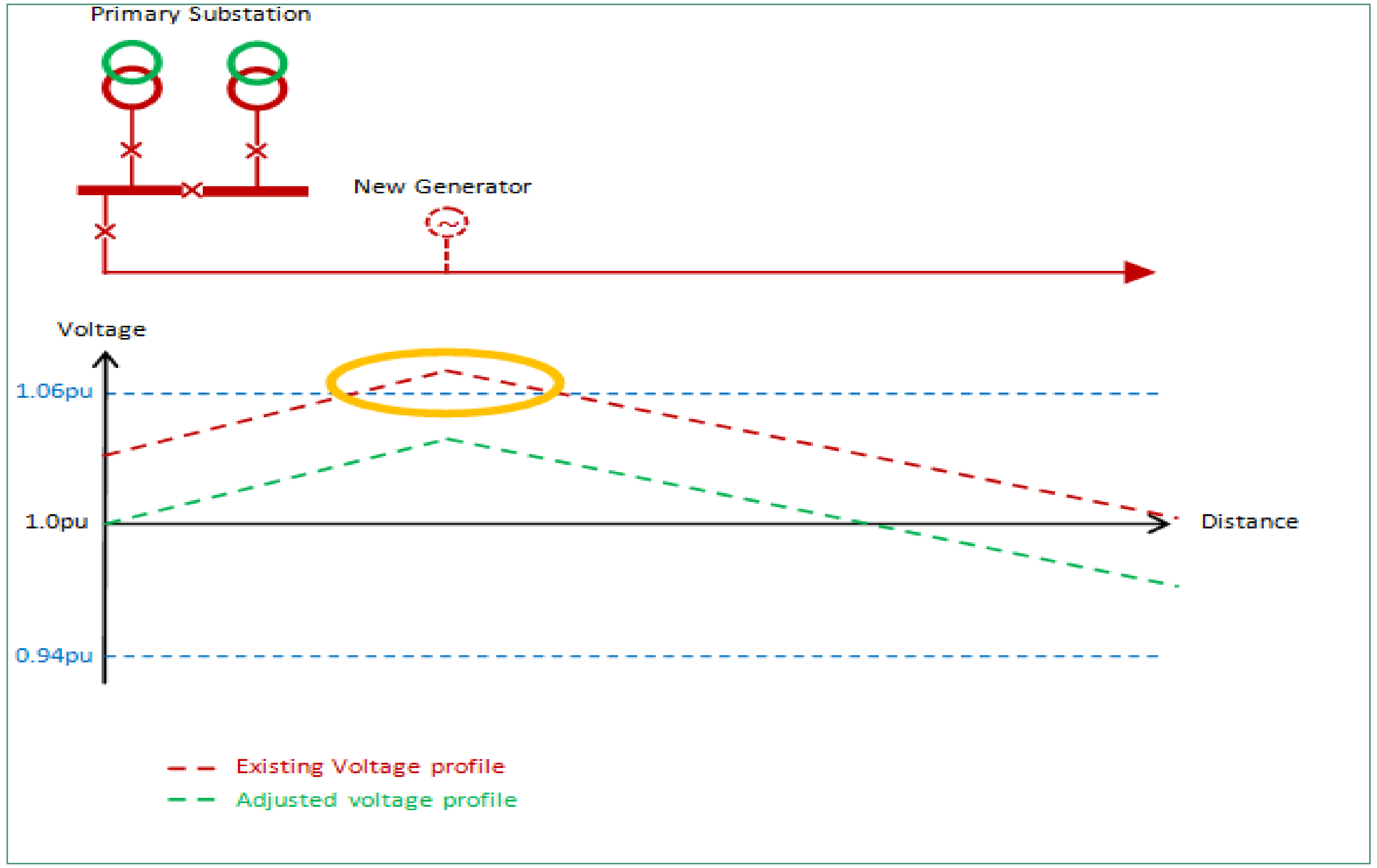
SYSTEM VOLTAGE OPTIMISATION (SVO)

What is the problem we want to solve?

Traditional Voltage Control Philosophy

- Relays at substations control On-Load Tap Changers (OLTC)
- Keeps voltage at substation close to pre-determined value
- This target voltage value historically set high to allow for voltage drop on demand dominated networks



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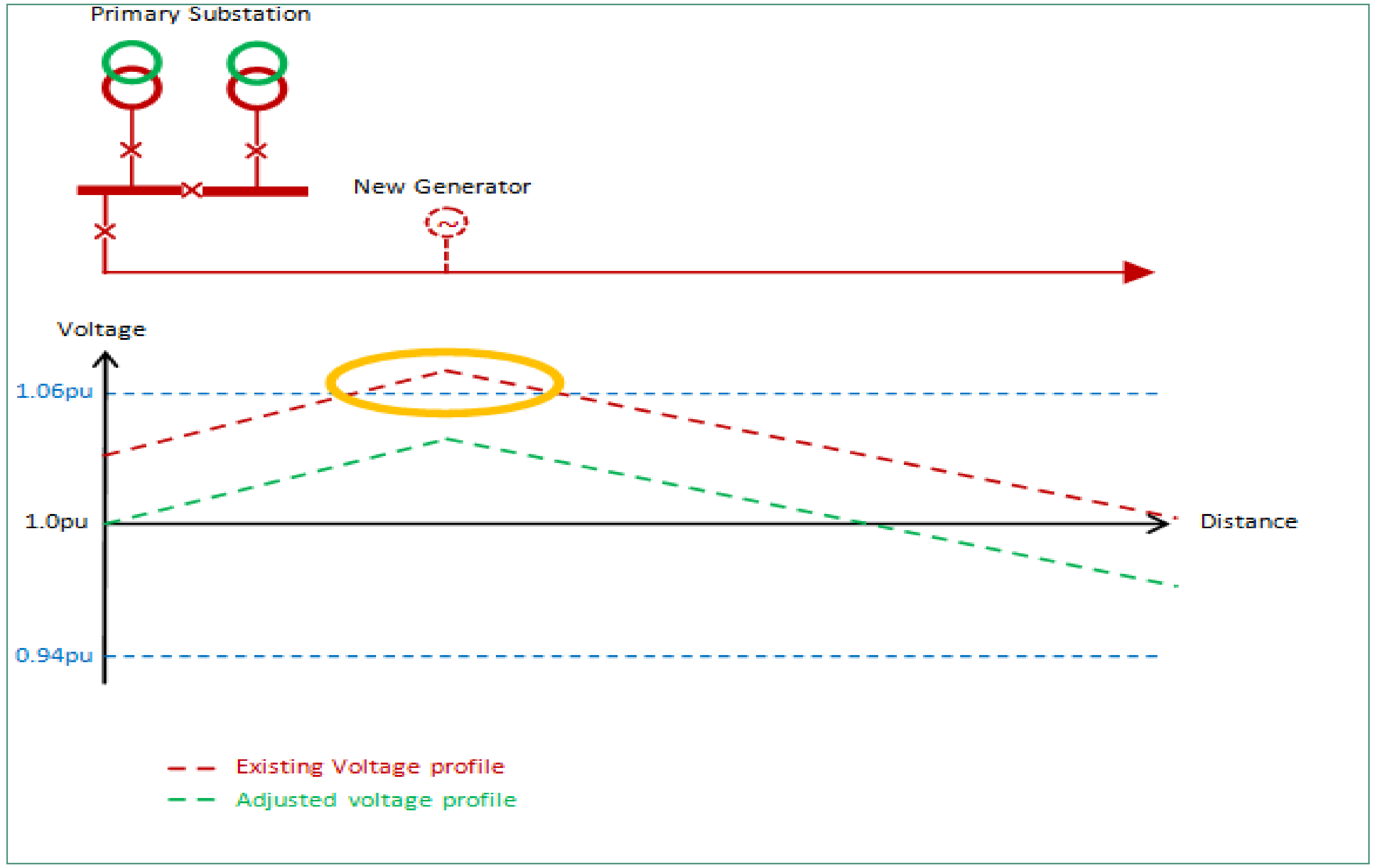
SYSTEM VOLTAGE OPTIMISATION (SVO)

What is the problem we want to solve?

Traditional Voltage Control Philosophy

- Keeping the voltages as high as possible at all times can limit the headroom for DG!

Network Capacity can be limited



SYSTEM VOLTAGE OPTIMISATION (SVO)

What is the solution?

SVO dynamically adjusts the previously static target voltage at the substation based on real-time operating conditions.

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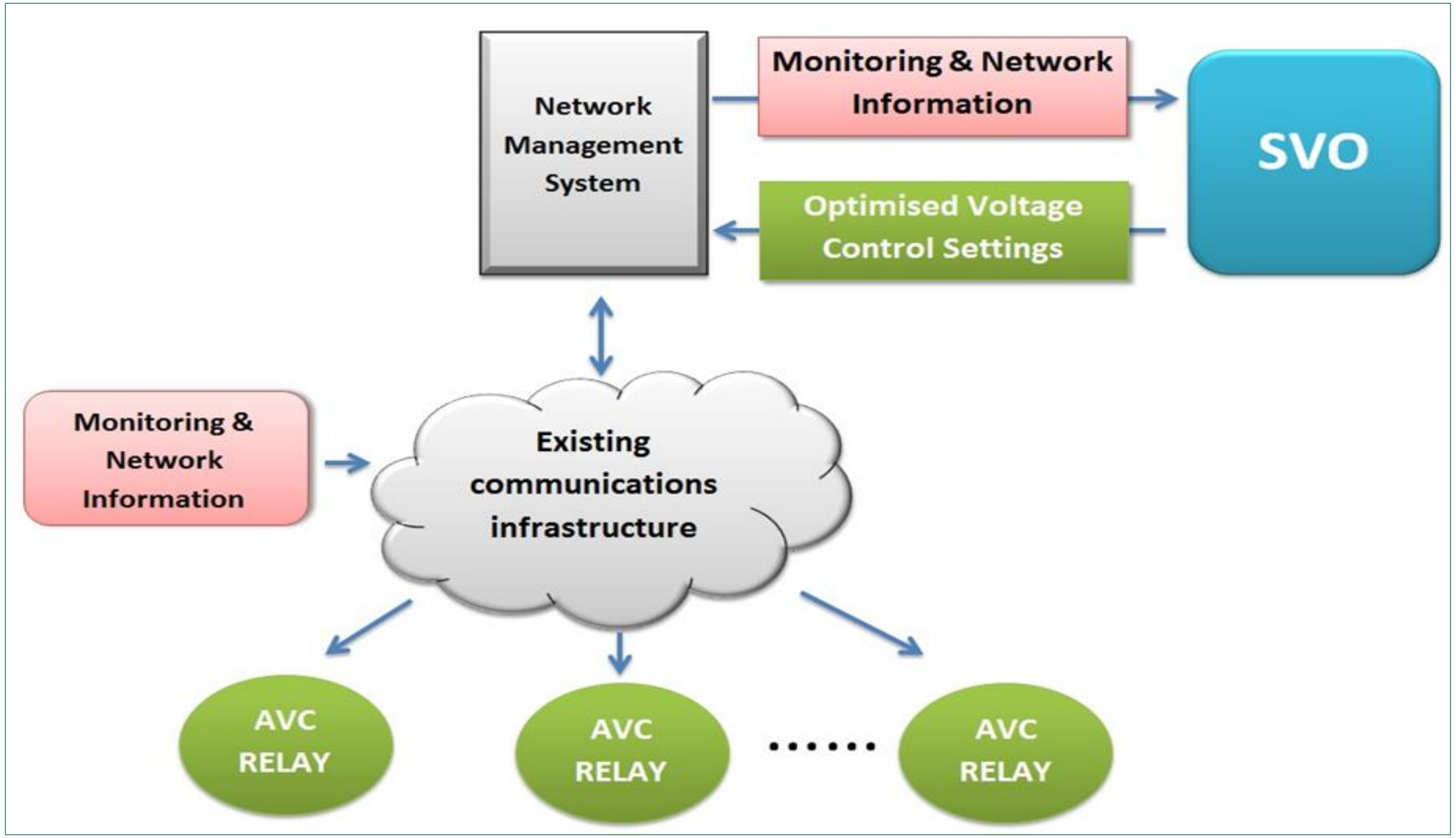
SYSTEM VOLTAGE OPTIMISATION (SVO)



SYSTEM VOLTAGE OPTIMISATION (SVO)

SVO Design – Selection of sites

>200 sites in South West area

↓

Selected 12 BSPs with highest voltages, 10 Primaries with largest volume of DG

↓

Selected 8 BSPs and 8 Primaries based on a number of criteria including available window for target voltage changes, existing AVC capability, site condition.

SYSTEM VOLTAGE OPTIMISATION (SVO)

SVO Design – AVC Relays and Site work

Fine Voltage Control implemented using **Fundamentals SuperTAPP SG relay**

Group Control implemented using **MicroTAPP relay**

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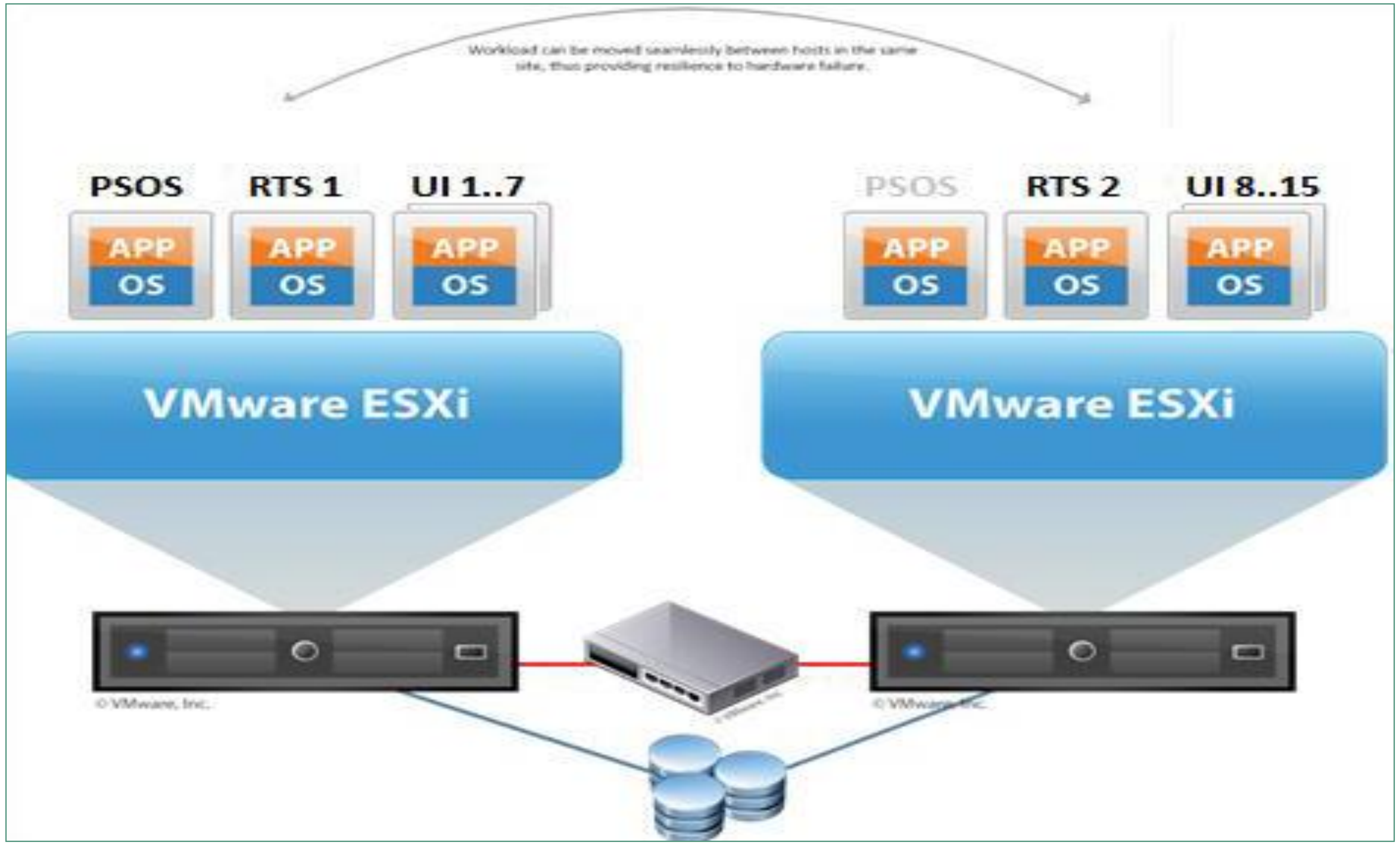
SYSTEM VOLTAGE OPTIMISATION (SVO)

SVO Design – IT Architecture/Spectrum Power 5 Implementation



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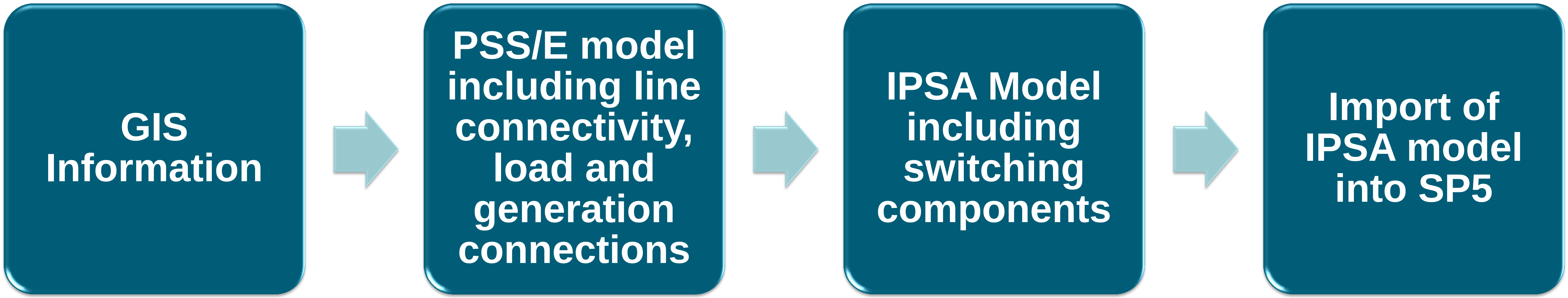
SYSTEM VOLTAGE OPTIMISATION (SVO)

SVO Design – Network Modelling



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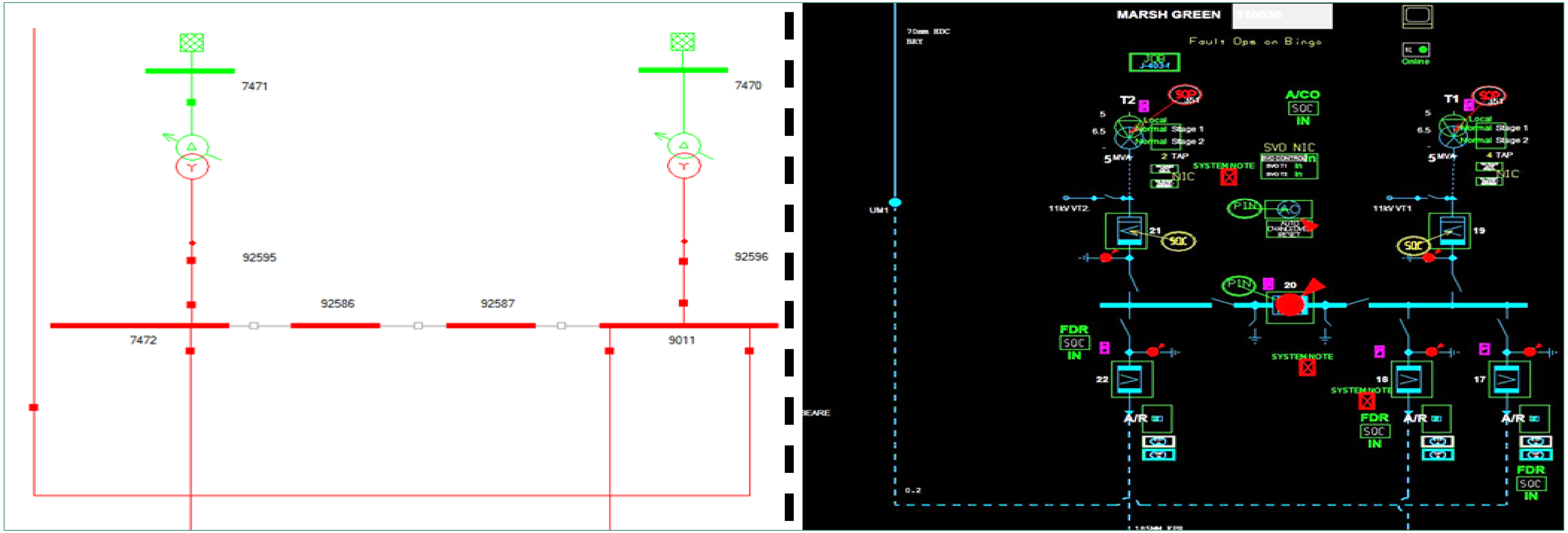
SYSTEM VOLTAGE OPTIMISATION (SVO)

SVO Design – Network Modelling



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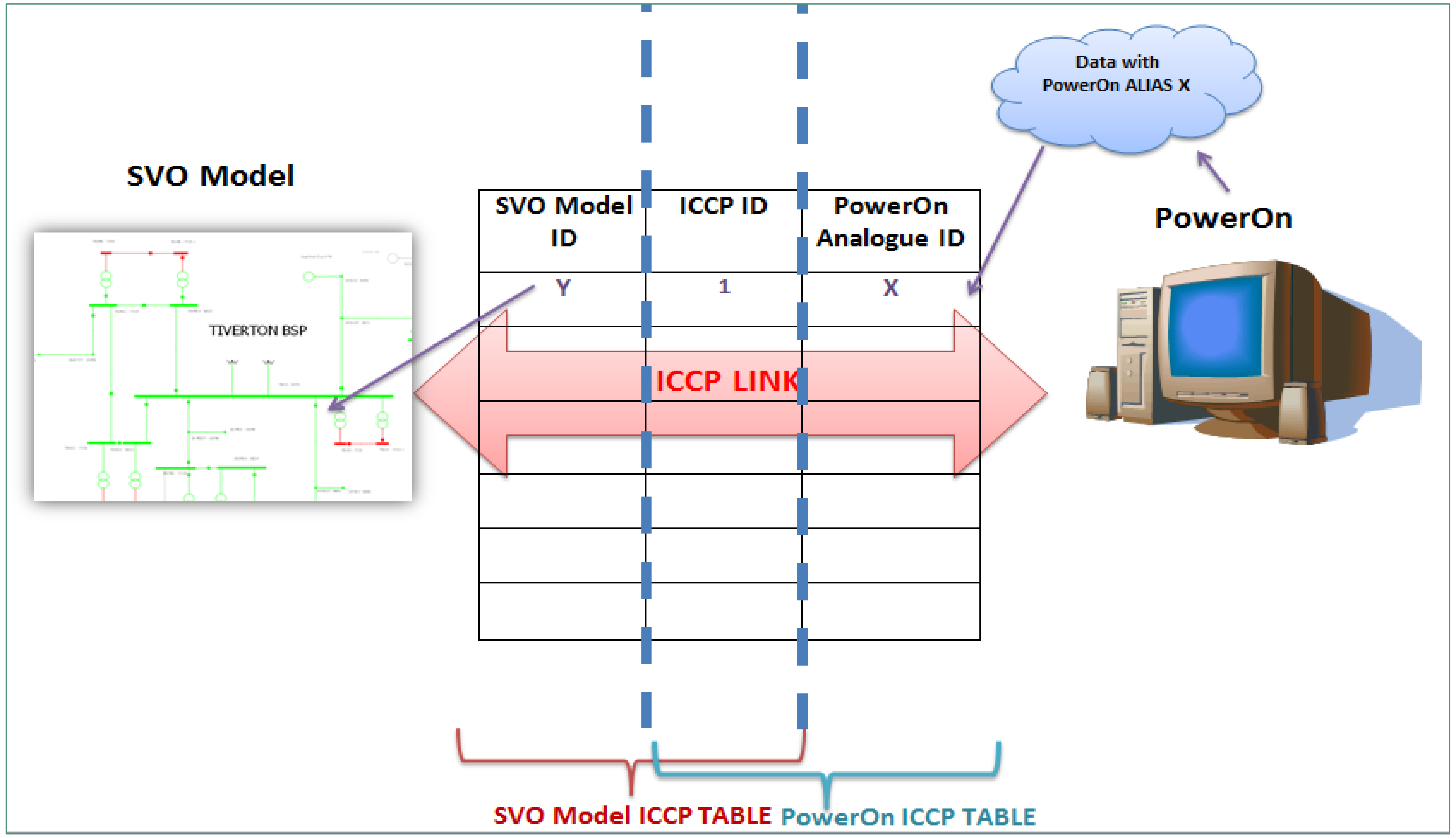
SYSTEM VOLTAGE OPTIMISATION (SVO)

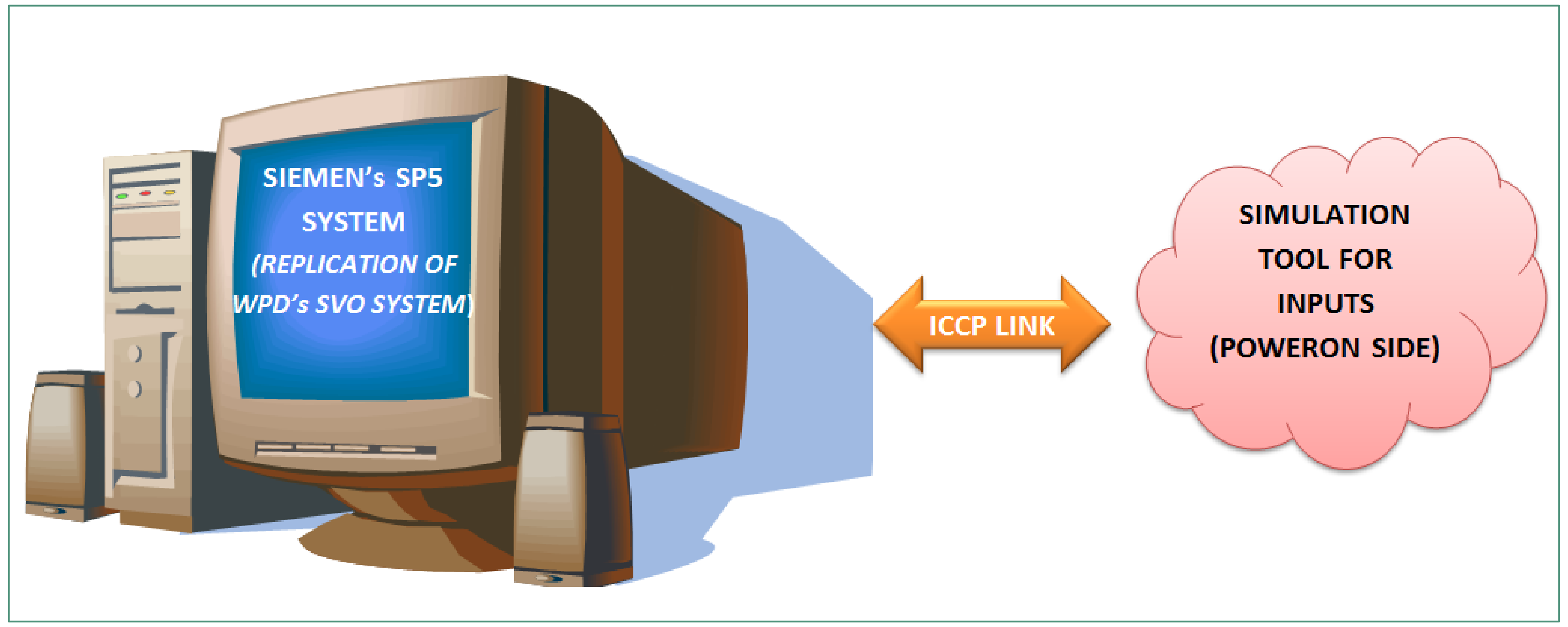
SVO Design – Network models and Integration with the Network Management System

- An ICCP link was configured to enable SVO to communicate with the NMS
- To ensure successful integration, the various components in the network model were given IDs that exist in the NMS



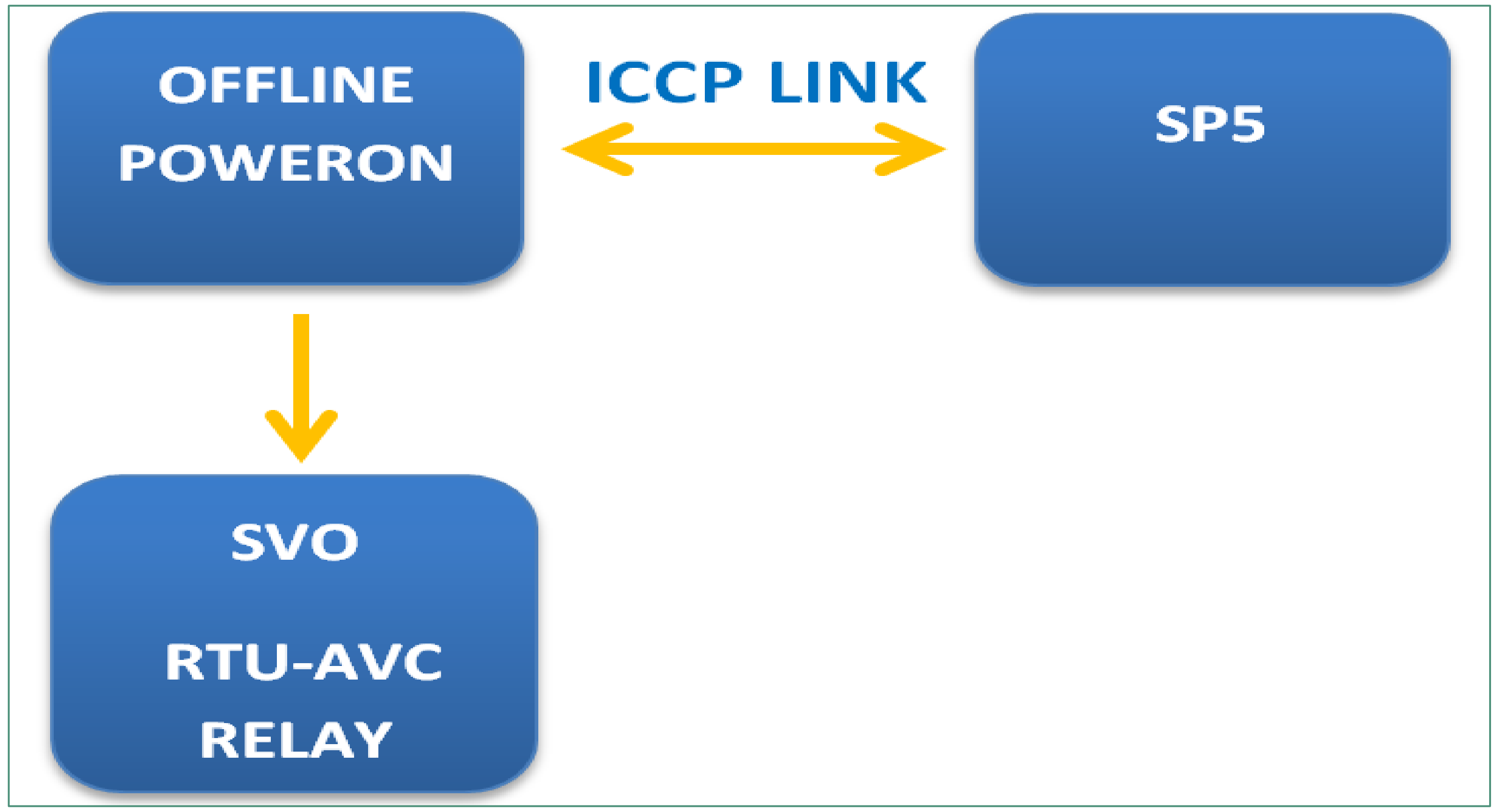
SYSTEM VOLTAGE OPTIMISATION (SVO)

FAT, SIT, SAT



The FAT tested the operation of the SP5 software and the various modules of the system.

The SIT proved the successful integration of SP5 with the NMS and site.

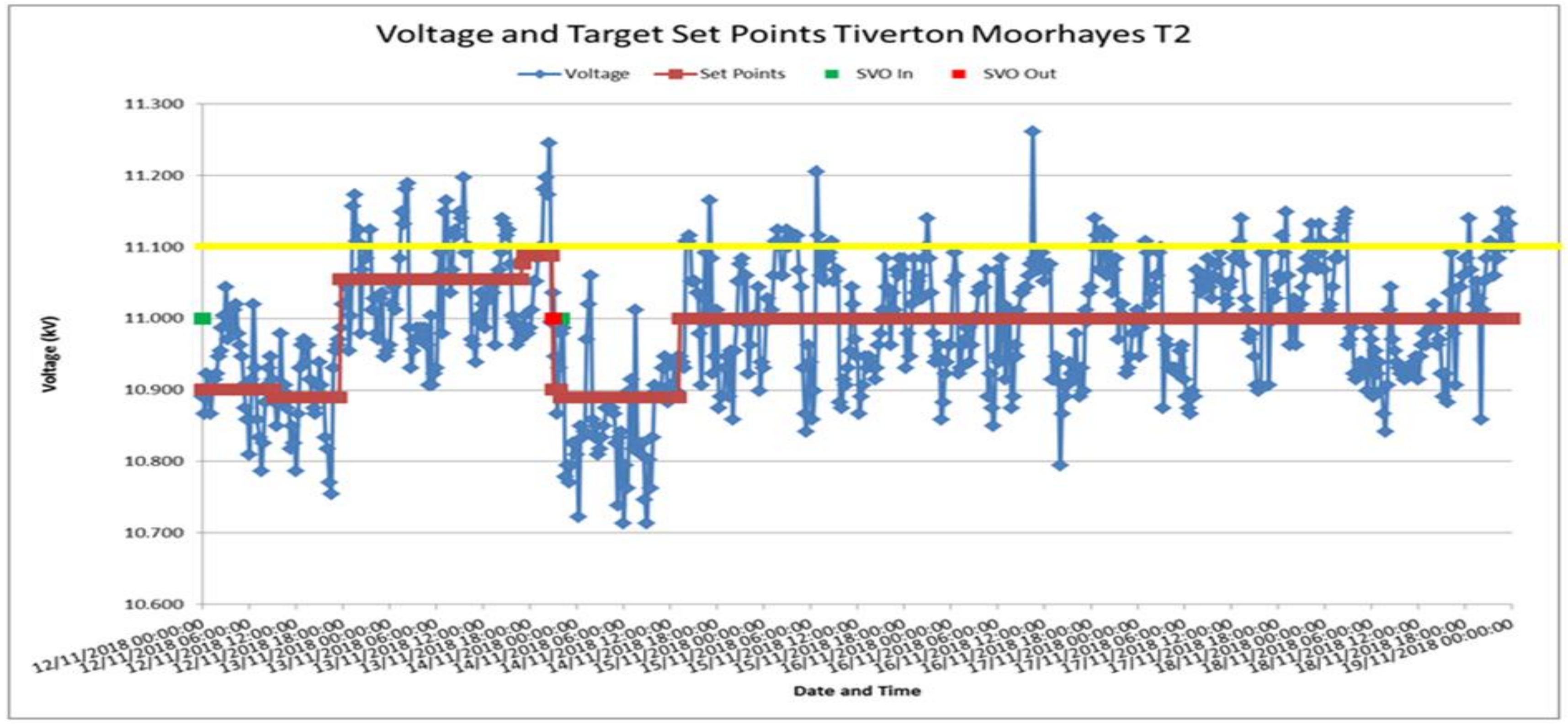


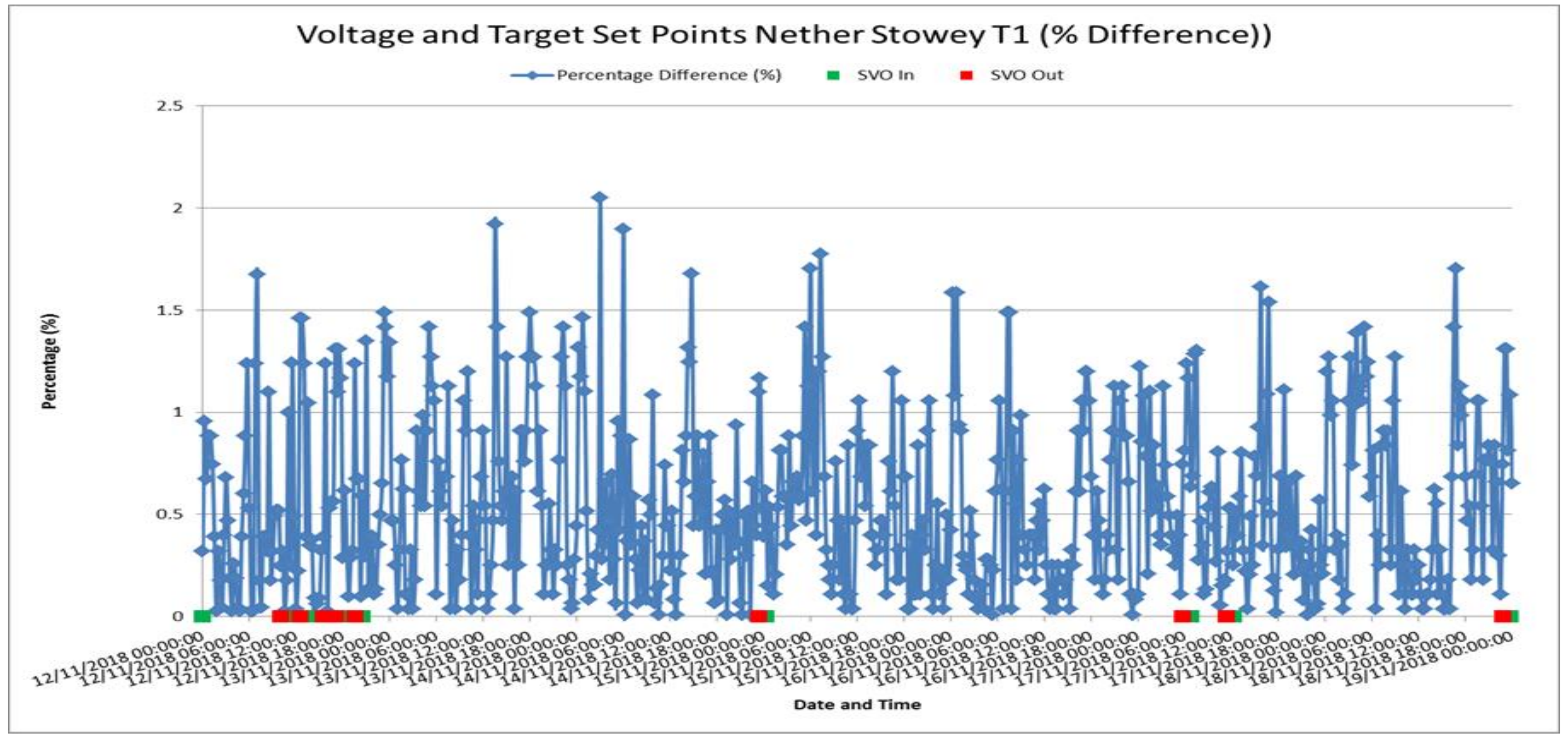
In the SAT, SP5 was connected to the live PowerOn system and was operating in open loop mode for a number of weeks before it was put in closed loop operation.

SYSTEM VOLTAGE OPTIMISATION (SVO)

Trials

- SVO trials have been running since March 2018
- Procedures have been developed for the weekly extraction and analysis of the trial data
- Through SVO's state estimation functionality, the trial data provided additional visibility on the operation of the network at the points where no measurements are available
- The decisions of SVO and operation of the technology were analysed on a weekly basis





SYSTEM VOLTAGE OPTIMISATION (SVO)

Trials

- The dynamic nature of each network is different
- Some SVO sites had more frequent set point changes than others
- The actual available headroom for target voltage amendment is larger than the estimated headroom in traditional power system studies

SVO Site	Set Point Changes
Colley Lane T1 T3	27
Nether Stowey T1	12
Marsh Green T1	66
Tiverton Moorhayes T1 T2	6
Bowhays Cross GT1 GT2	66
Tiverton GT1 GT2	162
Paignton GT1 GT2	9
Waterlake T1	1
Waterlake T2	23

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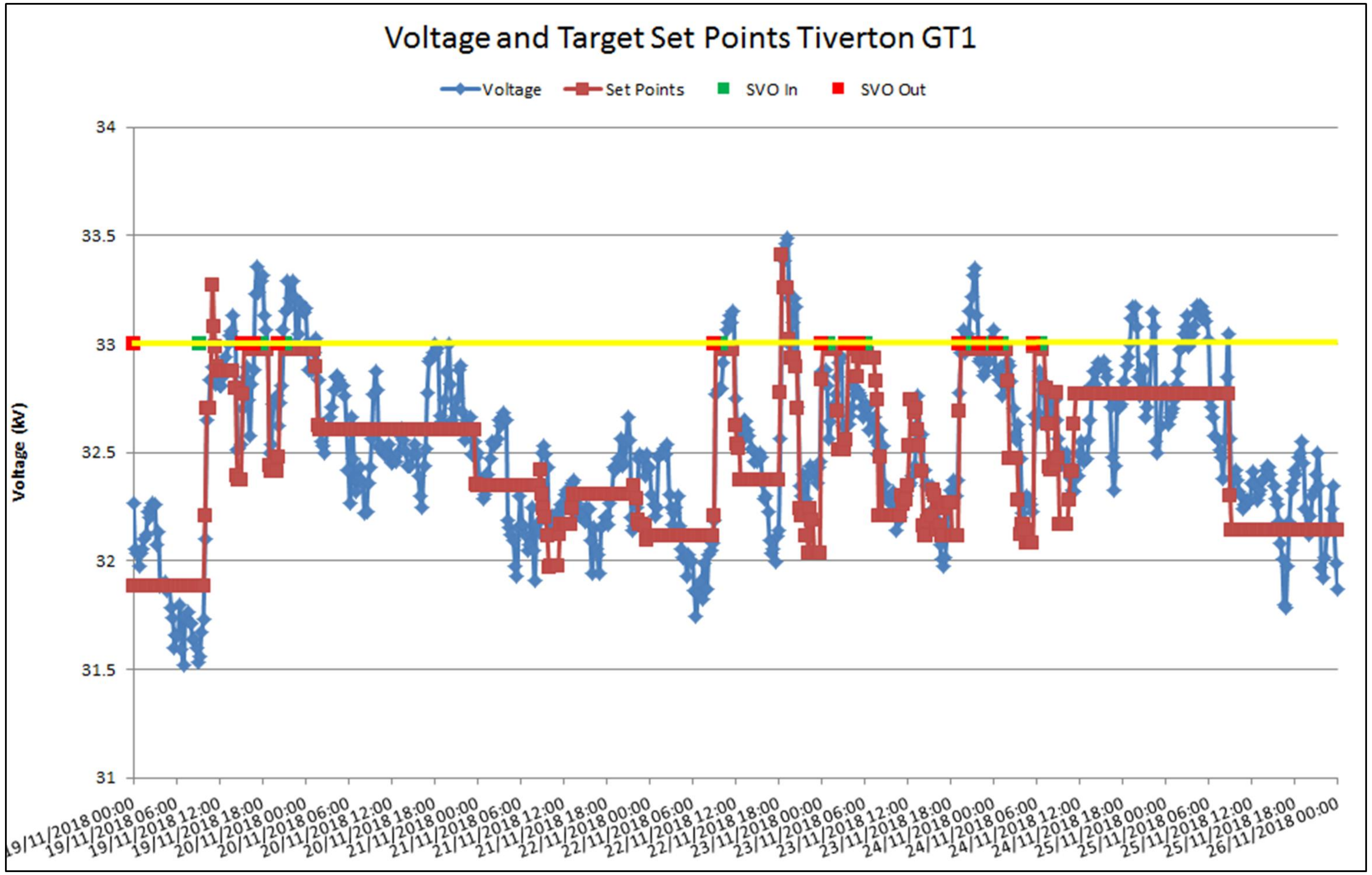
SYSTEM VOLTAGE OPTIMISATION (SVO)

Trials

- For the majority of the time, the optimised target voltage setting is lower to the default setting.

- Network operation is complex – need for sophisticated systems that can respond to dynamic changes.



SYSTEM VOLTAGE OPTIMISATION (SVO)

Conclusions

- SVO successfully amended the target voltage at both BSPs and Primaries in real time.
- There is sufficient headroom to shift voltage profiles both up and down.
- The use of state estimation is important for DSO functions.
- SVO is a viable method for providing dynamic network operation and releasing network capacity.

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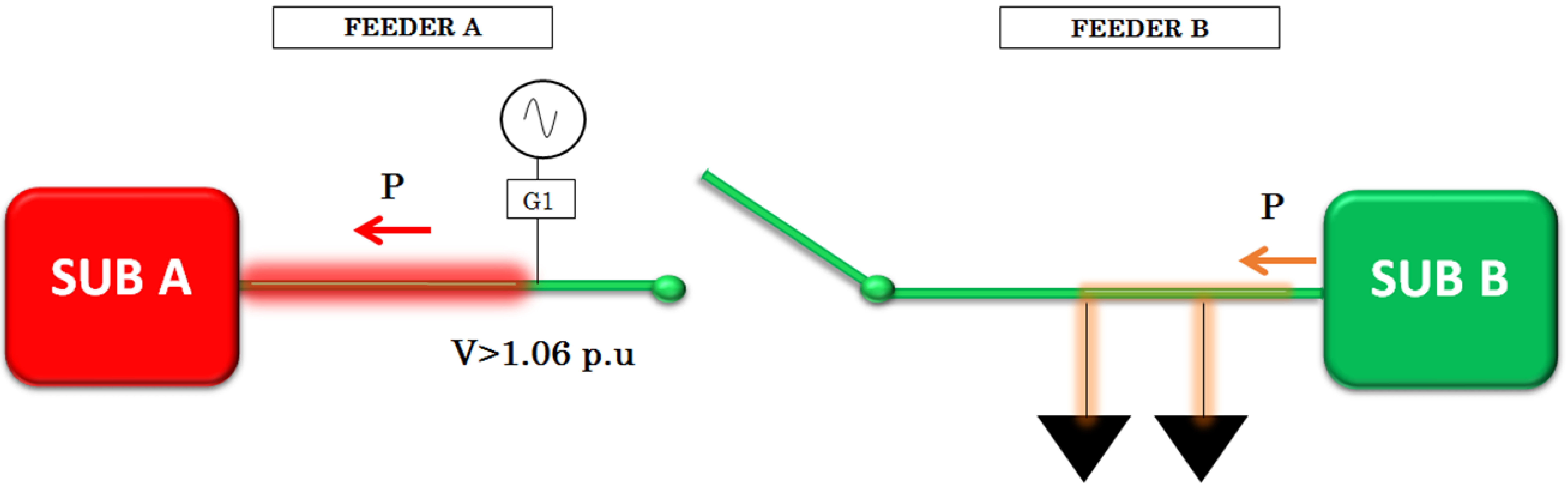
FLEXIBLE POWER LINK (FPL)

What is the problem we want to solve?



- SUB A is overloaded and V exceeds statutory limit!
- G1 cannot be connected!

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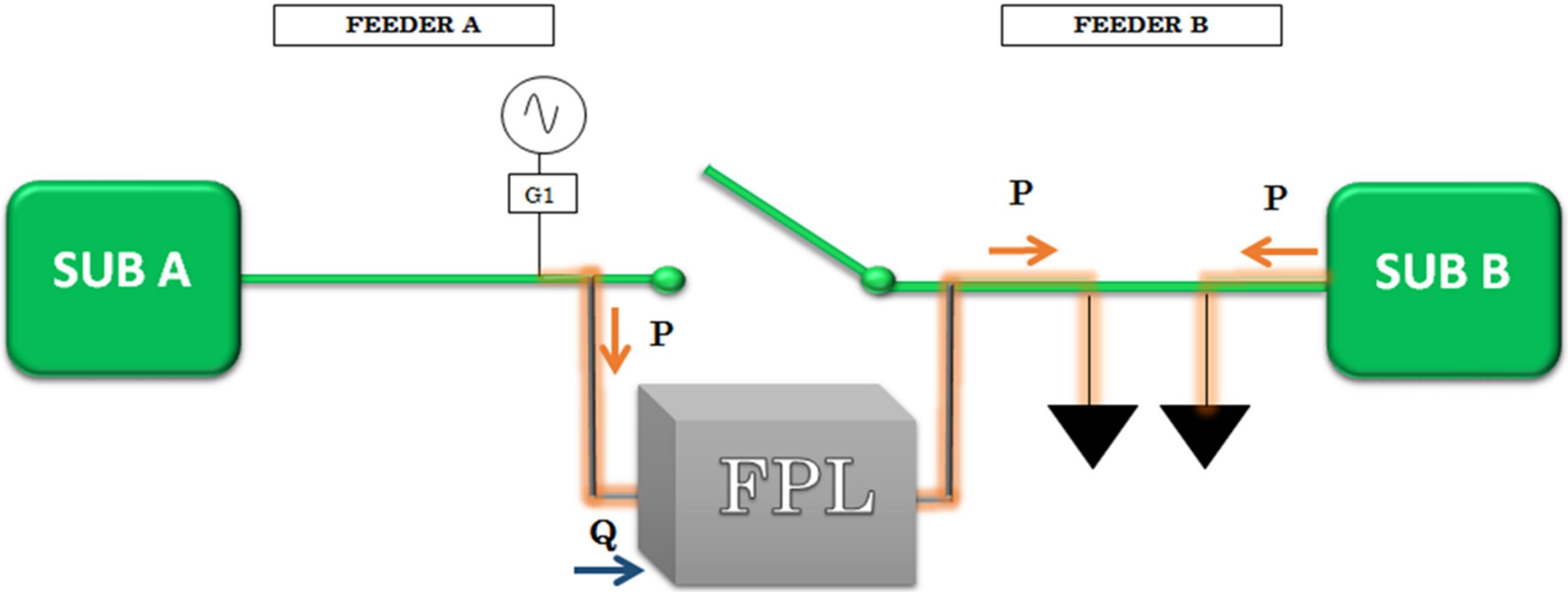
FLEXIBLE POWER LINK (FPL)

What is the solution?

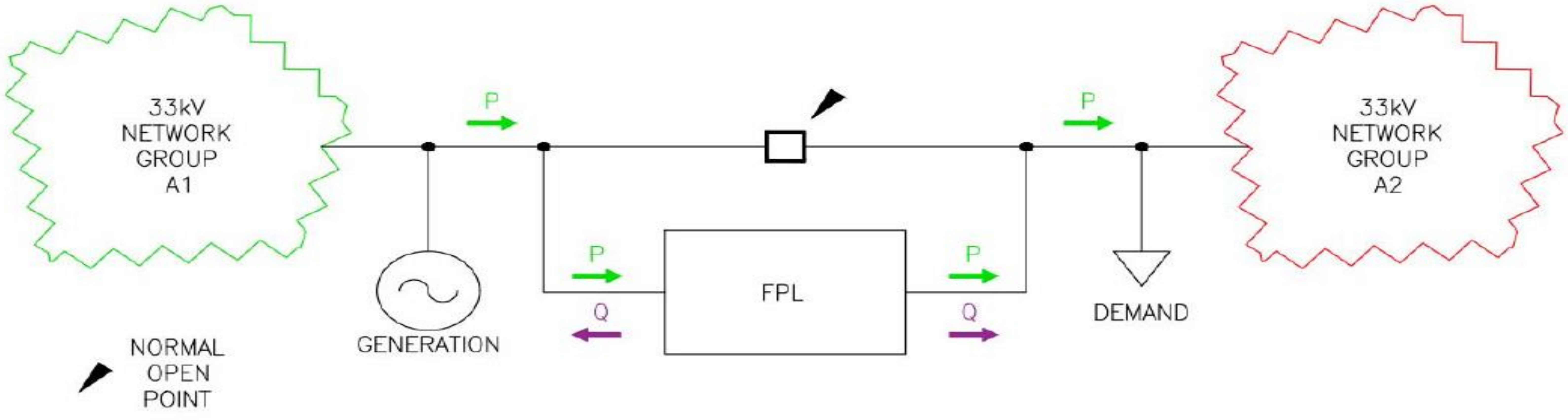


- FPL transfers P from feeder A to feeder B. Removes thermal constraint!
- FPL provides Q support on feeder A. Removes V constraint!
- G1 can connect!

FLEXIBLE POWER LINK (FPL)

What is the solution?

- Power electronic converter technology
- Back-to-back converter across a NOP
- 4-quadrant active and reactive power control



FLEXIBLE POWER LINK (FPL)

What is the solution?

- FPL supplied by ABB
- PCS 6000 medium voltage static frequency converter
- Voltage Source Converter (VSC) with back-to-back configuration
- Typically applied to connect three phase public grids to single phase railway power grids

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FLEXIBLE POWER LINK (FPL)

FPL Design – Site Selection

- 8 sites available for selection in the project area
- 4 sites shortlisted (2 sites with low power transfer capability and 2 with inadequate space)

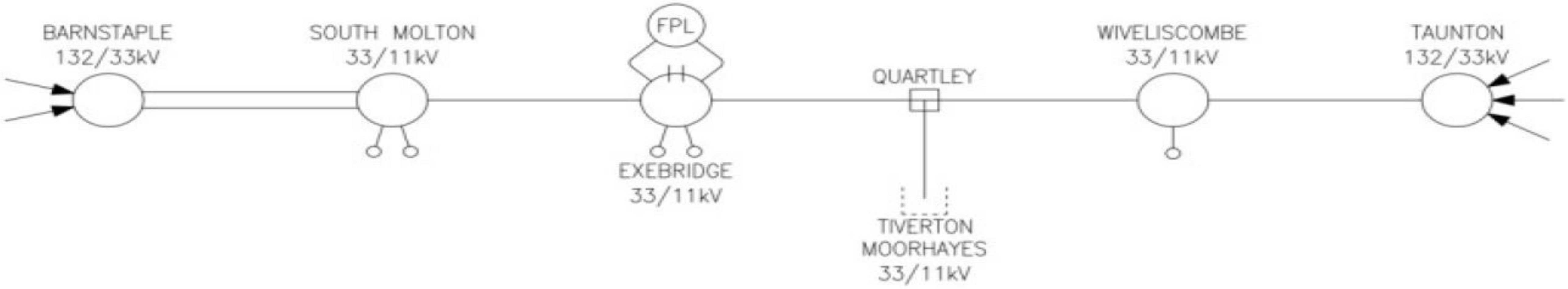
Site	BSPs to be connected	Availability of Space	Ease of Network Connection	Substation Access	Customer Impact
Exebridge Substation	Barnstaple – Taunton	✓	✓	✓	✓
Quartley Switching Station	Barnstaple – Taunton; or Tiverton – Taunton	✗	✗	✗	✗
Tiverton Moorhayes Substation	Tiverton – Taunton	✗	✗	✓	✓
Winslakefoot Switching Station	Exeter City – Tawton	✗	✓	✗	✗

FLEXIBLE POWER LINK (FPL)

FPL Design – Site Selection

- NOP normally at South Molton.

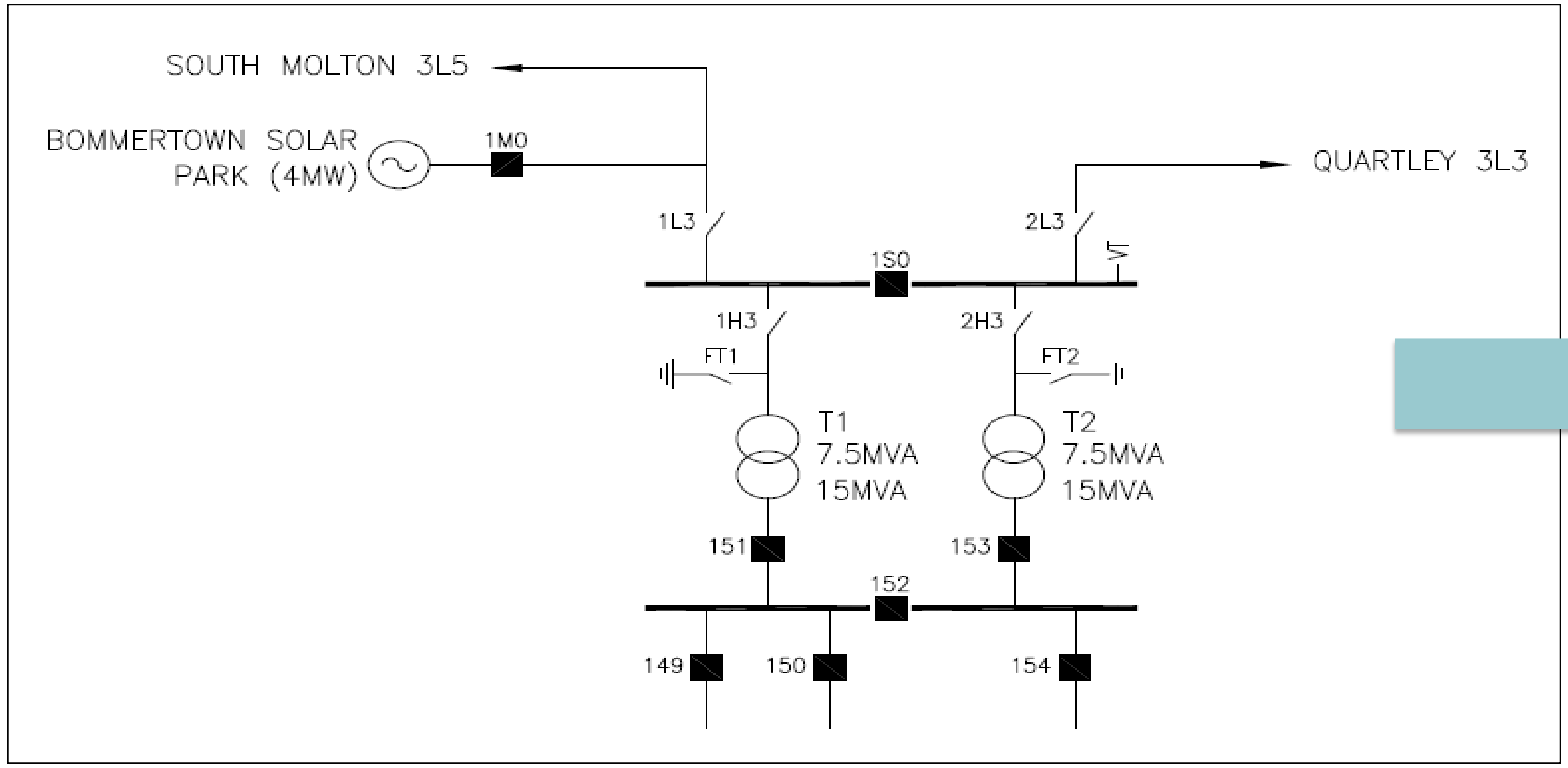
- Move of NOP to Exebridge 33/11kV substation.

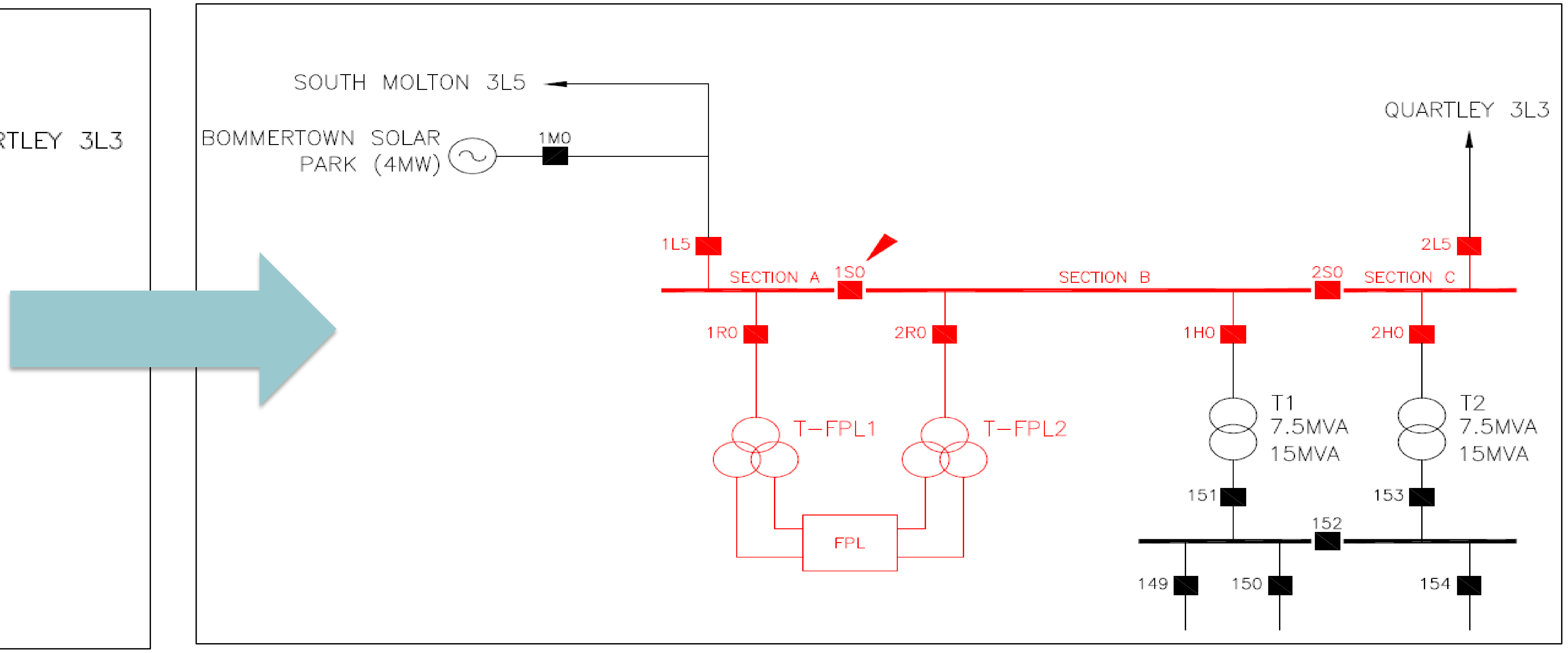


FLEXIBLE POWER LINK (FPL)

FPL Design – Network Integration

- New 33kV switchroom
- New Siemens NXPLUS 33kV switchgear
- NOP now at Exebridge





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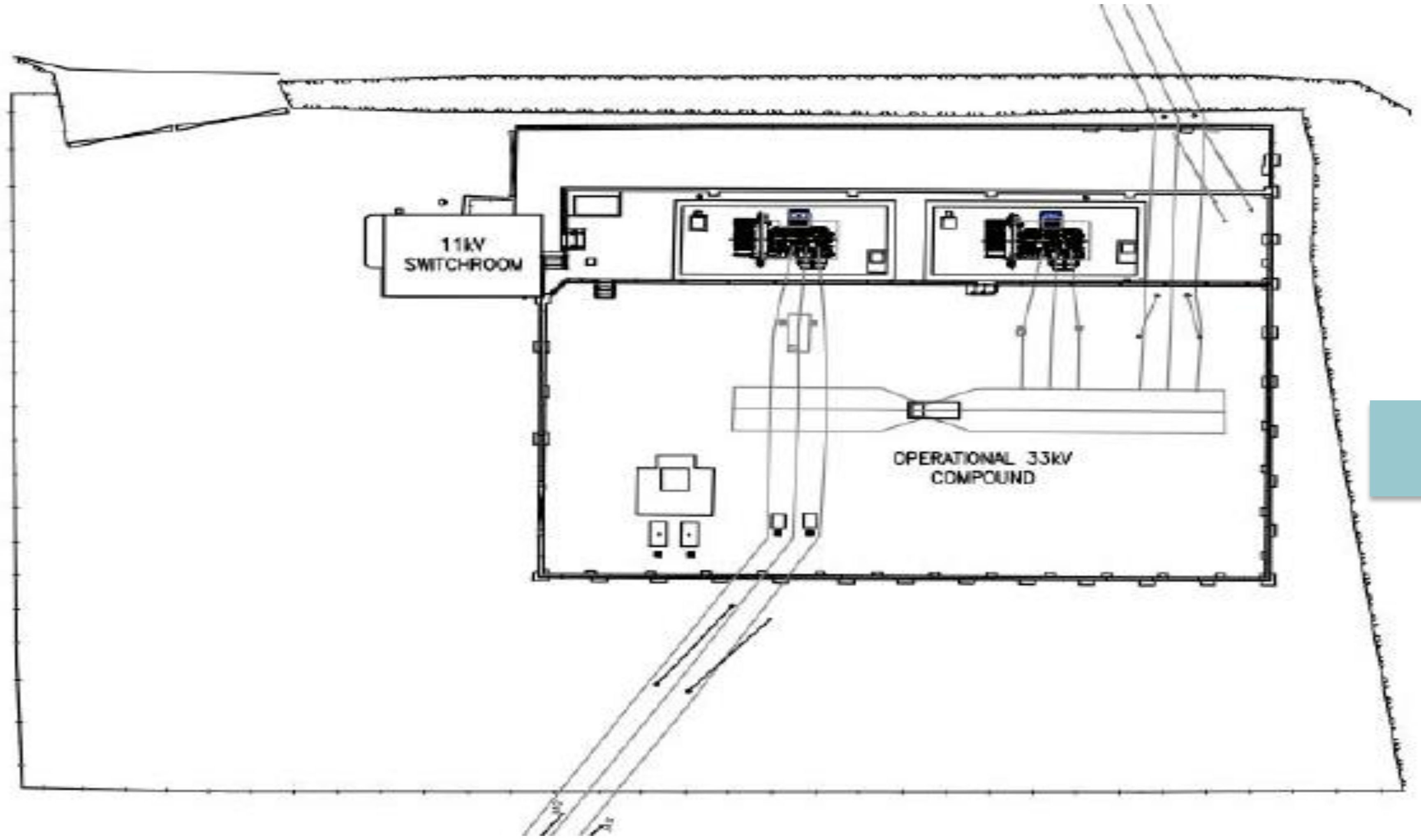
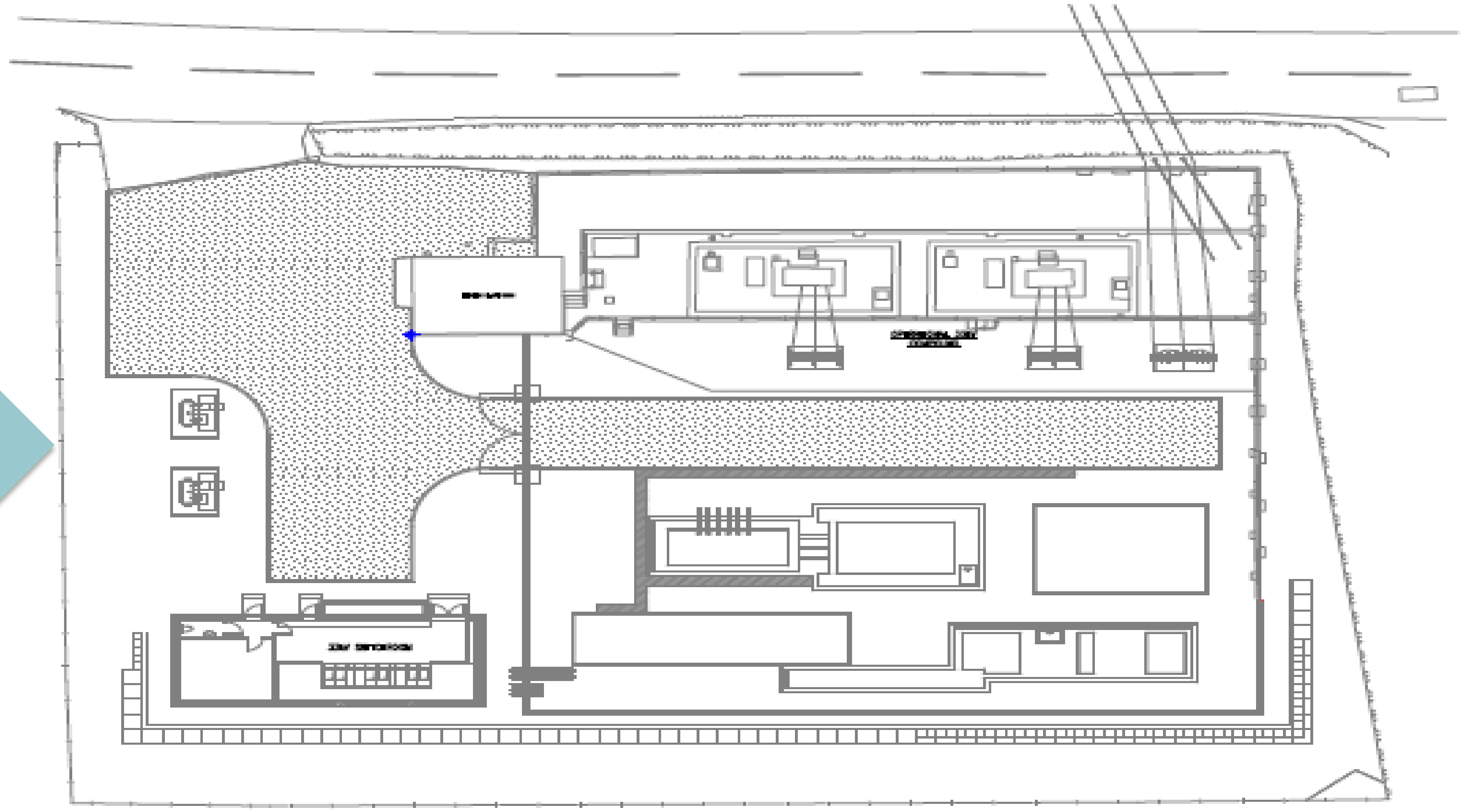
FLEXIBLE POWER LINK (FPL)

FPL Design – Network Integration

Before



After



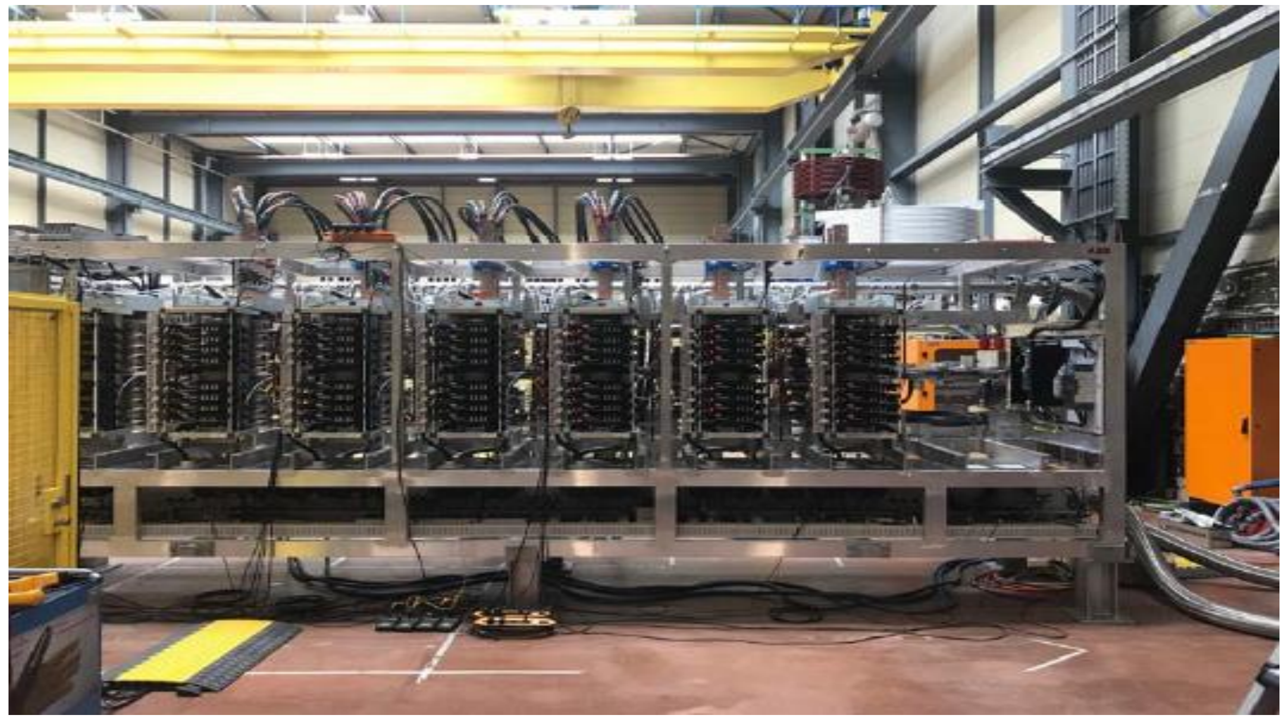
FLEXIBLE POWER LINK (FPL)

FPL FAT

- Test performance of power electronic modules

- Software tests (hardware-in-the-loop)

- Container tests:
  - Insulation tests performed on the 3.25kV AC and 2.5kV DC connections
  - Protection and control tests
  - Cooling system test
  - Pre-charger test
  - Auxiliary power consumption test



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FLEXIBLE POWER LINK (FPL)

FPL Installation

FPL converter container delivery at 15 Nov 2017

FPL transformer delivery at 17 Nov 2017

FLEXIBLE POWER LINK (FPL)

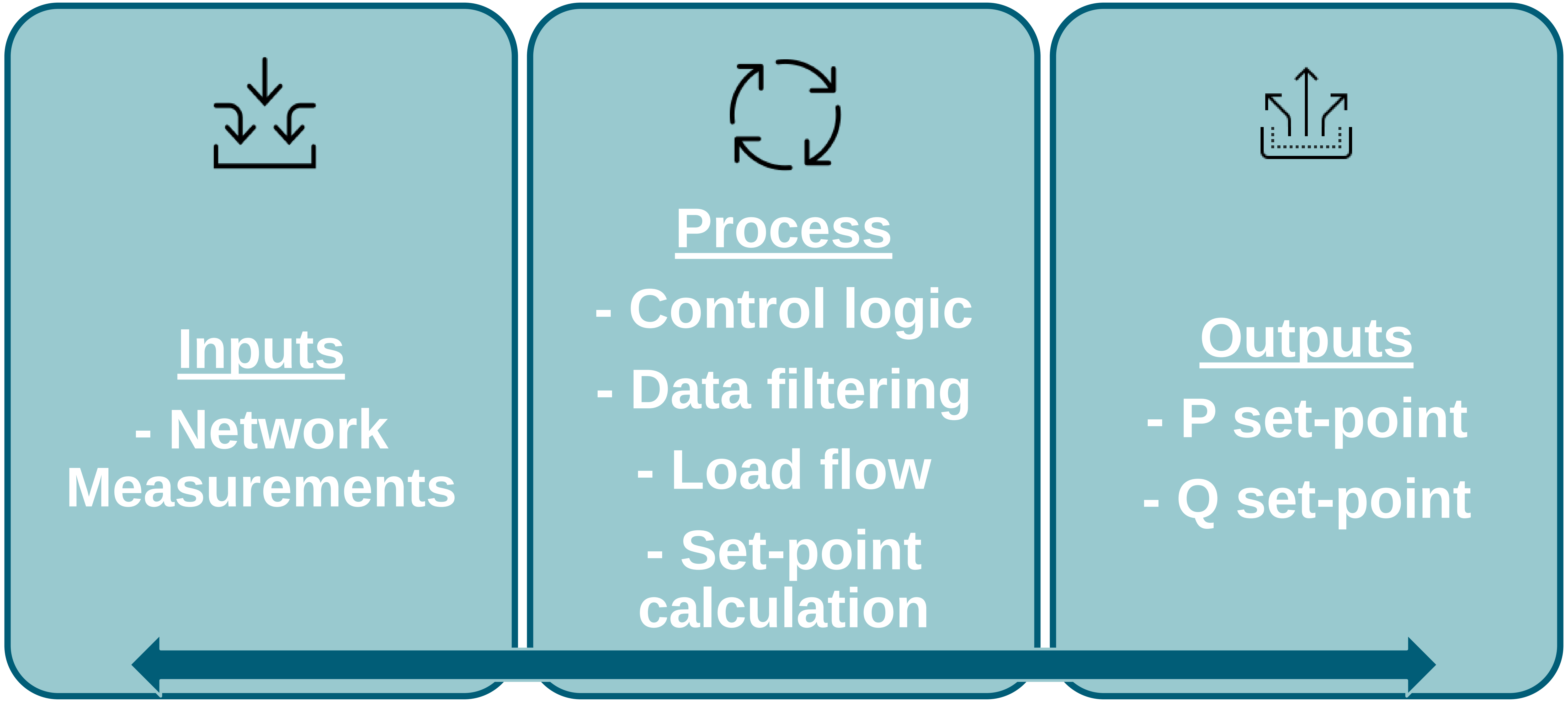
FPL SAT

- Heat run (temperature rise test)
  - Full power operation for 4 hours
- P/Q operating points check
- Noise measurement
  - Sound power was within 80dB limit at 1.5m away from all equipment
- Magnetic field measurement
  - <500μT
- Harmonic measurement
  - Harmonics within ER G5/4 planning levels
- Tests passed and successful open loop control

FLEXIBLE POWER LINK (FPL)

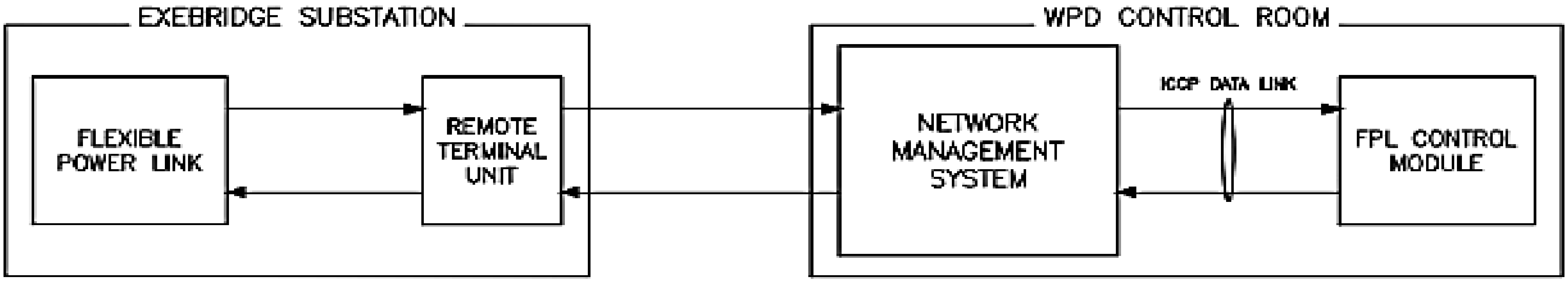
FPL Control Module

Centralised Control System Developed by Nortech



FLEXIBLE POWER LINK (FPL)

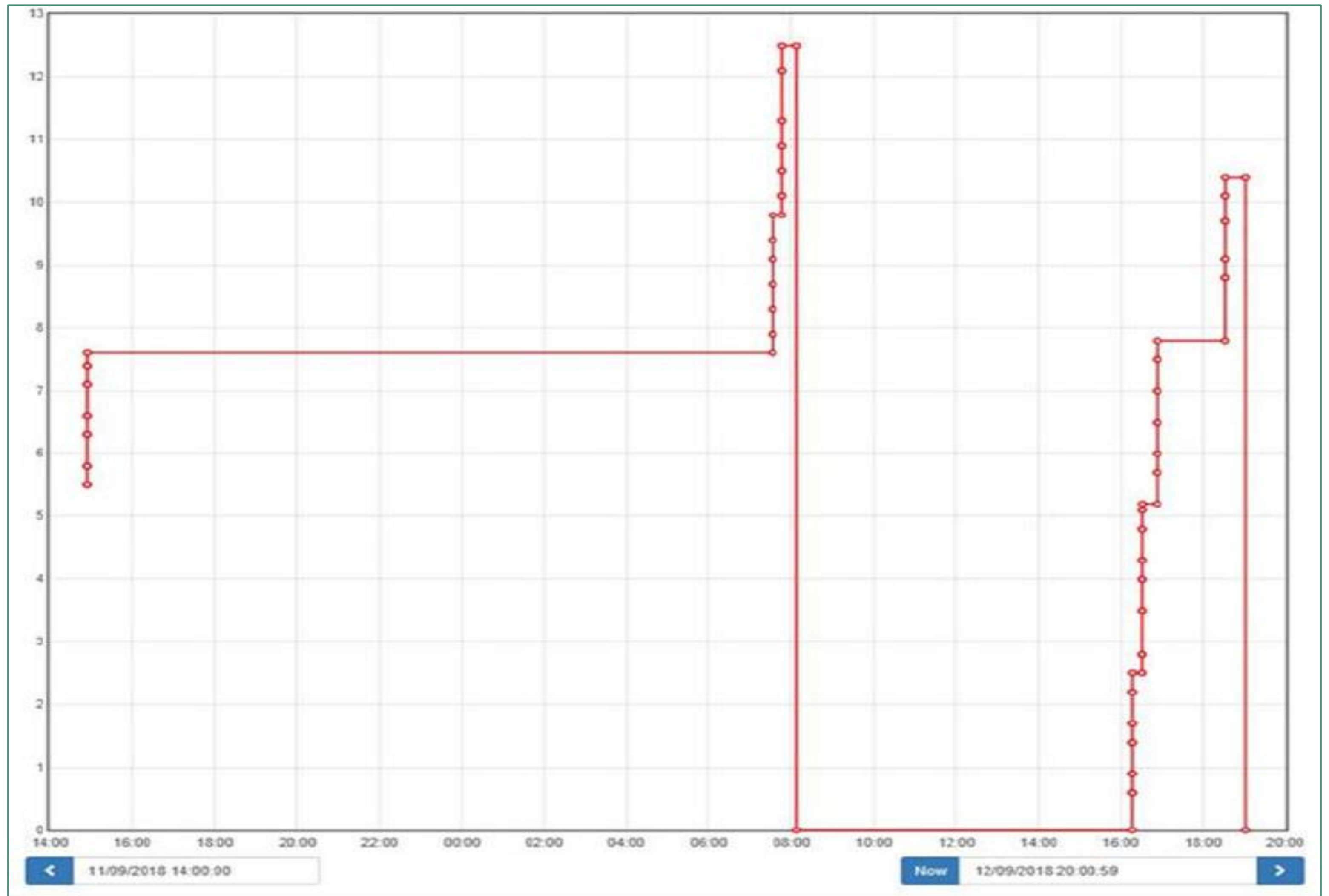
FPL Control Module Architecture

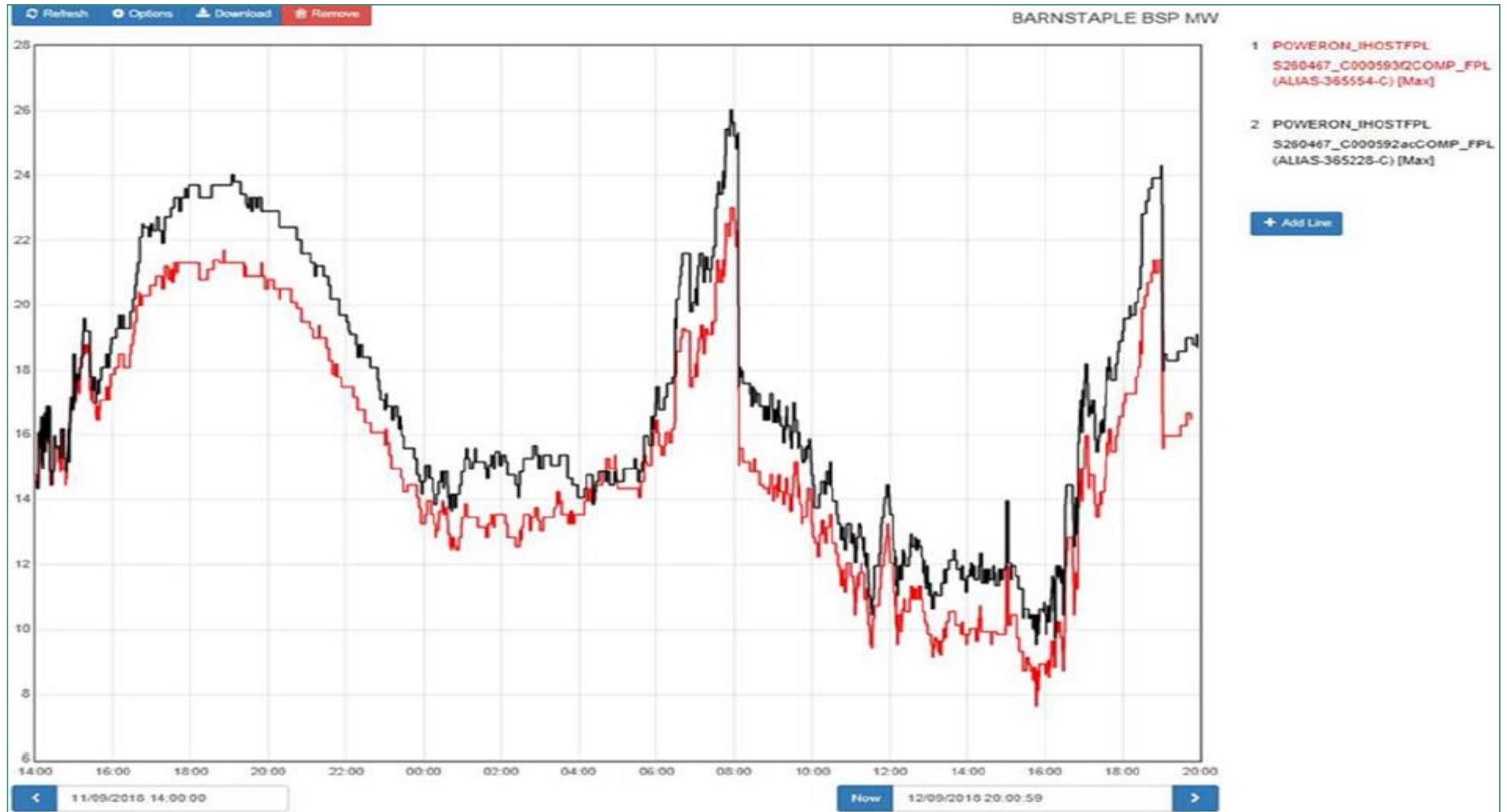


FLEXIBLE POWER LINK (FPL)

FPL Trials

- FPL connected in closed-loop mode since 10 Sept 2018
- Initially run in Operational Mode 1 (P set-point only)
- FPL transfers between 10.5MW and 12.5MW from Barnstaple to Taunton BSPs at morning and evening peak demand





FLEXIBLE POWER LINK (FPL)

FPL Trials

- FPL switched to Operational Mode 4 (P and Q set-point with priority on Q)
- Voltage limits for the FPL were set at ±4%
- FPL was absorbing reactive power on FPL 1 side (Barnstaple BSP) which is generation dominated
- Increase in reactive power coincided with windy and sunny weather

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FLEXIBLE POWER LINK (FPL)

FPL Conclusions

- A 33kV FPL and control system has been successfully developed, installed and trialled on the UK distribution network
- The development of the FPL has provided significant learning on MVDC technology
- The FPL successfully enabled the transfer of power flow between two networks that could not be otherwise interconnected

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Company Directive

STANDARD TECHNIQUE : OC1AC

Operation and Control of ABB 33kV Flexible Power Link installed at Exebridge Primary Substation for use on the Network Equilibrium project

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Company Directive

STANDARD TECHNIQUE : SP2CAD

Inspection and Maintenance of ABB 33kV Flexible Power Link installed at Exebridge Primary Substation for use on the Network Equilibrium project

Policy Summary

This document covers Western Power Distribution's requirements for the inspection and maintenance of the ABB 33kV Flexible Power Link (FPL) as part of the Low Carbon Networks Fund (LCNF) tier-2 Project, Network Equilibrium.

Author: J Berry

Implementation Date: April 2018

Approved by:

Policy Manager

Date: 13 April 2018

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ST:SP2CAD April 2018 - 1 of 28 -

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NETWORK EQUILIBRIUM PROJECT

Summary

- Network Equilibrium aimed to release network capacity for low carbon technologies
- Advanced Planning and intelligent voltage and power flow control
- EVA Study showed that voltage limits could be widened to +/-10% for 33kV and +/-8% for 11kV
- Further studies and industry working groups suggested

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NETWORK EQUILIBRIUM PROJECT

Summary

- SVO successfully implemented voltage optimisation in 33kV and 11kV networks
- Proved there is headroom in the network to dynamically shift voltages up/down
- Provided visibility in detailed network operation – necessary for DSO functions
- SVO will remain operational. Examining roll-out options

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NETWORK EQUILIBRIUM PROJECT

Summary

- FPL enabled intelligent power flow control in 33kV networks
- Provided knowledge and skills on using MVDC technologies in UK distribution networks
- Centralised control system necessary for coordinated network control
- Back-to-back converters can be used to interconnect 33kV distribution networks

WESTERN POWER DISTRIBUTION INNOVATION TEAM

THANK YOU FOR LISTENING

ANY QUESTIONS?

YIANGO MAVROCOSTANTI
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ymavrocostanti@westernpower.co.uk

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WESTERN POWER DISTRIBUTION INNOVATION TEAM

PNPQA

PRIMARY NETWORKS POWER QUALITY ANALYSIS

BALANCING ACT CONFERENCE

20th JUNE 2019

STEVEN PINKERTON-CLARK
WPD - INNOVATION & LOW CARBON NETWORKS ENGINEER

WESTERN POWER DISTRIBUTION
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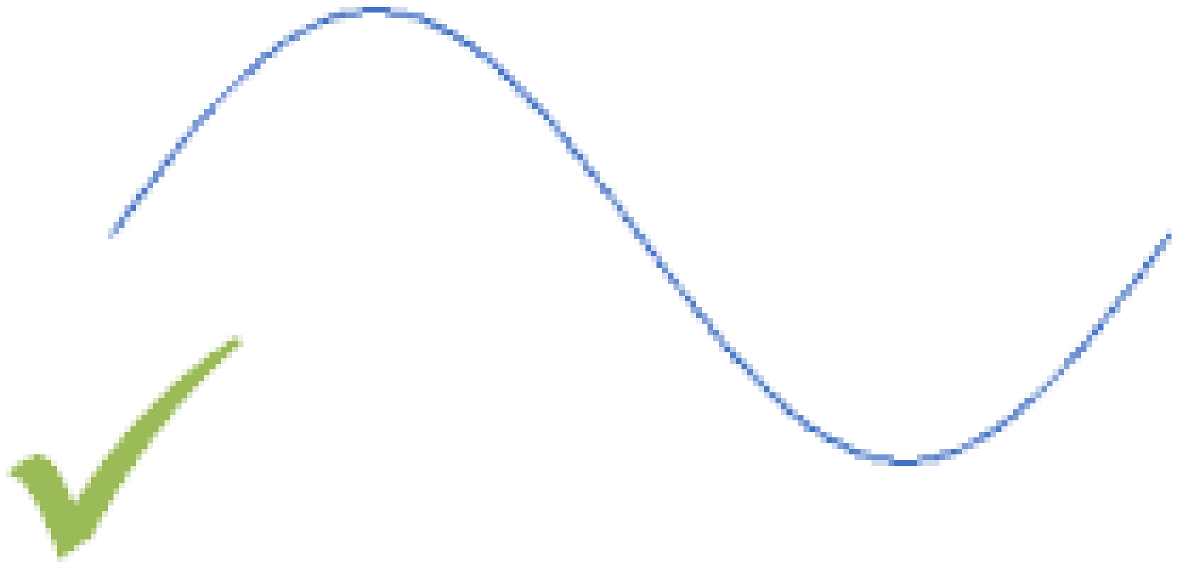
PROJECT OVERVIEW

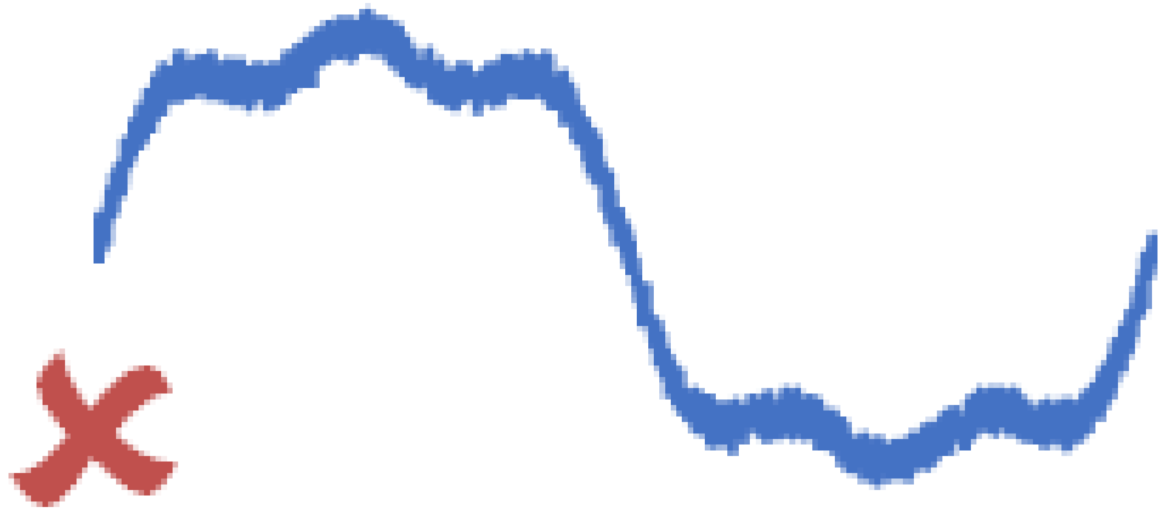
- WPD Network Innovation Allowance (NIA) Project.
- March 2018 – March 2021.
- £1.4m budget.
- Nortech are delivery and technology partner.

PROJECT OVERVIEW

What is Power Quality?

Distribution network operators (DNOs) must supply voltage waveform with minimum distortion.





Deviations are caused by system events and device current injections.
Poor power quality can cause equipment mal-operation and damage.

PROJECT OVERVIEW

Aims & Objectives

- Investigating transducers (Voltage Transformers VT’s etc.) to confirm that harmonics are being passed through to power quality monitors without introducing further harmonics or eliminating them.

- Selecting two areas of WPD’s network (Bulk Supply Points through to the LV side of Primary substations) for comparative assessments of harmonics and power quality. One area will be selected as a ‘control’ case with a low penetration of LCTs, whereas the other area will have a high penetration of LCTs.

PROJECT OVERVIEW

Aims & Objectives

- Installing communicating power quality monitors within the two areas to generate data for comparison with the models. Also, comparing co-located power quality monitors with each other for consistency of results.

- Generating power quality heat maps and decision support tools, including the modelling of future impacts of LCTs.

- Quantifying the harmonic content contribution of different types of power electronic devices and creating a series of templates for use in future analysis.

- Automating data retrieval and analysis tasks, which are currently manual and time-intensive, to allow valuable engineer resource to be used more effectively.

PROJECT OVERVIEW

Success Criteria

- Impact of LCTs on power quality and harmonics within primary networks better understood.
- Power quality monitors installed at trial locations and remote retrieval of data successfully demonstrated.
- Tools for automating power quality data retrieval and analysis demonstrated.
- Policies created to implement project outputs in WPD’s business.

PROJECT PLAN

This project is split into 3 main phases.

PROJECT PLAN

Design

Aquire VT’s (Voltage Transformers) which are representative to WPD assets currently in situ.

Work with the University of Manchester to test VT’s to determine their accuracy so we can better understand the effect on power quality monitors.

Produce a report on the findings of the testing and use this learning for more accurate power quality data monitoring.

PROJECT PLAN

Build

- Select and procure Power Quality monitors.
- A-eberle, Qube3 and Siemens.

- Develop the interface for each monitor and install onto WPD’s network
- Develop PQ analysis automation
- Modelling data gathering
  - Build power systems models
  - Build LCT models

PROJECT PLAN

Trial

- Main monitoring period – from November 2019 → November 2020.

- PQ Analysis Automation
  - Develop dashboards
  - Develop heat maps
  - Develop network assessment tools.

- Data Analysis
  - Develop LCT analysis templates.

TECHNICAL DETAIL

nortech

JAMES KING – PROJECT MANAGER

NORTECH MANAGEMENT LIMITED

VT TESTING – VTS FOR PQ MONITORING

Current Practice

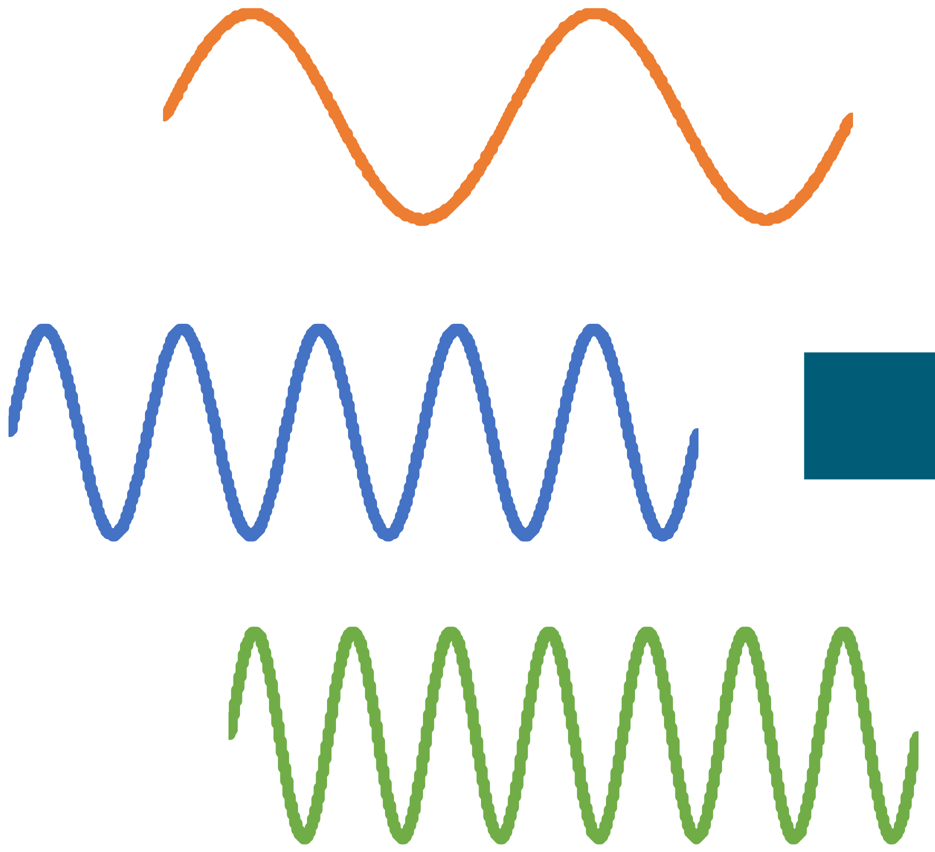
- PQ monitoring uses existing voltage transformers (VTs)
- No explicit specification for PQ performance
- No explicit testing for PQ performance

Question

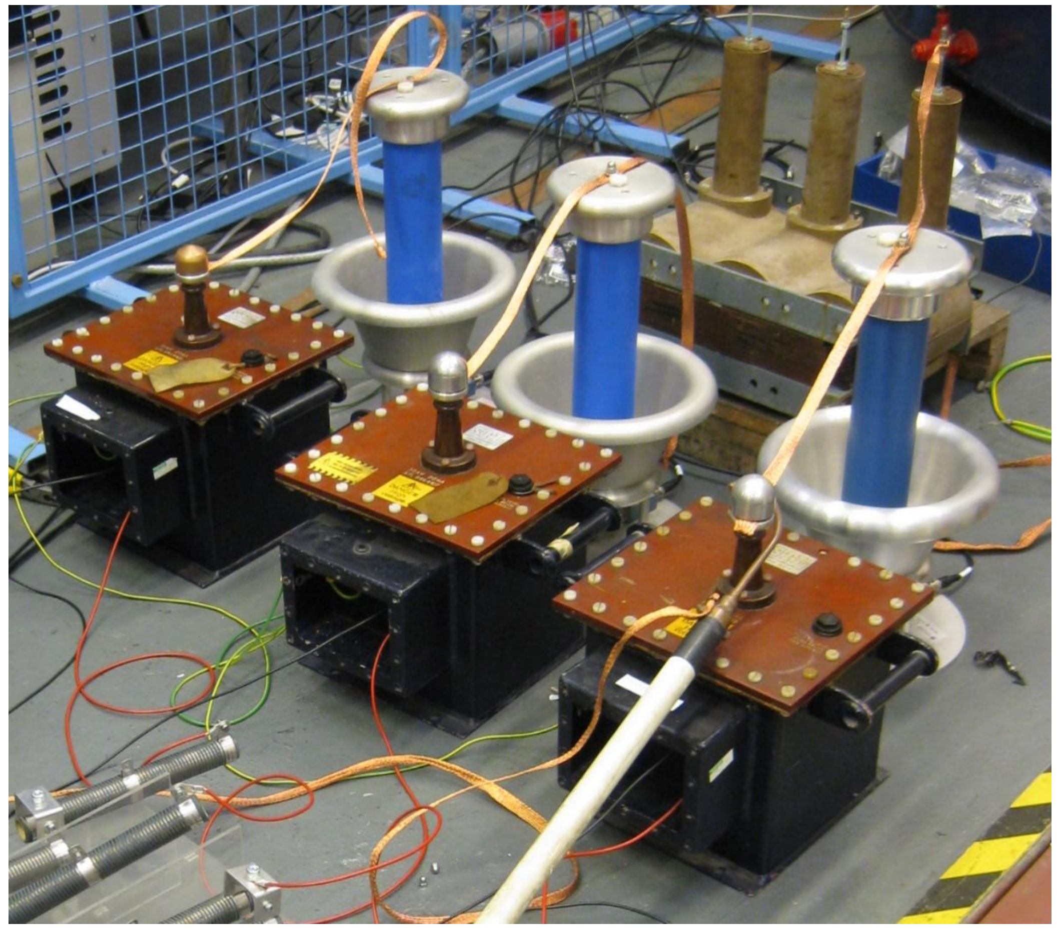
- Are existing VTs adequate for PQ monitoring?

VT TESTING – TESTING CIRCUIT

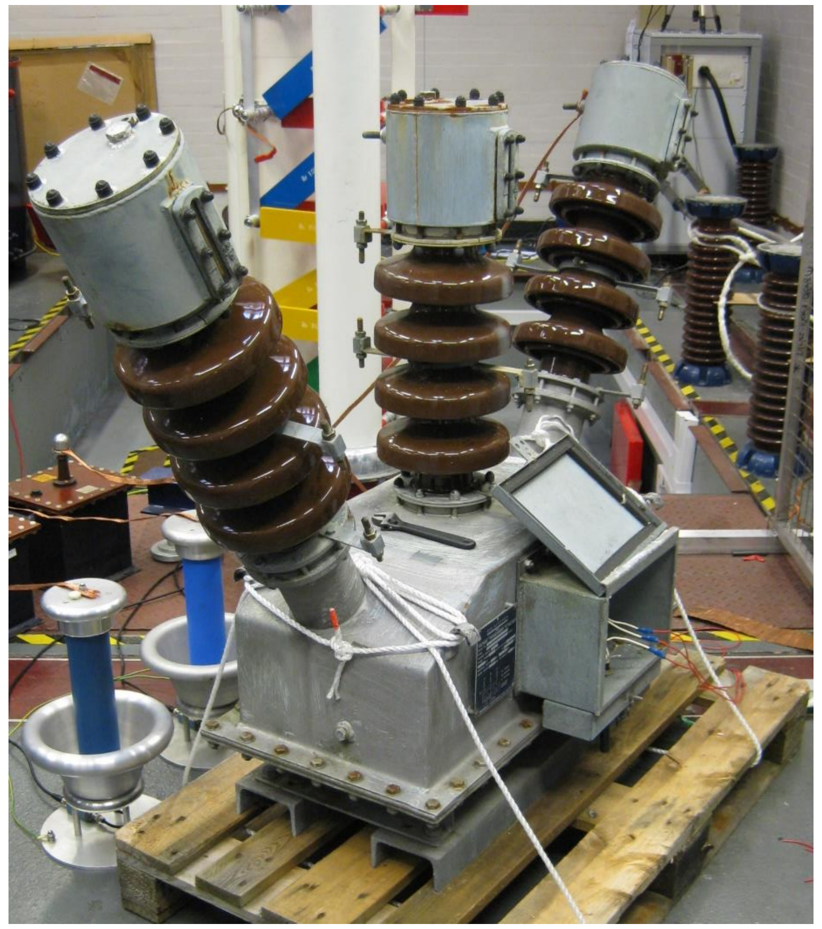
Test harmonic waveforms generated



Step-up transformers & HV voltage dividers



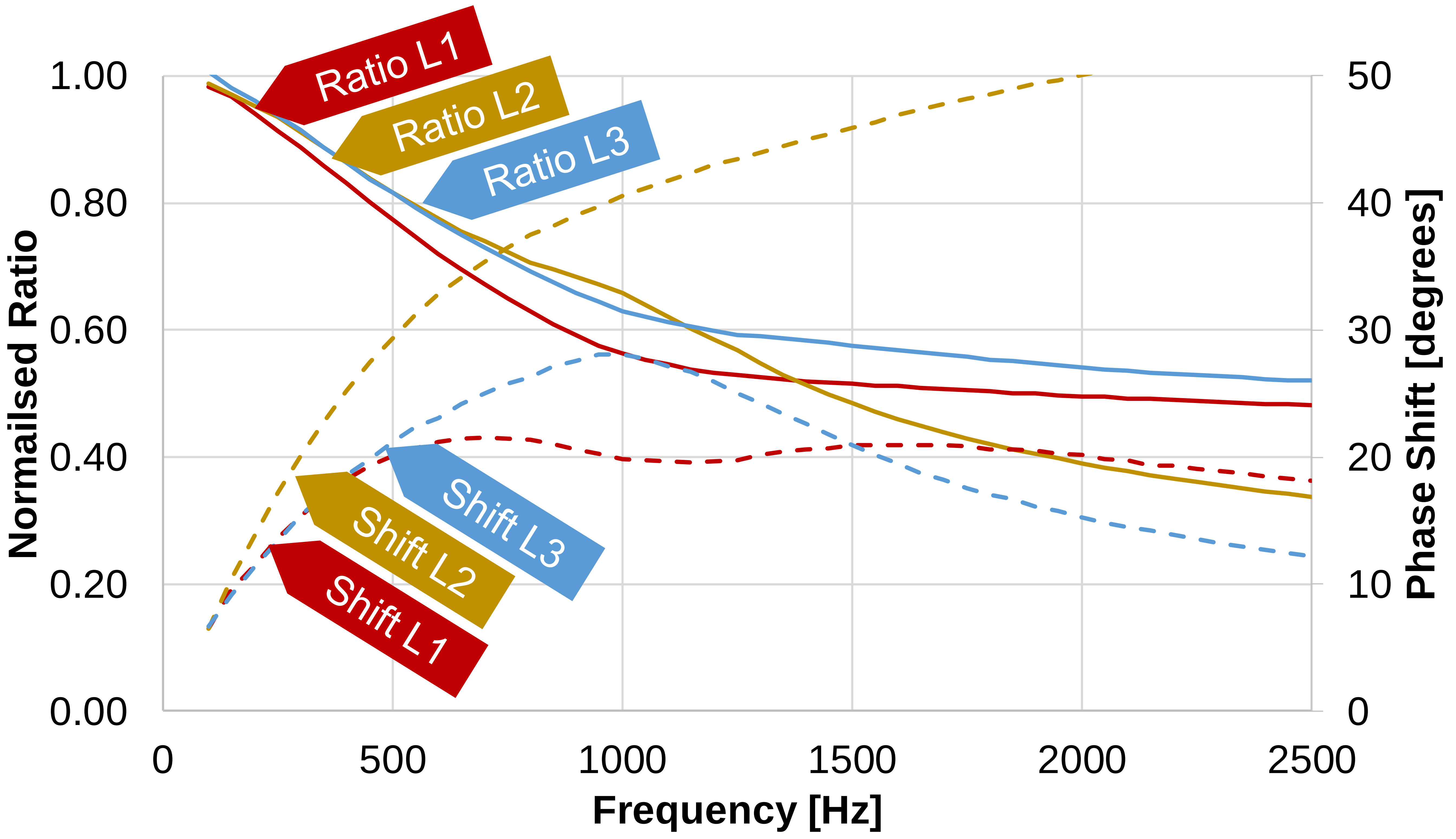
VT under test

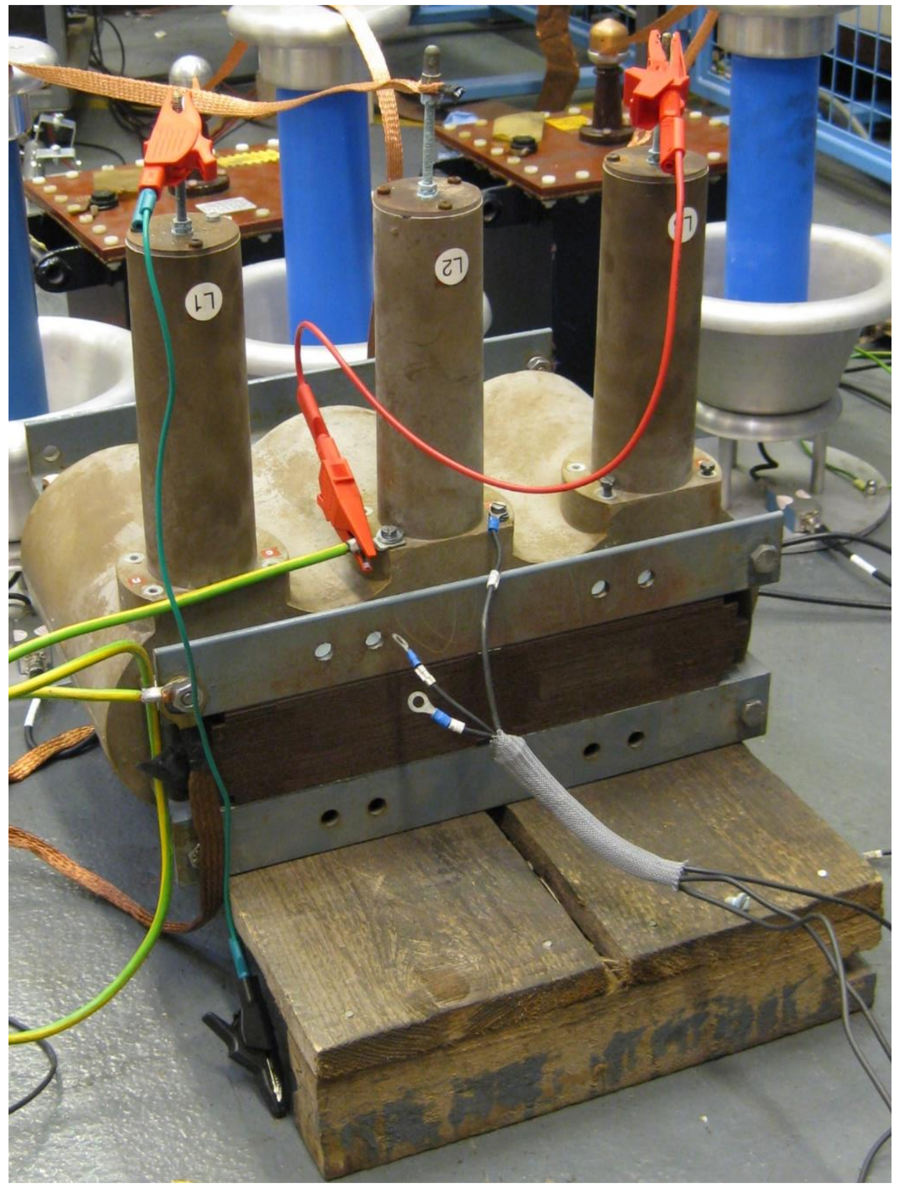


Primary voltage measurement

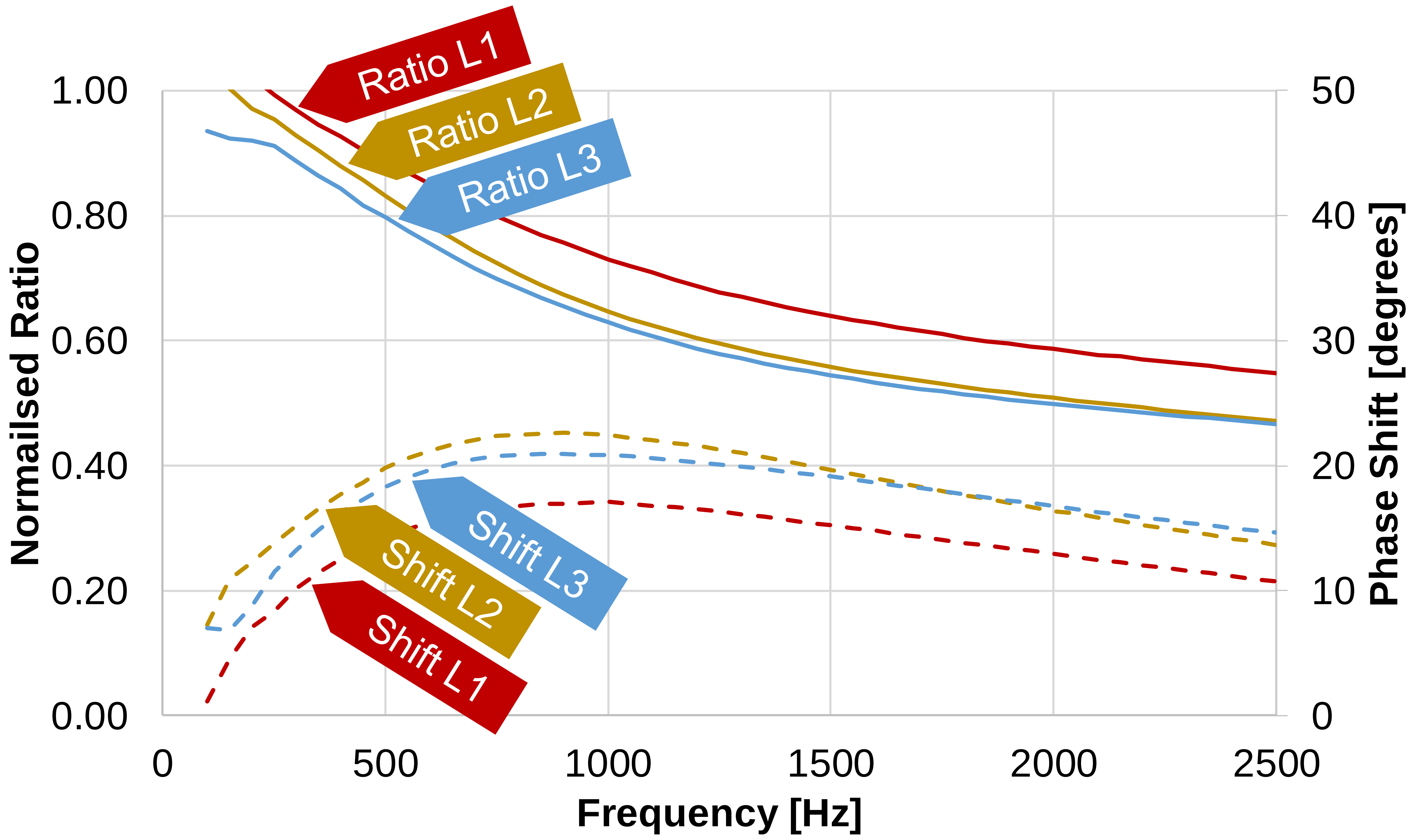
Secondary voltage measurement

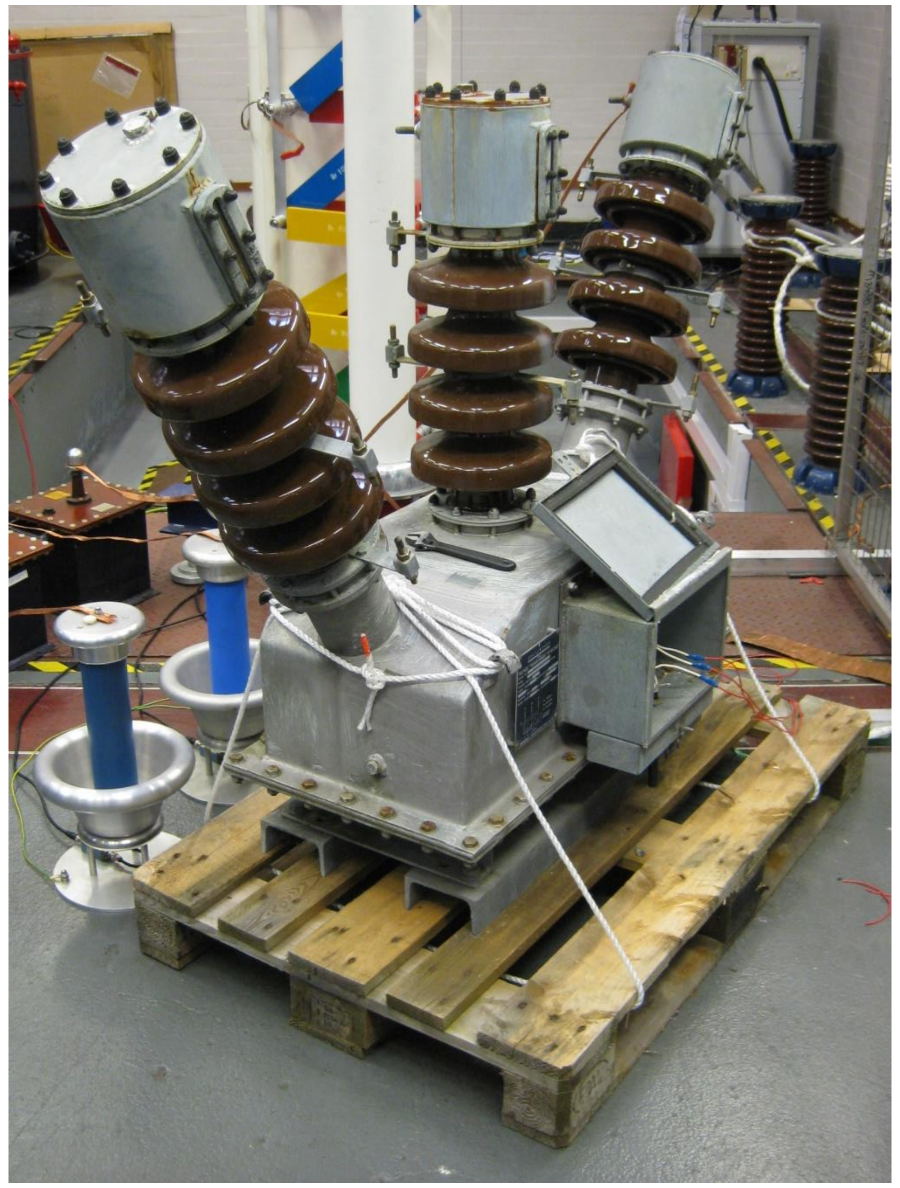
VT TESTING – 3-PHASE 11 kV VT



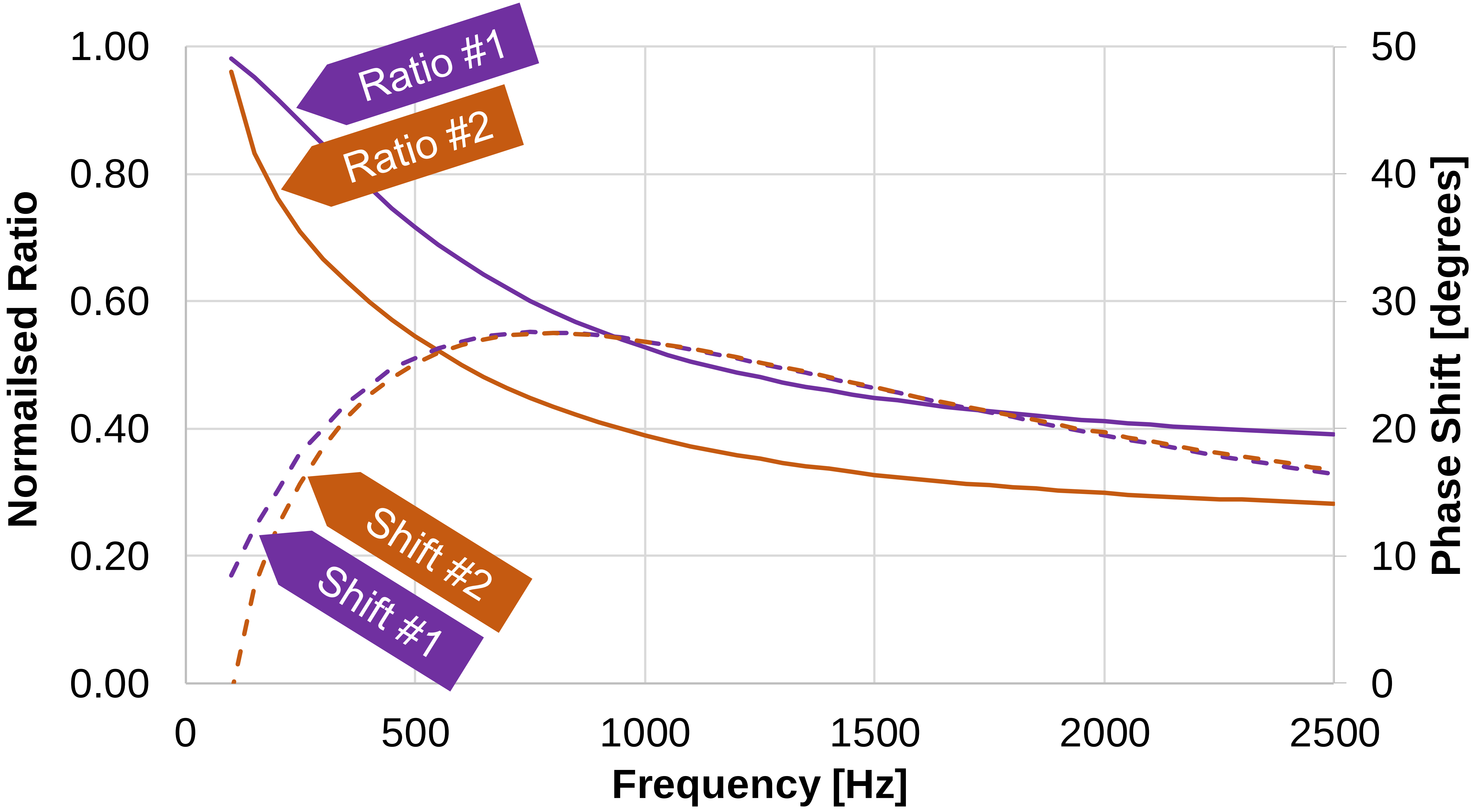


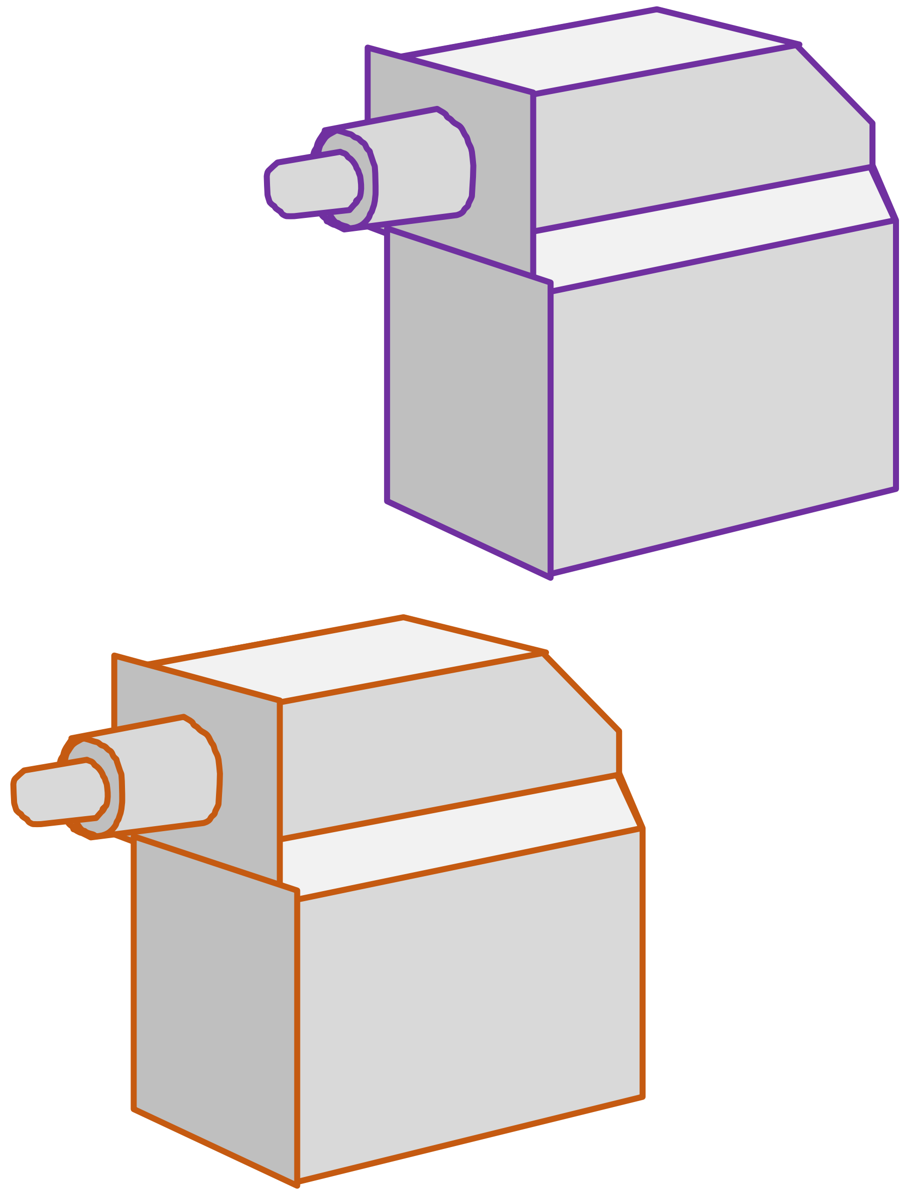
VT TESTING – 3-PHASE 33 kV VT





VT TESTING – 1-PHASE 33 kV VTS





VT TESTING – CONCLUSIONS

Lessons Learned

- The VTs tested increasing attenuate higher frequency harmonics.
- The VTs tested do not introduce additional/spurious harmonics.
- Many more types of VTs on the system, with potentially difference responses.

Next Steps

- Use of correction factors.
- In-situ characterisation of VT performance to test other VTs.

PQ MONITORING PILOT TRIAL

- Gain some early learning before the main trial of communicating PQ monitors.
- PQ monitor and communications unit installed at Meaford C BSP.
- Monitoring over 6 weeks in mid-2018.

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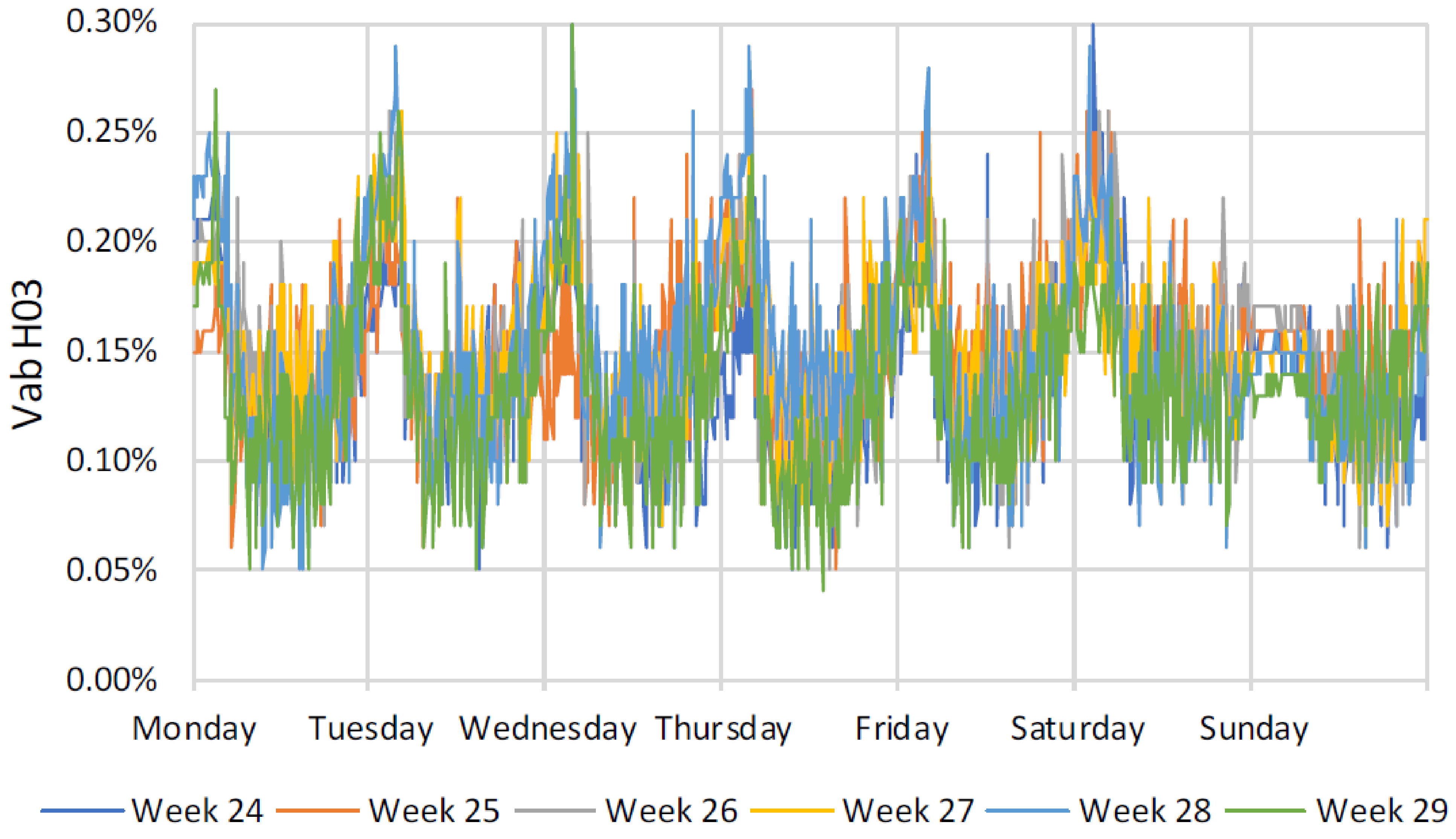
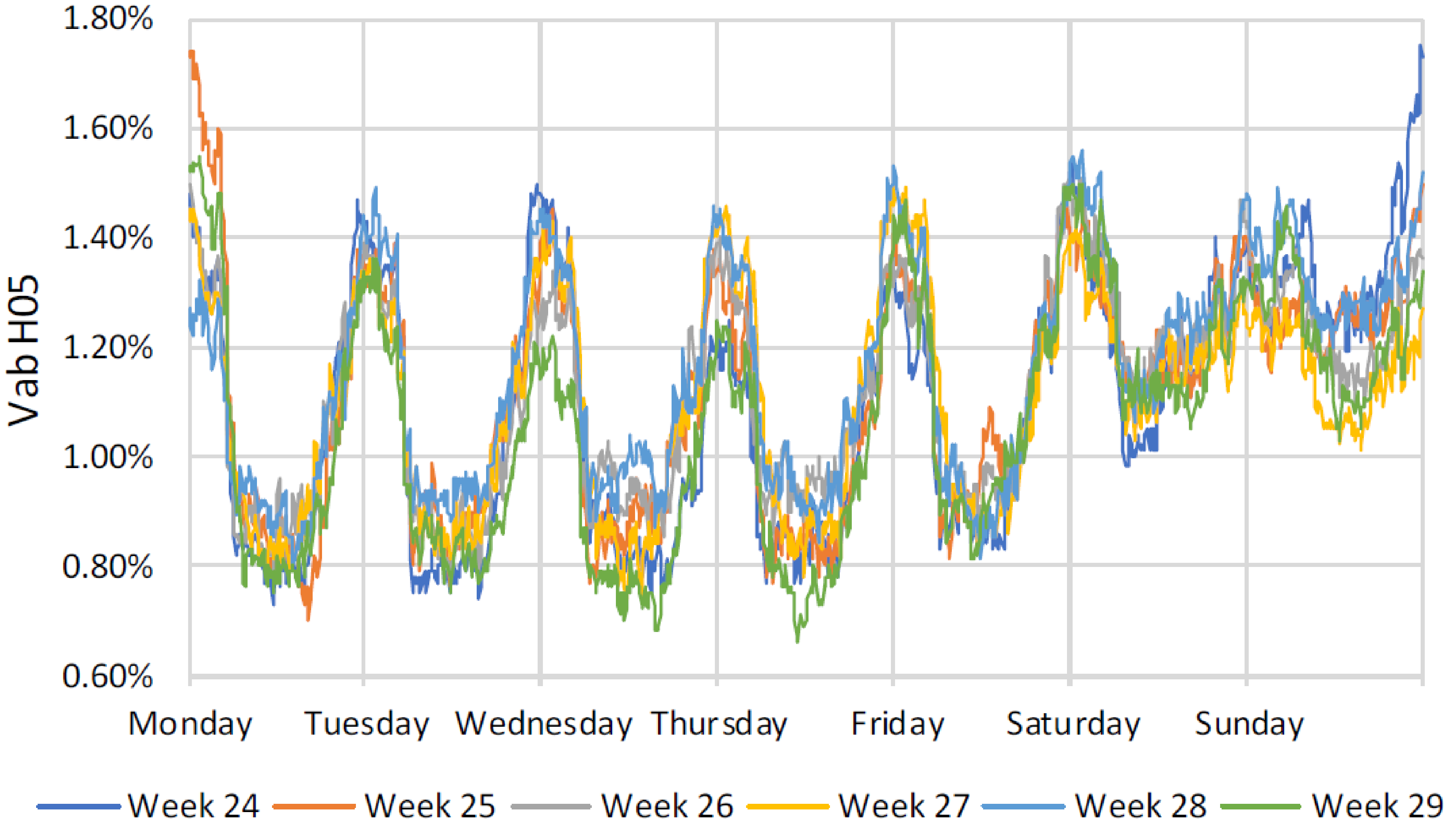
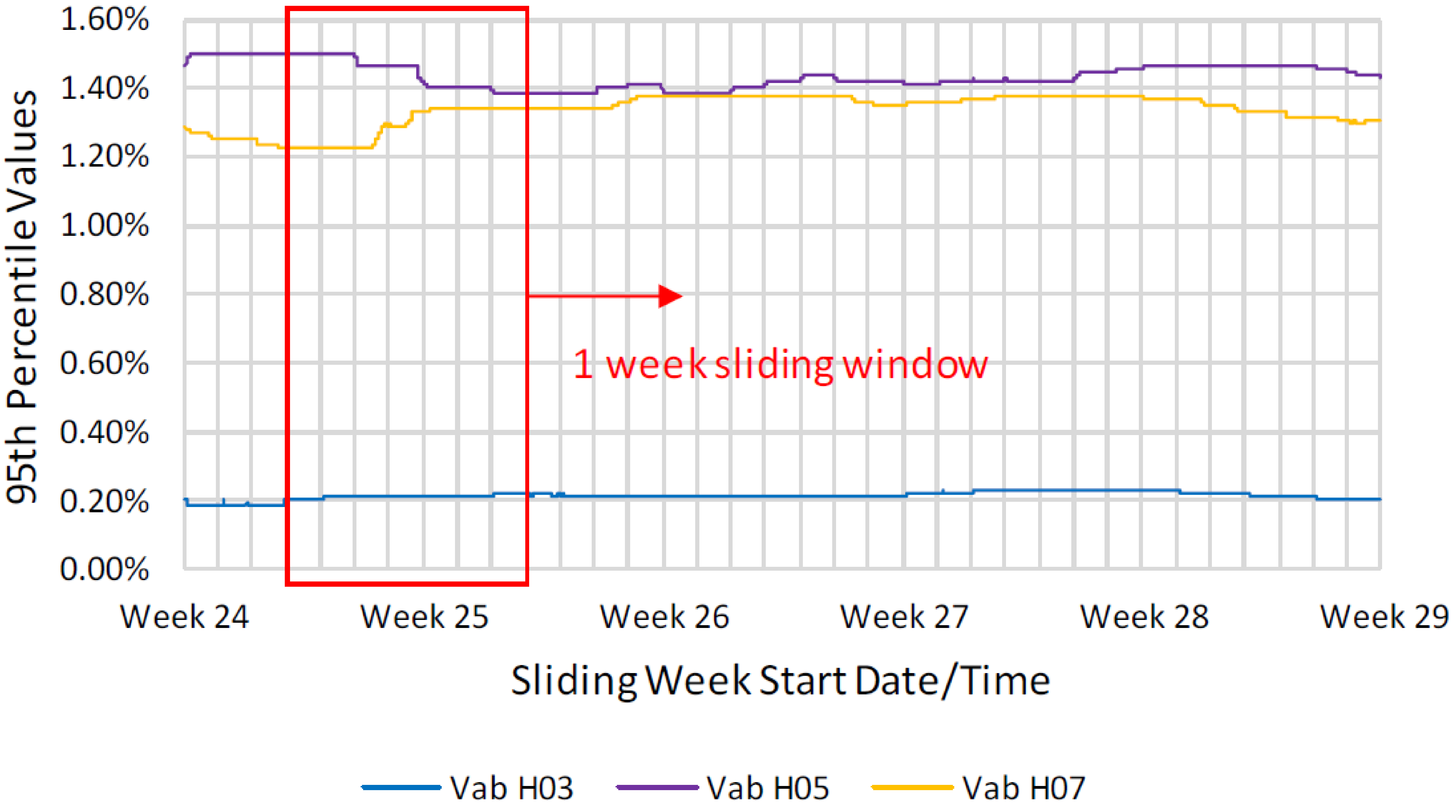
PQ MONITORING PILOT TRIAL – TEMPORAL EFFECTS

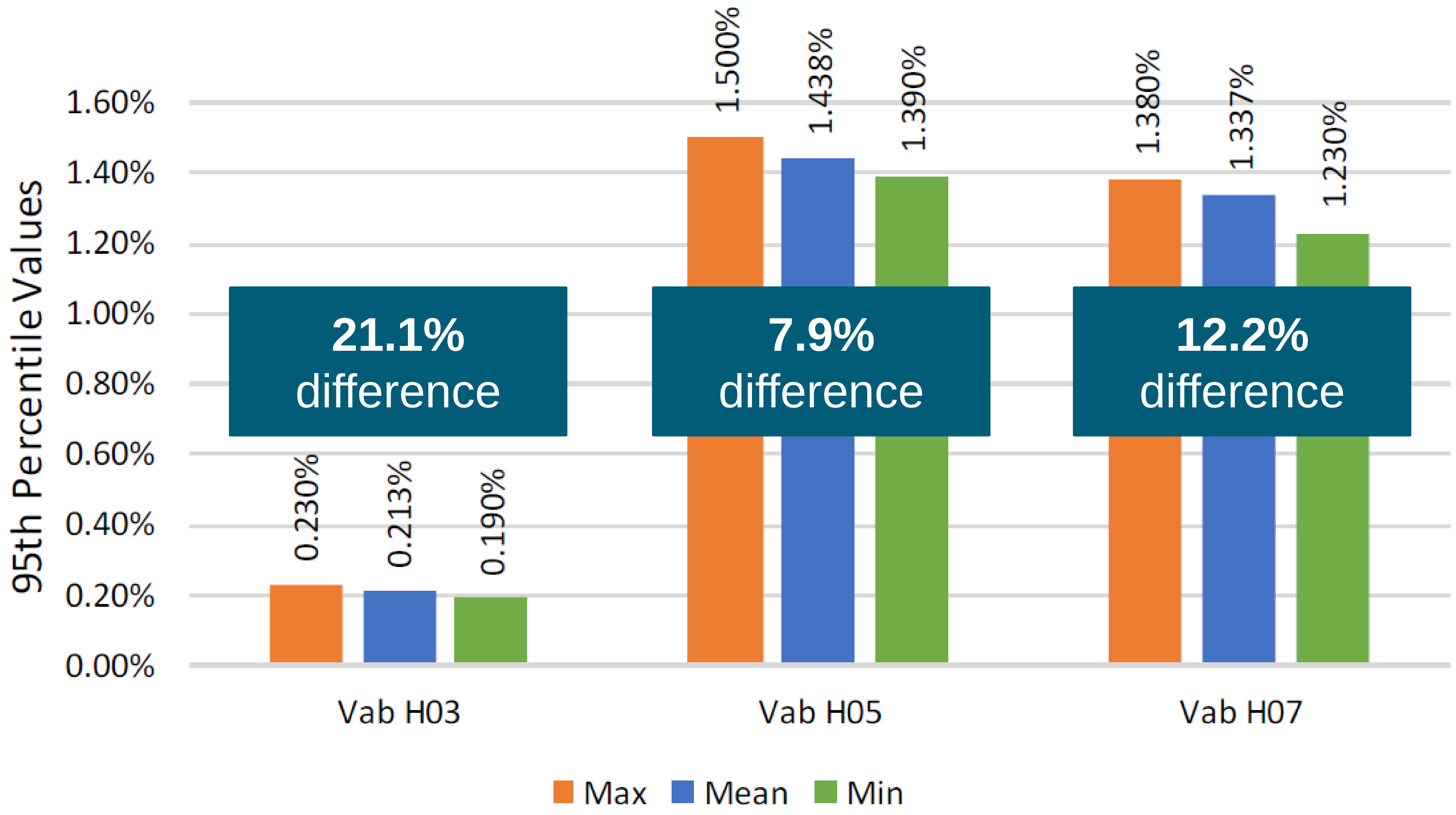




PQ MONITORING PILOT TRIAL – TEMPORAL EFFECTS



PQ MONITORING PILOT TRIAL – TEMPORAL EFFECTS



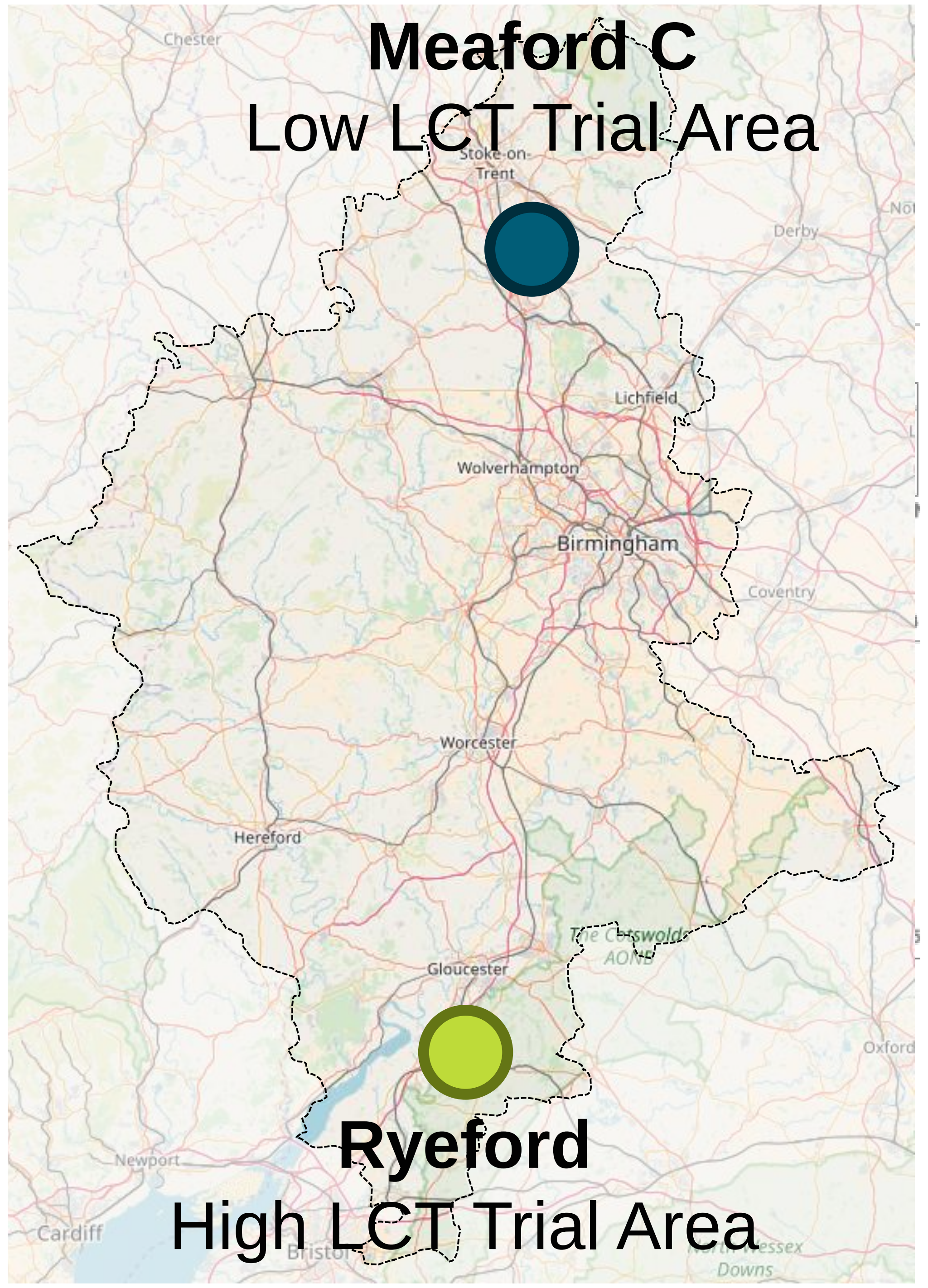
PQ MONITORING PILOT TRIAL – CONCLUSIONS

Lessons Learned

- The monitoring period/window can affect the overall PQ results.

Next Steps

- Large scale trial of communicating PQ monitors across two 33 kV network areas for a year.
- Investigate temporal and spatial effects.
- Investigate effects of different LCTs.



THANK YOU FOR LISTENING

ANY QUESTIONS?

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WESTERN POWER DISTRIBUTION INNOVATION TEAM

REFRESHMENTS BREAK

RESUME AT 11.50

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WESTERN POWER DISTRIBUTION INNOVATION TEAM

PANEL SESSION

ROGER HEY - WPD (CHAIR)

ADRIAN TIMBUS - ABB

GRAHAM AULT - SMARTER GRID SOLUTIONS

LAURENCE CARPANINI - IBM

NIGEL TURVEY - WPD

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WESTERN POWER DISTRIBUTION INNOVATION TEAM

LUNCH BREAK

RESUME AT 13.30

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WESTERN POWER DISTRIBUTION INNOVATION TEAM

EDGE - FCLi

BALANCING ACT CONFERENCE

20TH JUNE 2019

FAITHFUL CHANDA
WPD - INNOVATION & LOW CARBON NETWORKS ENGINEER

URI GARBI
GRIDON - VP R&D

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AGENDA

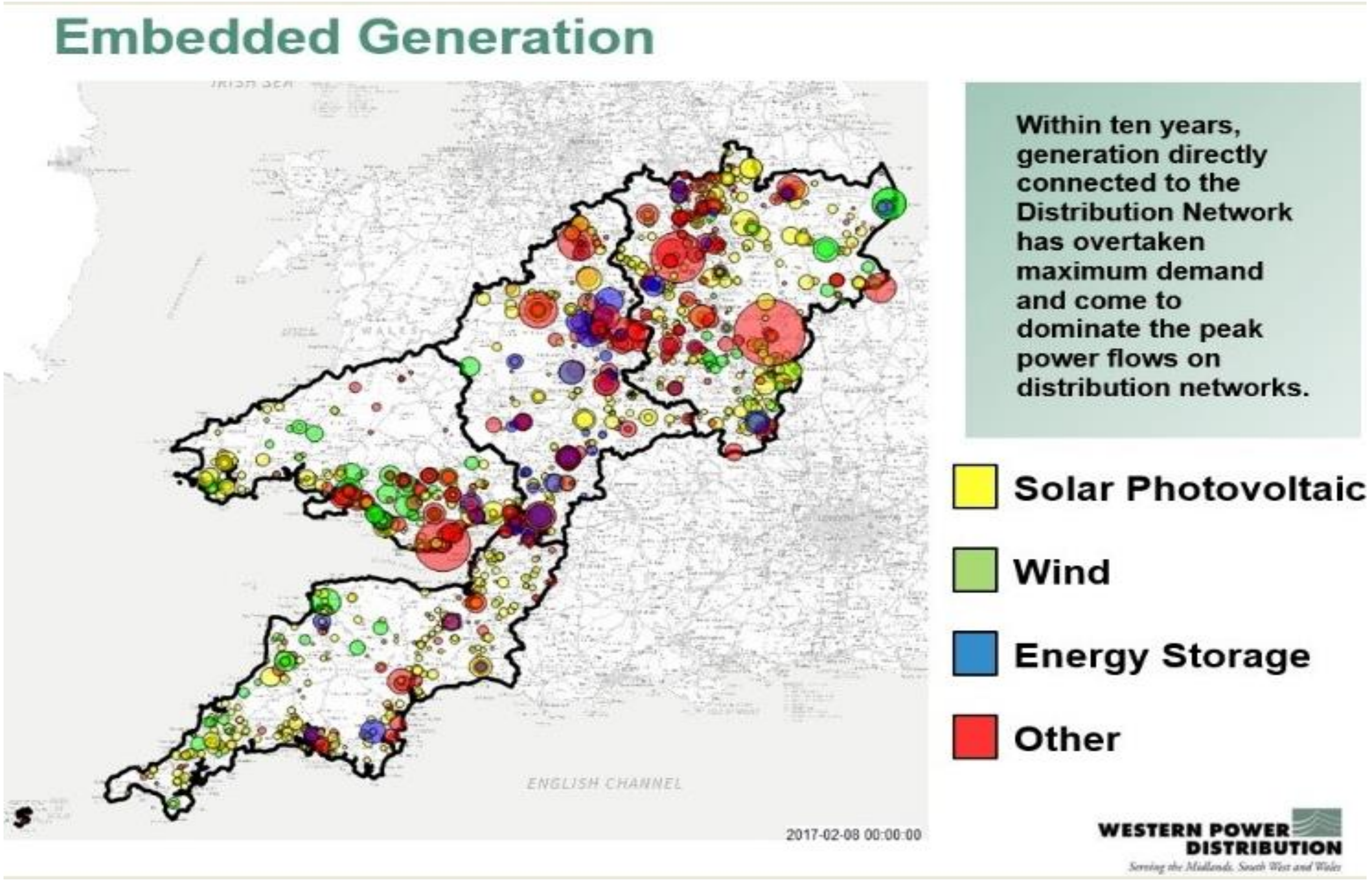
- Overview of the project
- Aims and objectives
- Network changes
- Work packages
- What is the FCLi
- Next steps

PROJECT OVERVIEW

- NIA funded project £2,110,590
- Project partners: GridON, RINA and the University of Warwick (UoW)
- 29th September 2018 start, 2 years and 3 months
- Finish November 2020

WHAT HAS CHANGED?

- Increasing penetration of embedded generation
- More network interconnectivity
- Rising distribution network fault levels
- Close to the rated capability of existing equipment
- Connection requests by generators are often rejected by DNOs due to lack of fault current headroom in their networks



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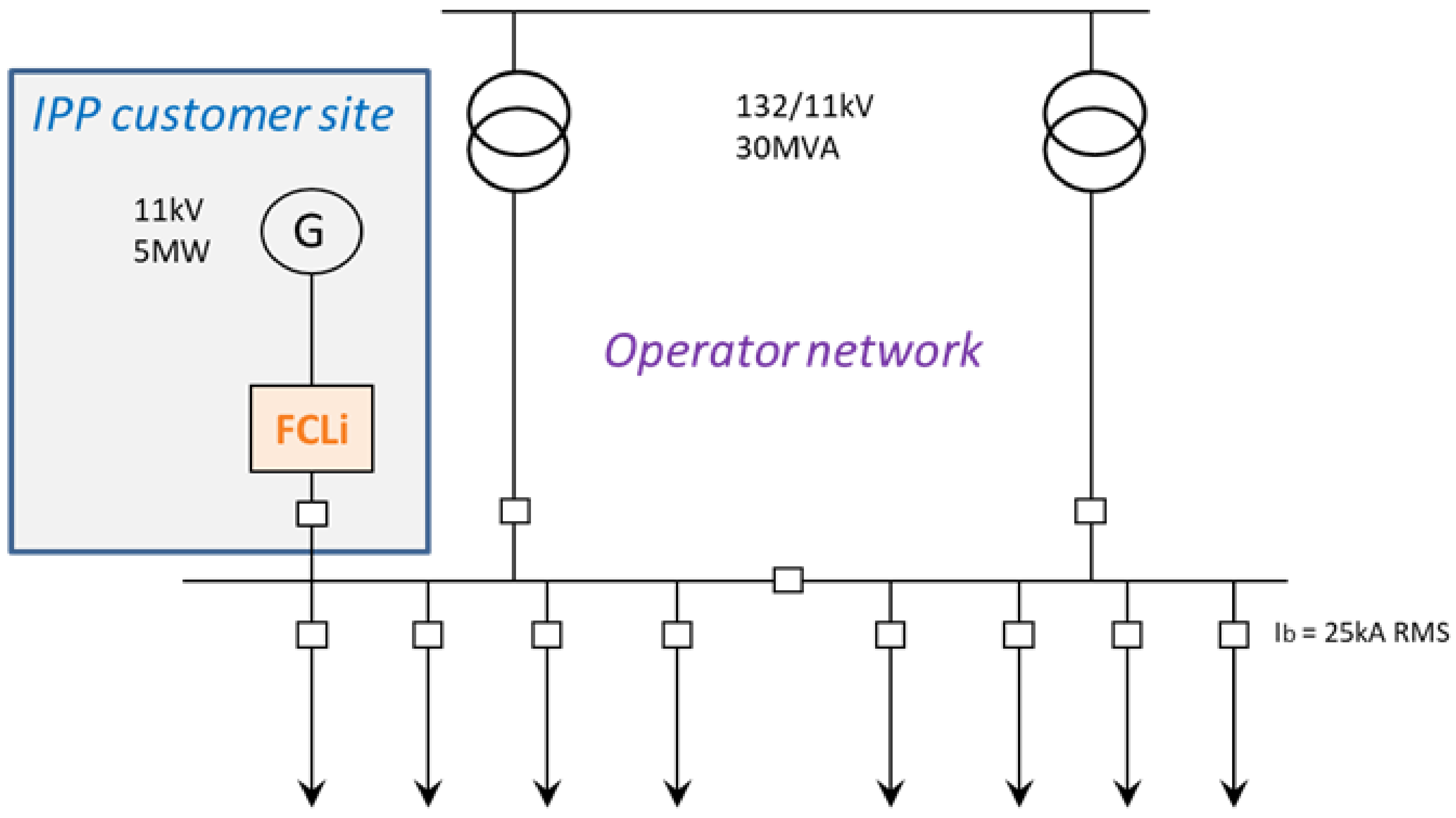
AIMS AND OBJECTIVES OF THE PROJECT

- To successfully design, manufacture, install, integrate into the network and energise the FCLi
- To choose generator(s) and network(s) that can provide instances for which the FCLi response can be assessed
- To scale-up GridON's FCLi technology from prototype level to a commercial scale device
- Targeted for cost effective connection of distributed generation
- Demonstrate its operation in a live network
- The 3-phase FCLi will be designed for 11kV, 330A.



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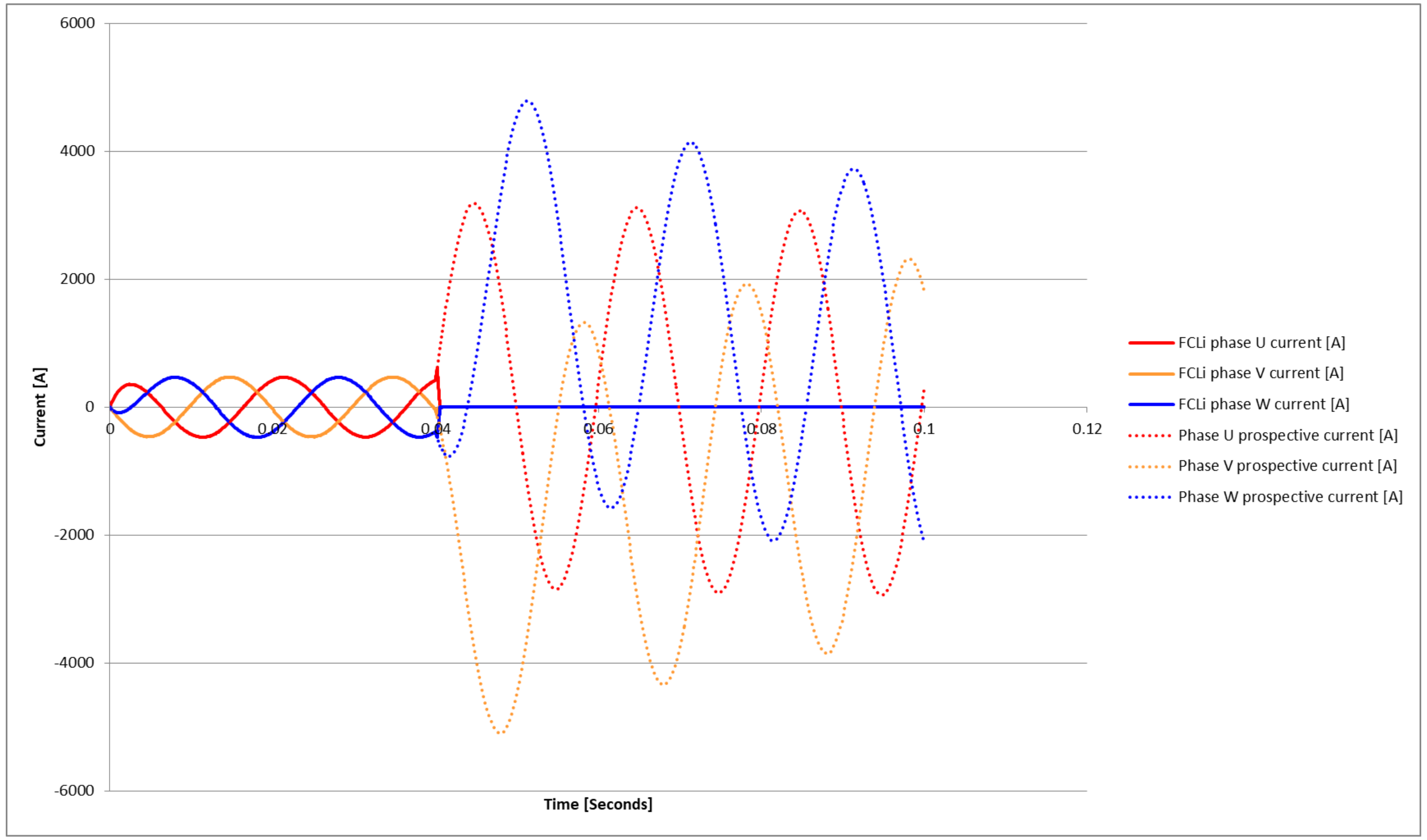
WHAT IS HAPPENING ON THE NETWORK?

- Short circuits in electrical grid are inevitable and they result in excessive currents called “Fault Currents”
- Increasing power generation and grid interconnection leads to higher fault currents which cascade across the grid, and often exceed protection ratings of aging network switchgear
- Excessive fault levels are seen as a barrier to the connection of distributed generators
- Traditional solutions such as grid reinforcement are expensive and time consuming



Active fault current limiting technologies are the way forward

FCLi OPERATION

- During fault conditions on the network, limit the fault current from the generator, and reduce the current to near zero before the first peak.

- During normal operation, the FCLi should introduce minimal disturbance to the network operation.

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WORK PACKAGES

- Device specifications
- Preliminary FCLi design and review
- Detailed FCLi design and review
- Site design, review and preparation
- FCLi manufacturing and testing
- Installation, commissioning energisation and field operation

Collaboration is key

WPD, RINA, GridON, and the host site UoW should work together to achieve the aims and objectives of the project

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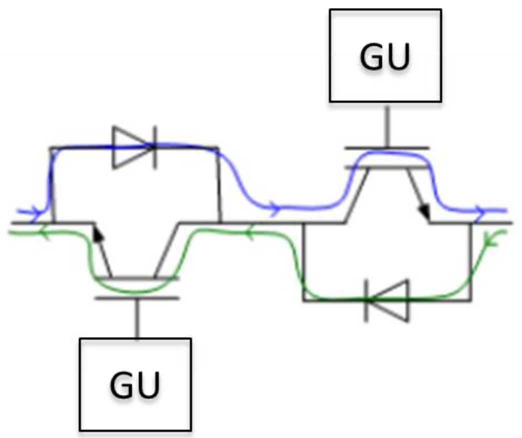
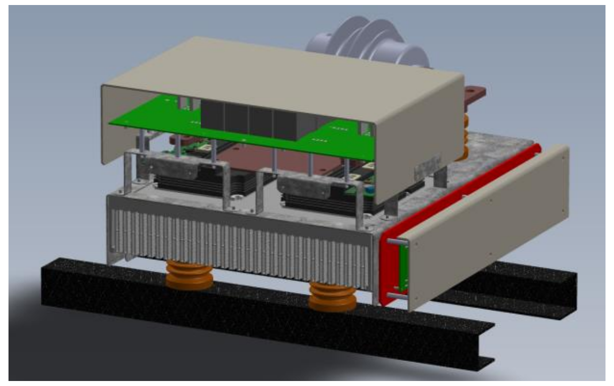
FCLi – DEVELOPMENT STATUS

Sep 2018 | Nov 2018 | Feb 2019 | Jun 2019 | Sep 2019 | Nov 2019 | Dec 2019

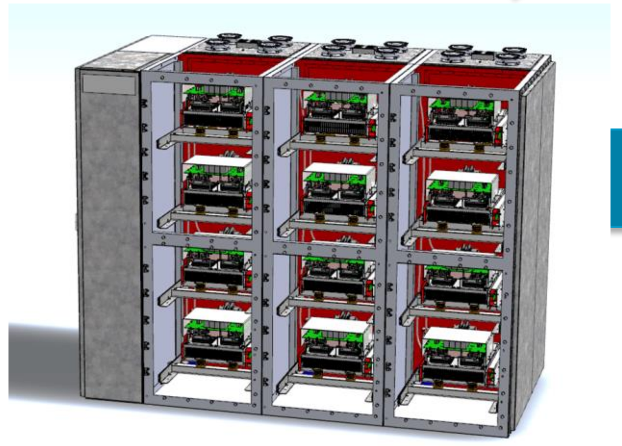
Concept. Design



Prelim. Design



Final Design



Manufacture

Testing

To Site

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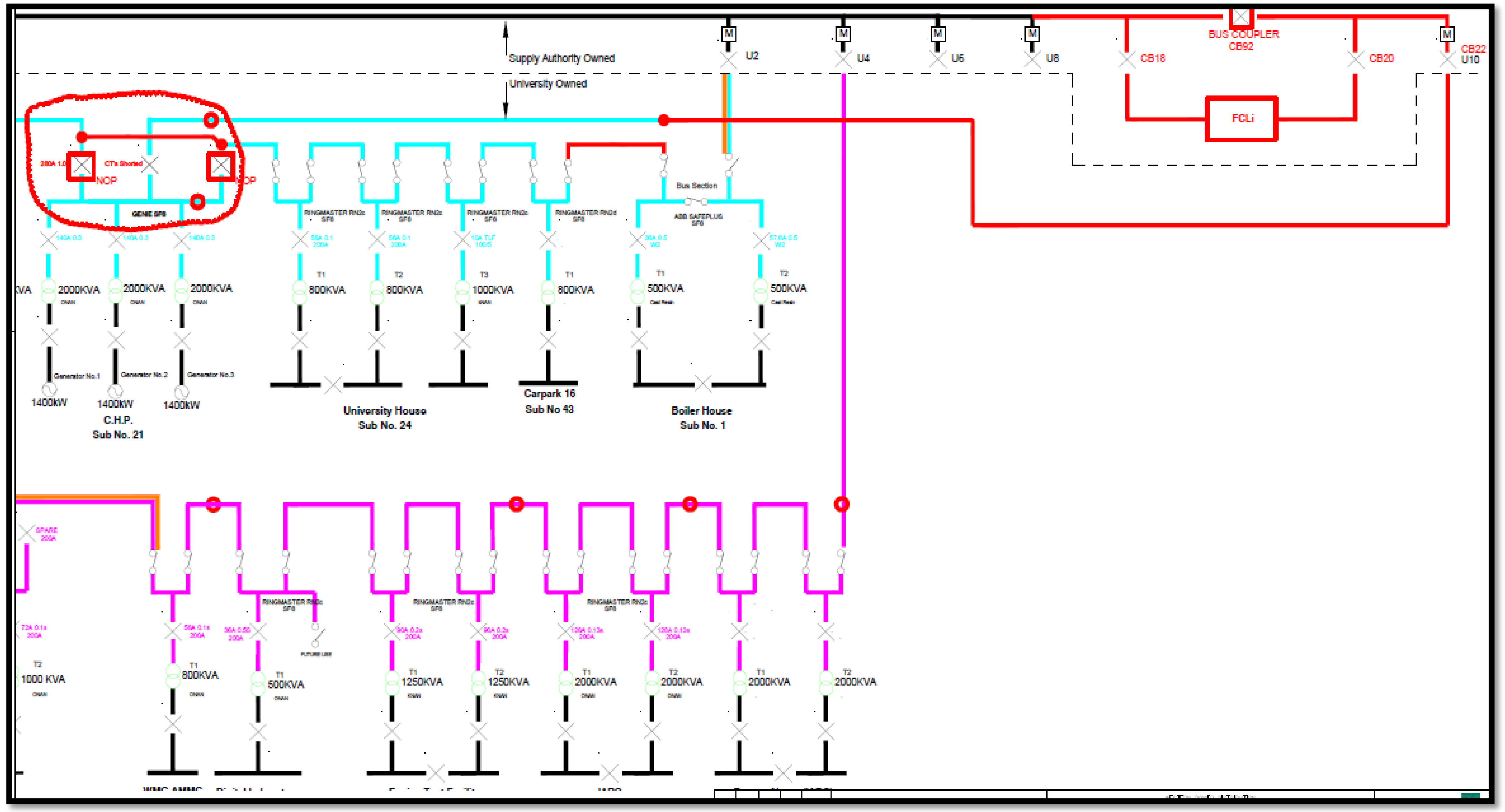
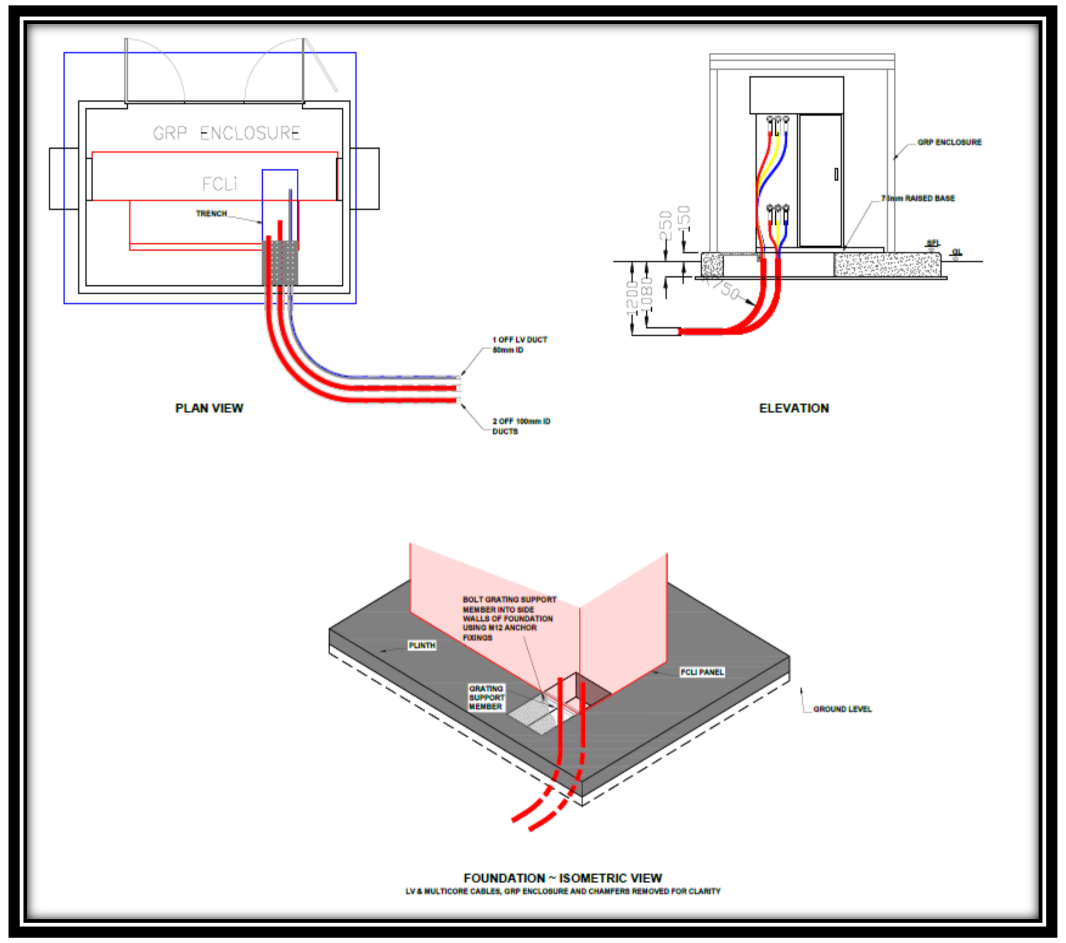
DEMONSTRATION SITE – UNIVERSITY OF WARWICK PRIMARY SUBSTATION

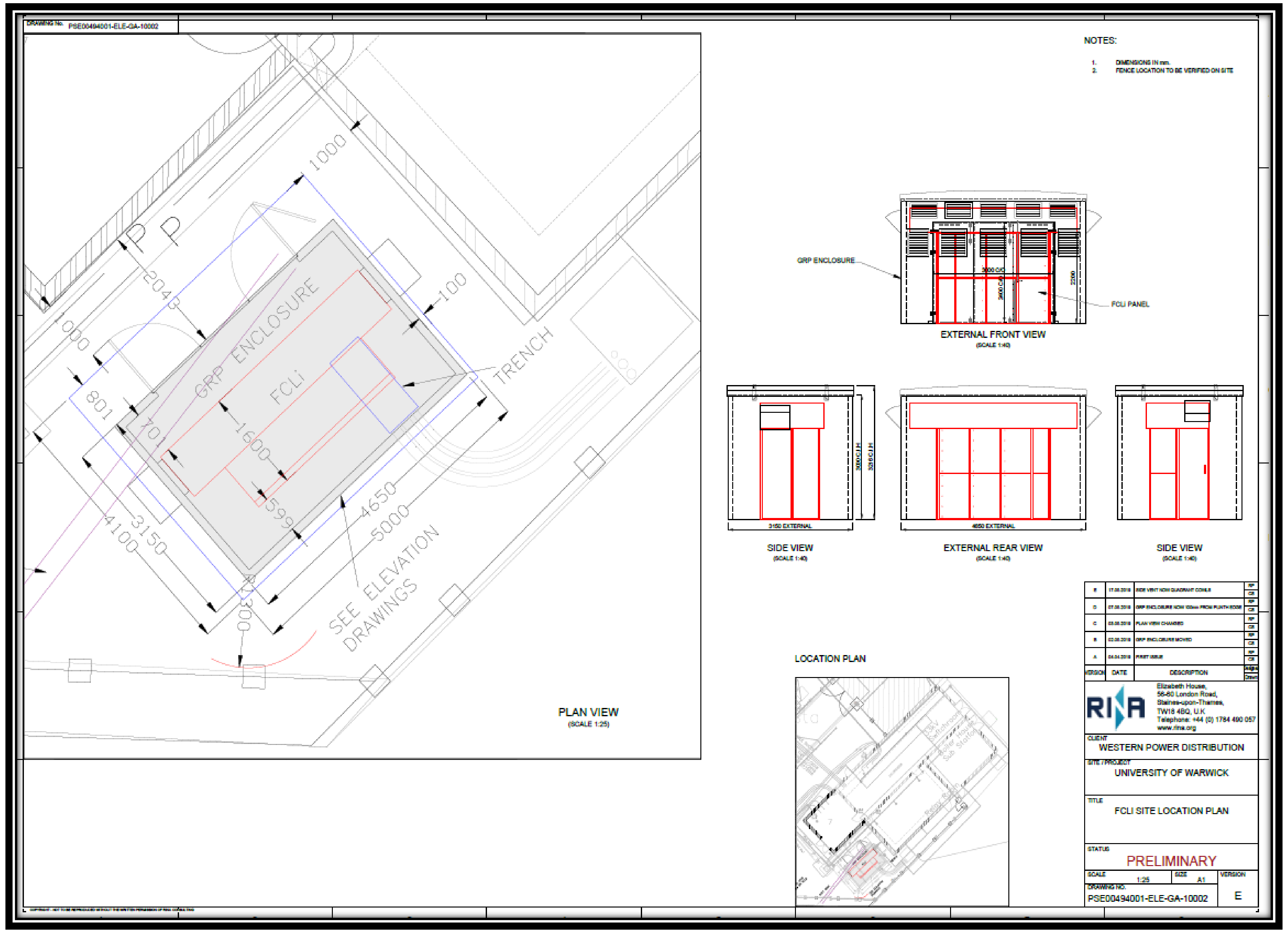
- FCLi will be connected in series to the 3 CHP generating units at the University of Warwick
- Total 4.2 MW
- Modifications to the site connection arrangements to primary substation



DEMONSTRATION SITE – DESIGN & PREPARATION

- Electrical and civil designs of demo site are completed
- FCLi will be placed inside a GRP enclosure





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NEXT STEPS

- Site preparation works will start in July and completed by mid September 2019
- FCLi manufacturing by September 2019
- FAT testing by November 2019
- Short circuit testing by December 2019
- FCLi to site December 2019
- Energisation by January 2020

Live demo starts at the beginning of 2020 and runs until October 2020

WHAT WILL SUCCESS LOOK LIKE?

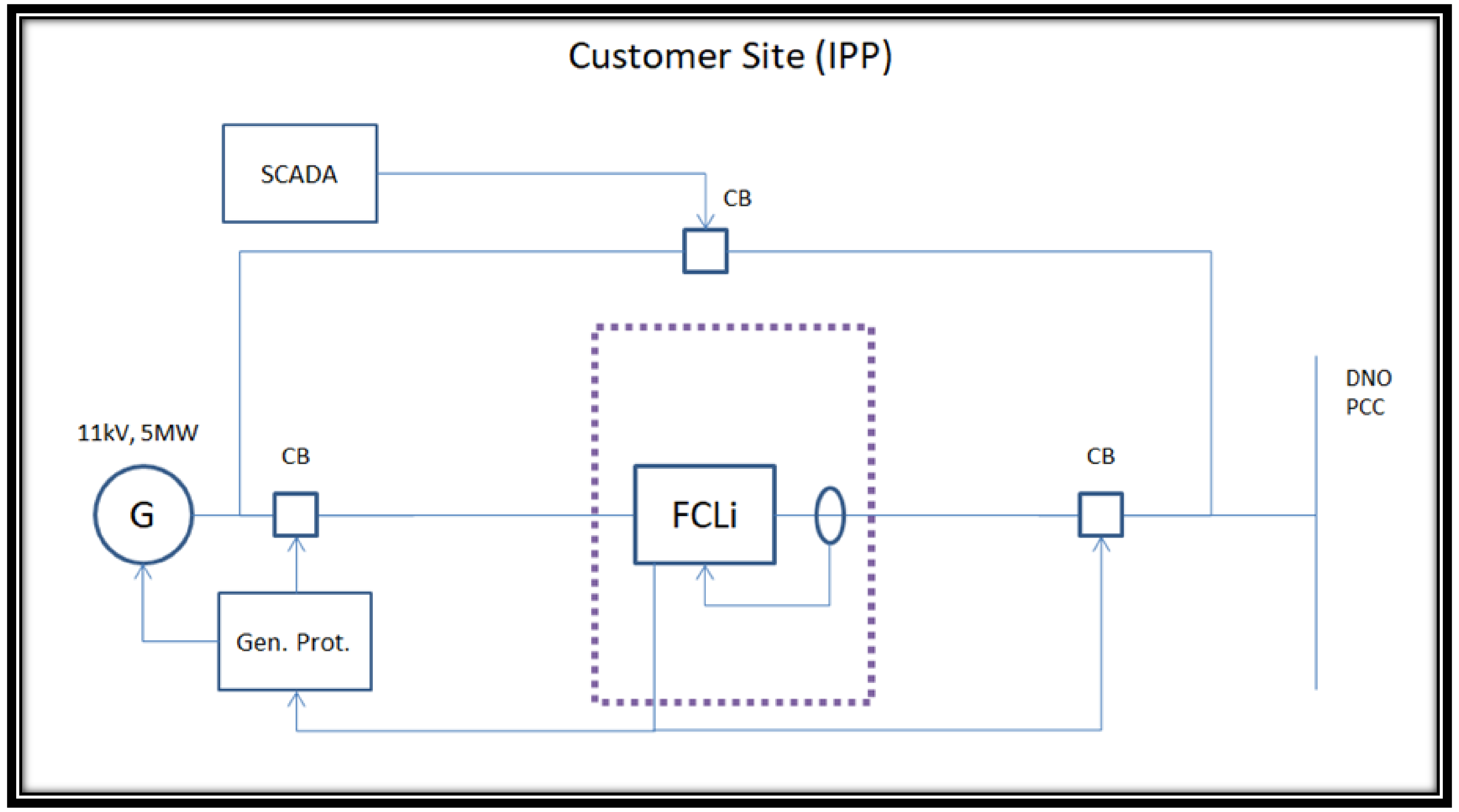
- The FCLi limits and reduces down to zero before the first peak the fault current contribution of the generator during a network fault
- The FCLi introduces minimal disturbance to the network and the generator during normal operation
- The FCLi remains in normal conduction mode for transient non-fault related events and for faults outside the 11kV network on to which it is connected
- Any device failures are minor and do not render the plant unavailable for more than a few hours
- The project presents a cost effective solution for fast DG connection

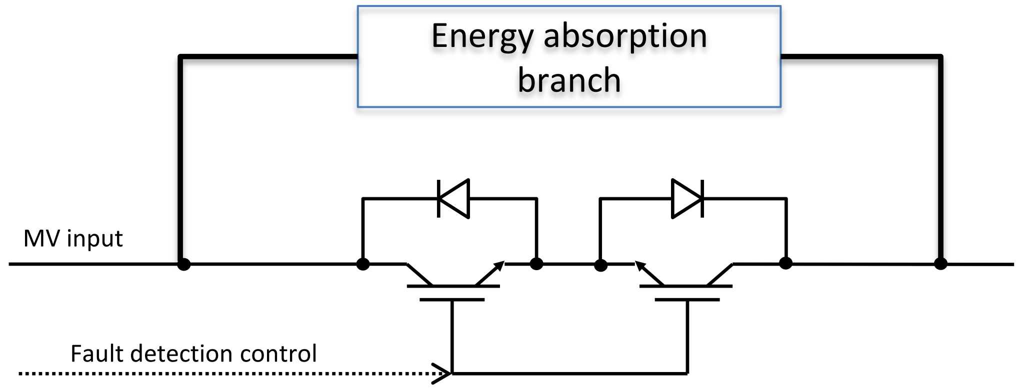
GridON

Protecting the Grid. Wisely.

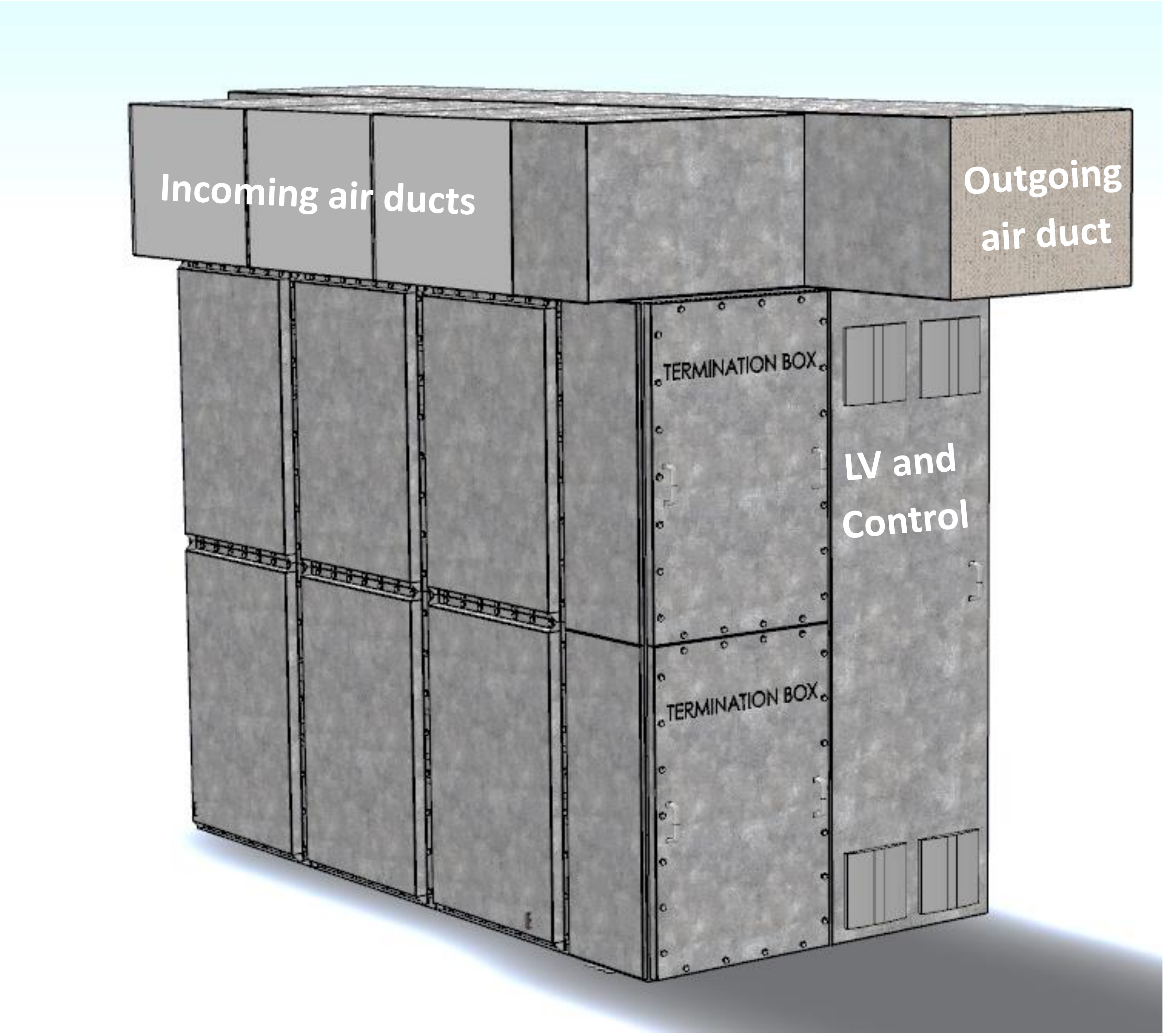
FAULT CURRENT LIMITING INTERRUPTER (FCLi)

- FCLi – a current limiting interrupter based on standard solid-state power devices (IGBTs)
- Current flows through one IGBT and one diode in each half cycle during normal operation
- A fault detection system issues a tripping command well before significant rise of the current
- The IGBTs are switched off immediately to interrupt the current
- The energy absorption branch assures the energy stored in the grid inductance is safely dissipated
- Series and parallel connection of modules enables operation at different voltage and current levels
- A 1-ph laboratory prototype was built and tested to validate the basic concept of operation





FCLi OUTLINE



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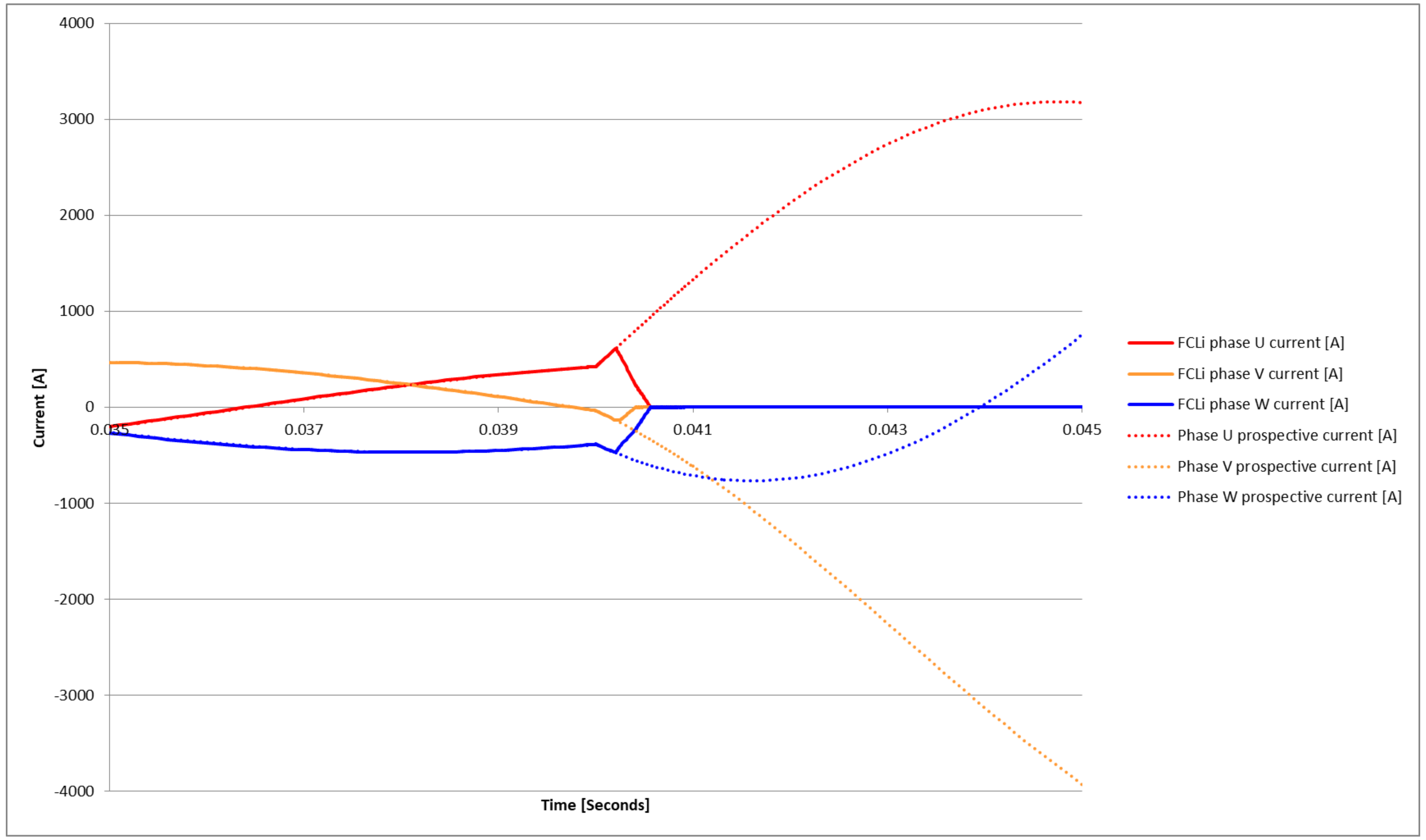
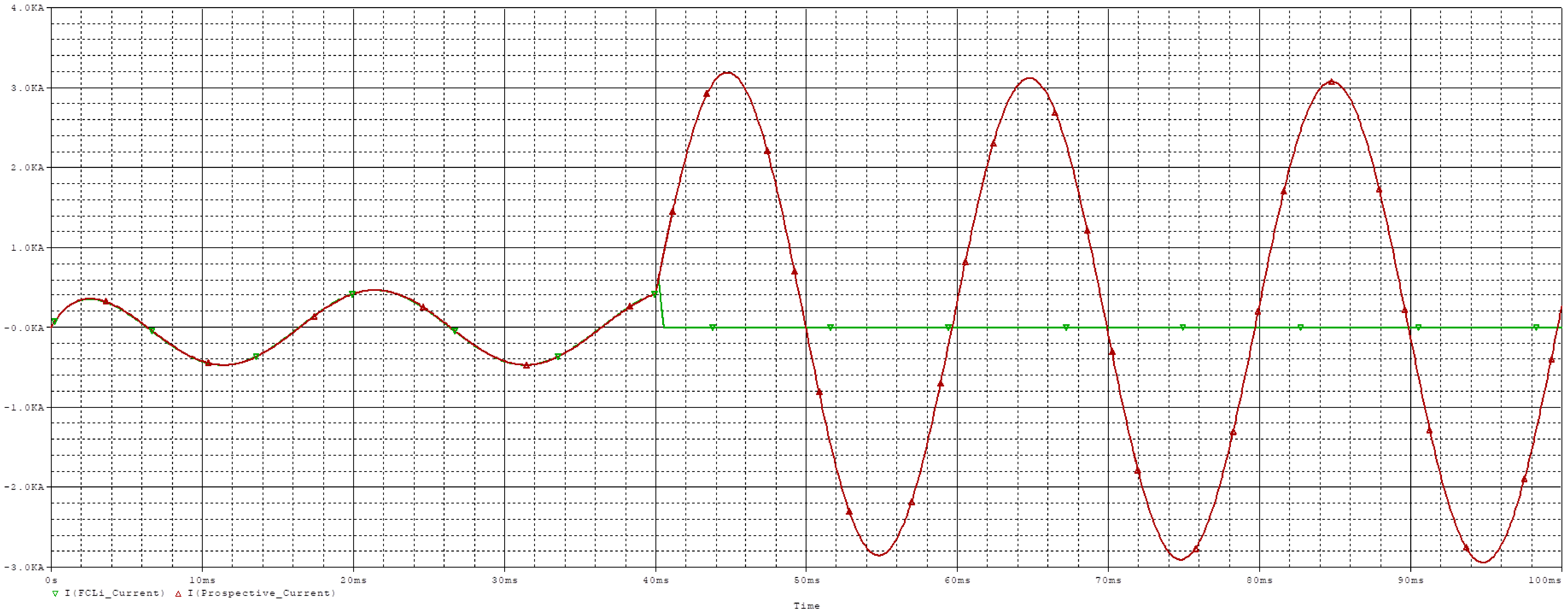
FCLi KEY FEATURES

- A standard unit suitable for up to 5MW of generation connection
- Virtually transparent to the network during normal operation
- Interrupts fault currents before the first current peak
- Fast recovery after fault clearance
- Quick ROI – typically within 1- 2 years



FAULT CURRENT INTERRUPTION



WESTERN POWER DISTRIBUTION INNOVATION TEAM

THANK YOU FOR LISTENING

ANY QUESTIONS?

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WESTERN POWER DISTRIBUTION INNOVATION TEAM

VIRTUAL STATCOM

BALANCING ACT CONFERENCE

20th JUNE 2019

GRANT McCORMICK
PSC UK LTD - POWER SYSTEM ENGINEER

PSC
Specialist Consultants
to the Electricity Industry

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PRESENTATION OVERVIEW

- PROJECT OBJECTIVE
- PROJECT BACKGROUND
  - Passive distribution networks
  - Accommodating distributed generation
- VIRTUAL STATCOM CONCEPT
- PROJECT STRUCTURE/TIMELINE
- KEY FINDINGS/UPDATE FROM
  - WP1 - Data gathering/validation and study zone selection.
  - WP2 – Power flow simulations and Virtual STATCOM algorithms.
- NEXT STEPS

PROJECT OBJECTIVE

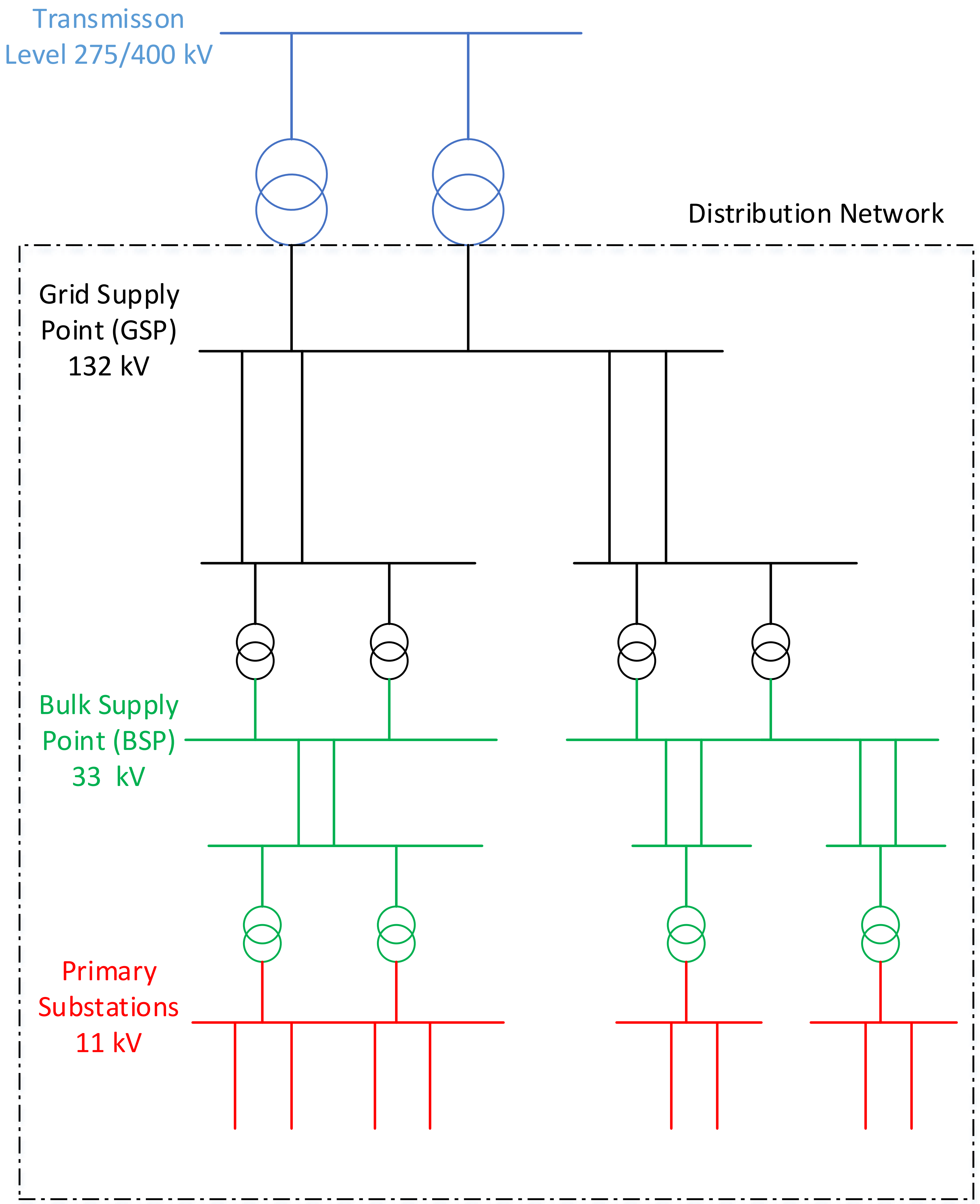
- To determine the technical feasibility of increasing a *network's hosting capacity*, through implementing an algorithm to control and coordinate the reactive power output of existing generators in the distribution network.

- If the project demonstrates benefit it will enable more generation and load to be connected to distribution network without the need for network reinforcement.

PROJECT BACKGROUND

Passive Distribution Networks

- Top down approach.
- Purpose to deliver power from the transmission power source to the end consumers of electricity.
- Power flows in a single direction (i.e. high voltage to lower voltages).
- Radial in design.



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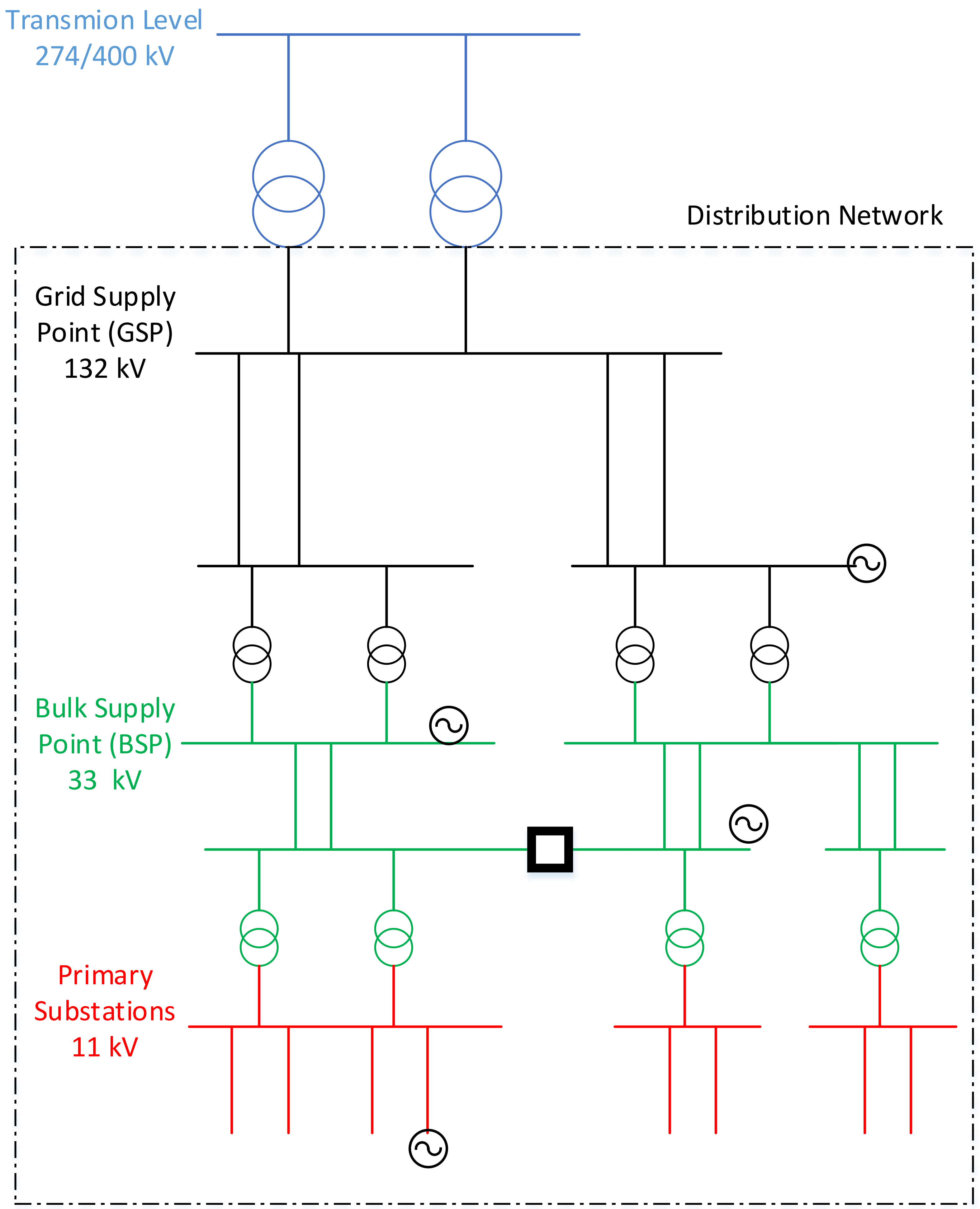
PROJECT BACKGROUND

Todays Distribution Networks

- Increasing levels of distributed generation, wind and solar
- Power flows can be in either direction (dictated by changing loads and generation which is likely to be intermittent in nature).
- Increasingly meshed networks in design/operation.



PROJECT BACKGROUND

Accommodating distributed generation

- Initially distributed generation has benefits of providing low carbon energy.
- Can relieve thermal network constraints.
- However, there is a limit on the amount of distributed generation that can be connected to a distribution network for technical reasons.
- The **Hosting Capacity** of a network is defined as the total amount of distributed generation that the network can accommodate without violating predefined operational, physical and statutory limits.

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PROJECT BACKGROUND

Technical factors that affect hosting capacity

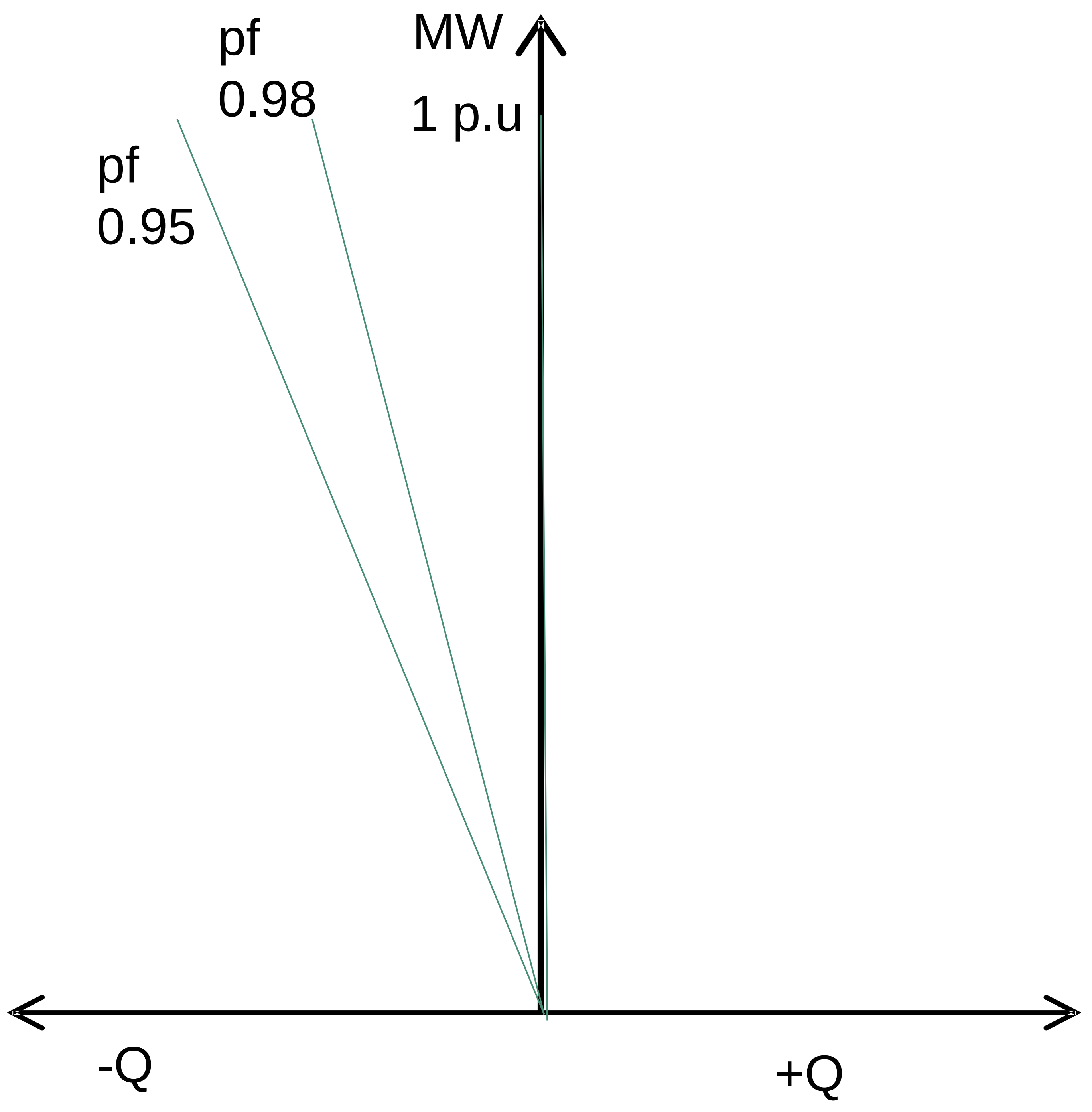
- Voltage step constraints
- Voltage regulation
- Thermal ratings
- Power quality
- Fault levels

VIRTUAL STATCOM CONCEPT

- Existing DGs connected to WPD's BSPs and primary networks operate with a fixed power factor.
- Between unity and 0.95 leading (import reactive power).
- Appropriate for the extreme case of maximum generation and minimum load.
- **Is a fixed power factor appropriate for all network conditions?**

Virtual Statcom will:

- assume that DGs can operate across a power factor range.
- optimise the reactive power output of DGs for different conditions.

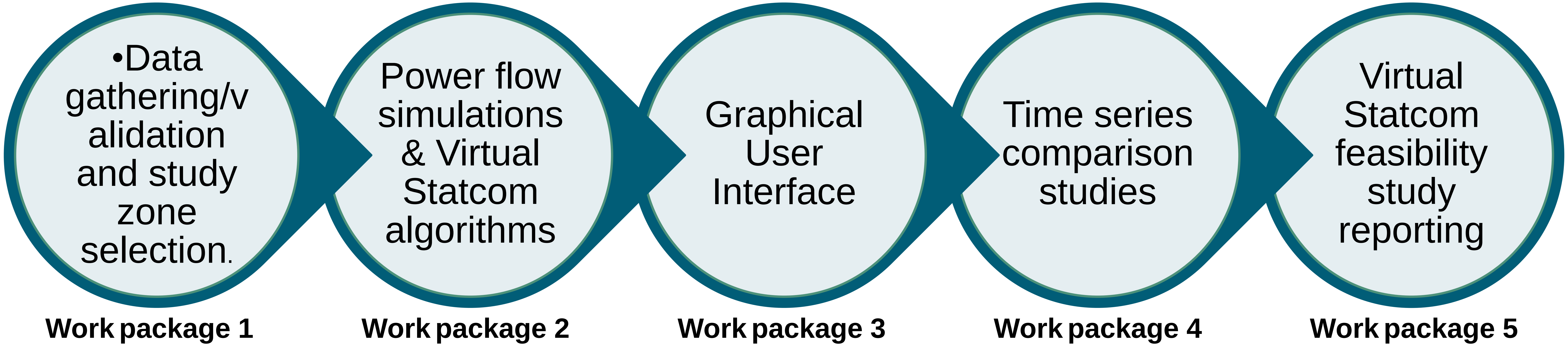


PROJECT STRUCTURE

- Project is being run by WPD and funded under the Ofgem Network Innovation Allowance (NIA).

- PSC UK LTD has been engaged to deliver the Virtual STATCOM project.

- The project is structured into the following 5 work packages:



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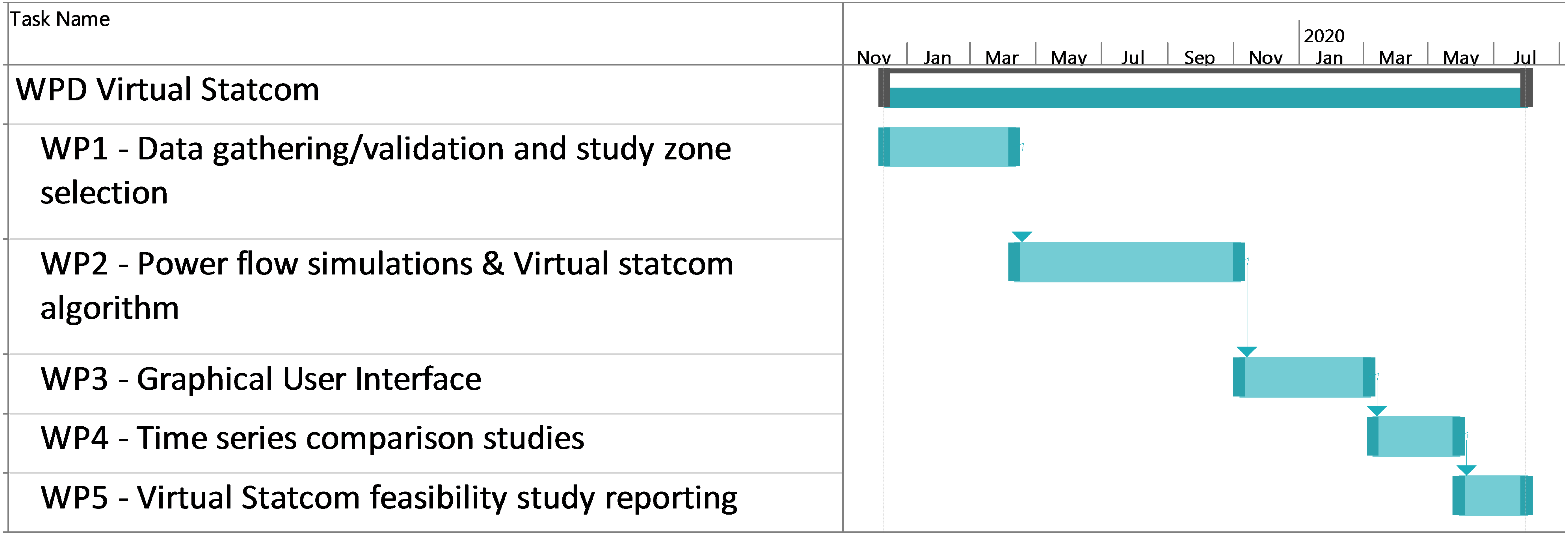
PROJECT TIMELINE



WP1 - DATA GATHERING/ VALIDATION AND STUDY ZONE SELECTION

- Literature review
- Networks selected for study
- Network hosting capacity algorithms design
- Virtual Statcom optimisation algorithms design

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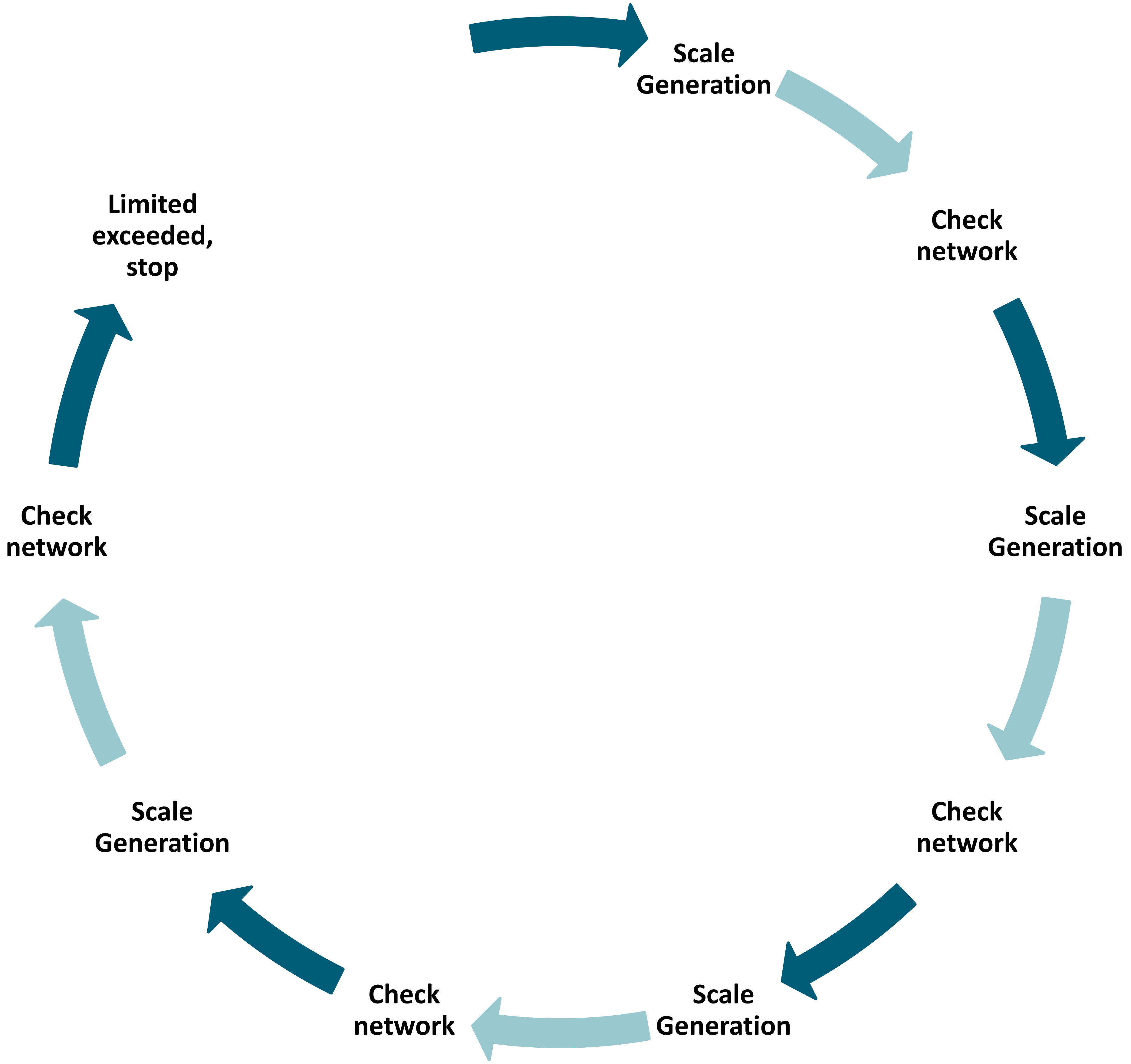
LITERATURE REVIEW

Hosting Capacity Approach

- Per node non-concurrent hosting capacity
  - Scaling up 1 generator at a bus until limits are met.
- **Concurrent hosting capacity**
  - The total amount for a network/zone

Concurrent hosting capacity calculation methods

- **Iterative scaling method**
- Optimal power flow method



LITERATURE REVIEW

Hosting Capacity Optimisation

- Focused on the Optimal reactive power dispatch (ORPD) problem.

$$Minimise \sum_{n=1}^{br} Plosses_n$$

Where br = Total number of branches in the network
$Plosses_n$ = Calculated real power losses in branch n

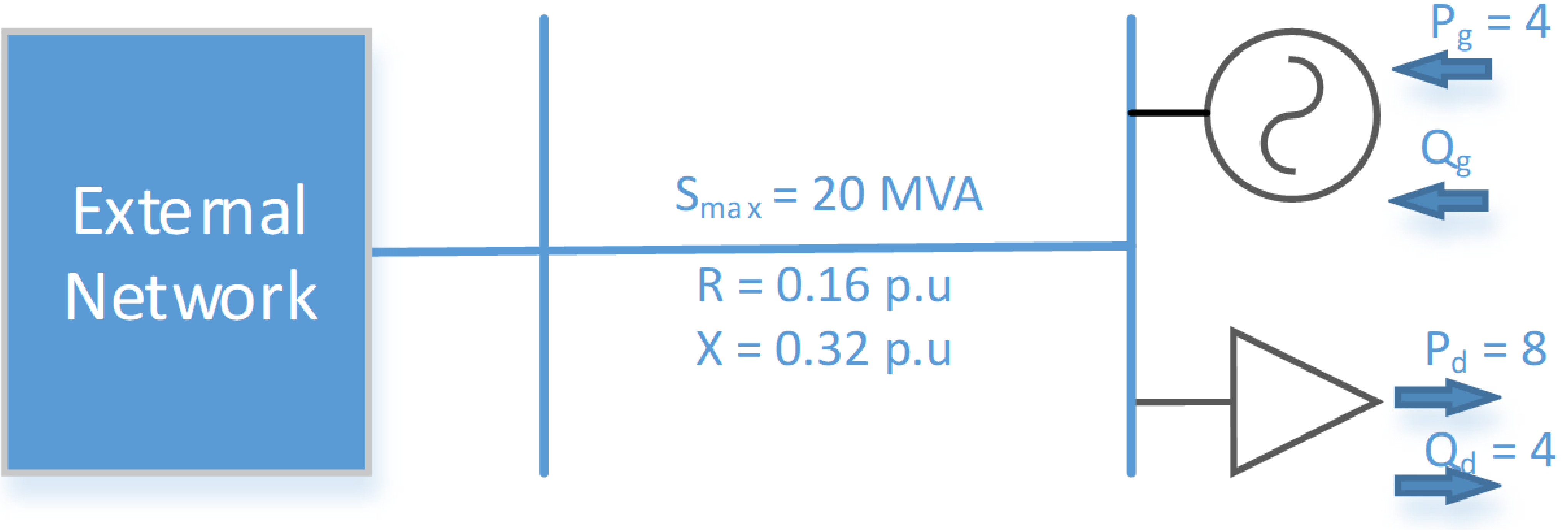
Subject to (constraints):

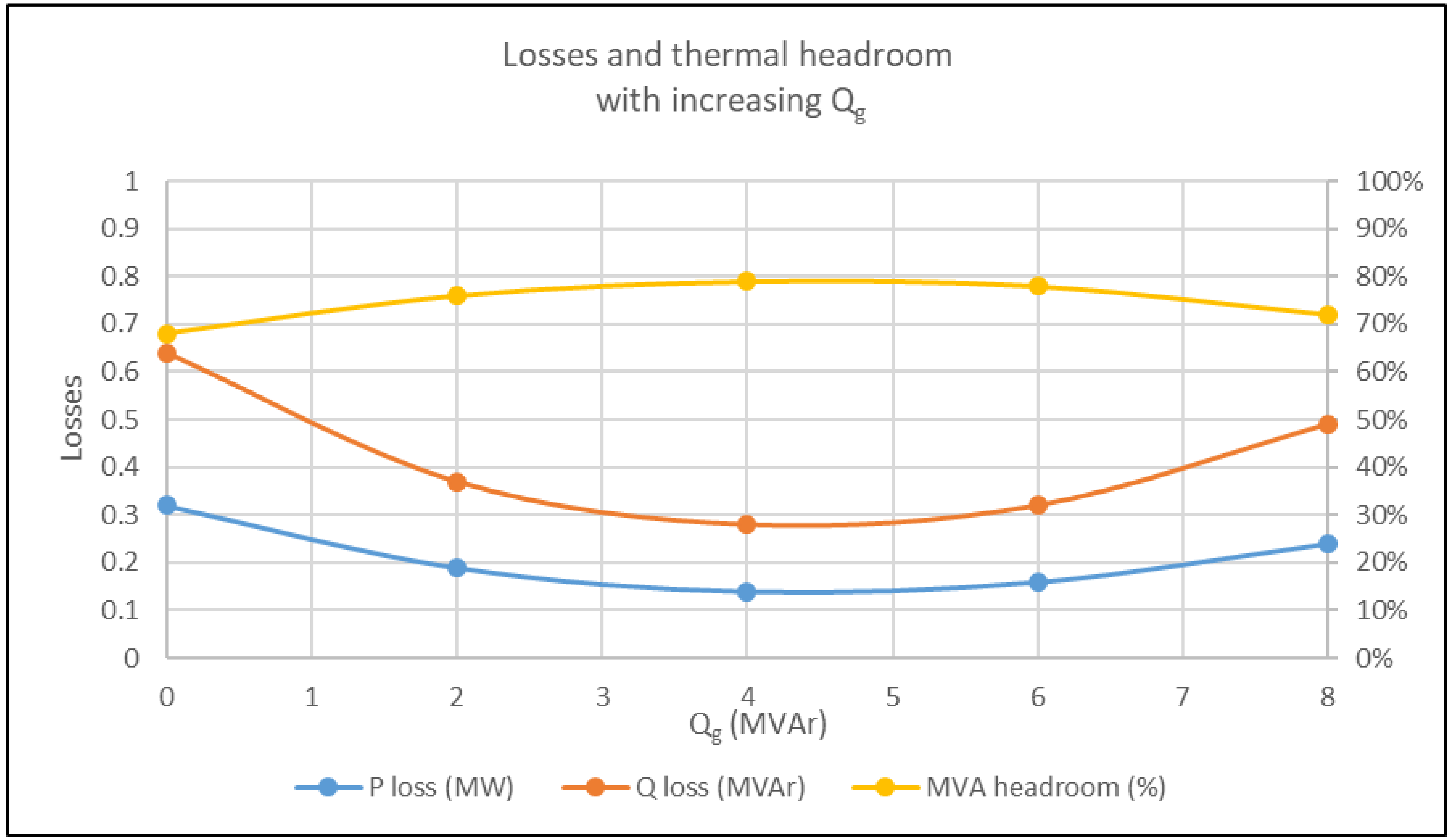
- Limits on control variables
- Real and Reactive power balance (i.e. load demand is still met)
- Bus voltage limits
- Branch flow limits (i.e. thermal limits)

LITERATURE REVIEW

Hosting Capacity Optimisation (example)

- The objective is to minimise the real power losses of the network using the reactive power of the generator – Qg is the control variable
- All other values are fixed i.e. Pg, Pd, Qd, R, X, Smax.
- Only apply the real and reactive power balance and thermal constraints. i.e. ignore the reactive power limits of the generator and the bus voltage limits.





LITERATURE REVIEW

Optimisation Solvers

- Literature identified multiple gradient free algorithms have been applied to ORPD problems.

- Particle Swarm Optimisation (PSO) has been selected for the initial solver for the Virtual Statcom algorithm.

  - PSO is a proven method and often used as a benchmark for ORPD problems.

  - Open source Python PSO packages are available.

  - For the size of WPD's 33kV & 11kV networks the computational time advantages of other solvers compared to PSO is expected to be minimal

NETWORKS SELECTED

A variety of networks to test algorithm:

33kV Networks

- Barnstaple 33 kV BSP
- Pyworthy and North Tawton 33 kV
- Tiverton 33 kV BSP

11kV Networks

- Tiverton Moorhayes 11 kV Primary

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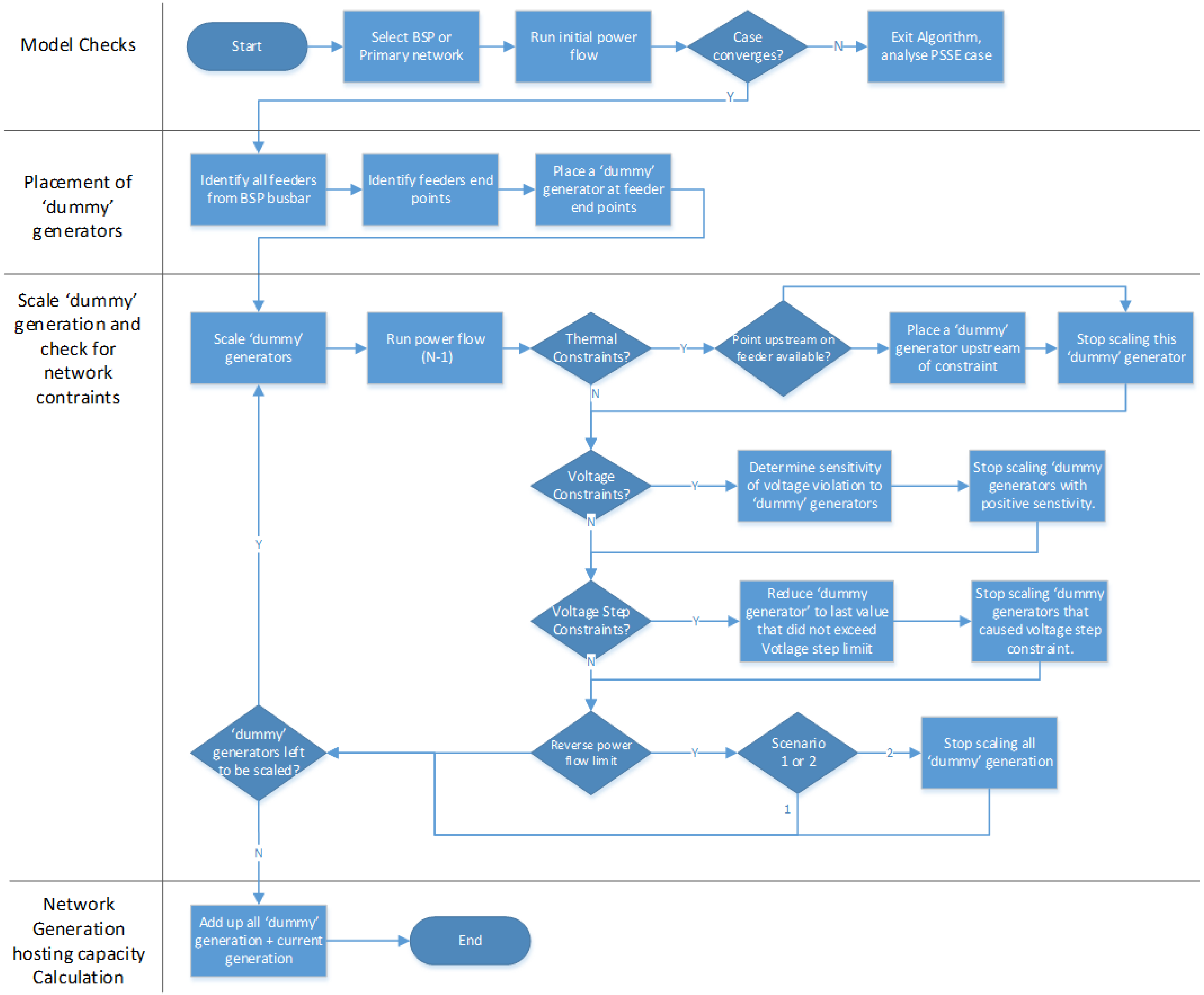
NETWORK HOSTING CAPACITY ALGORITHMS (GENERATION)



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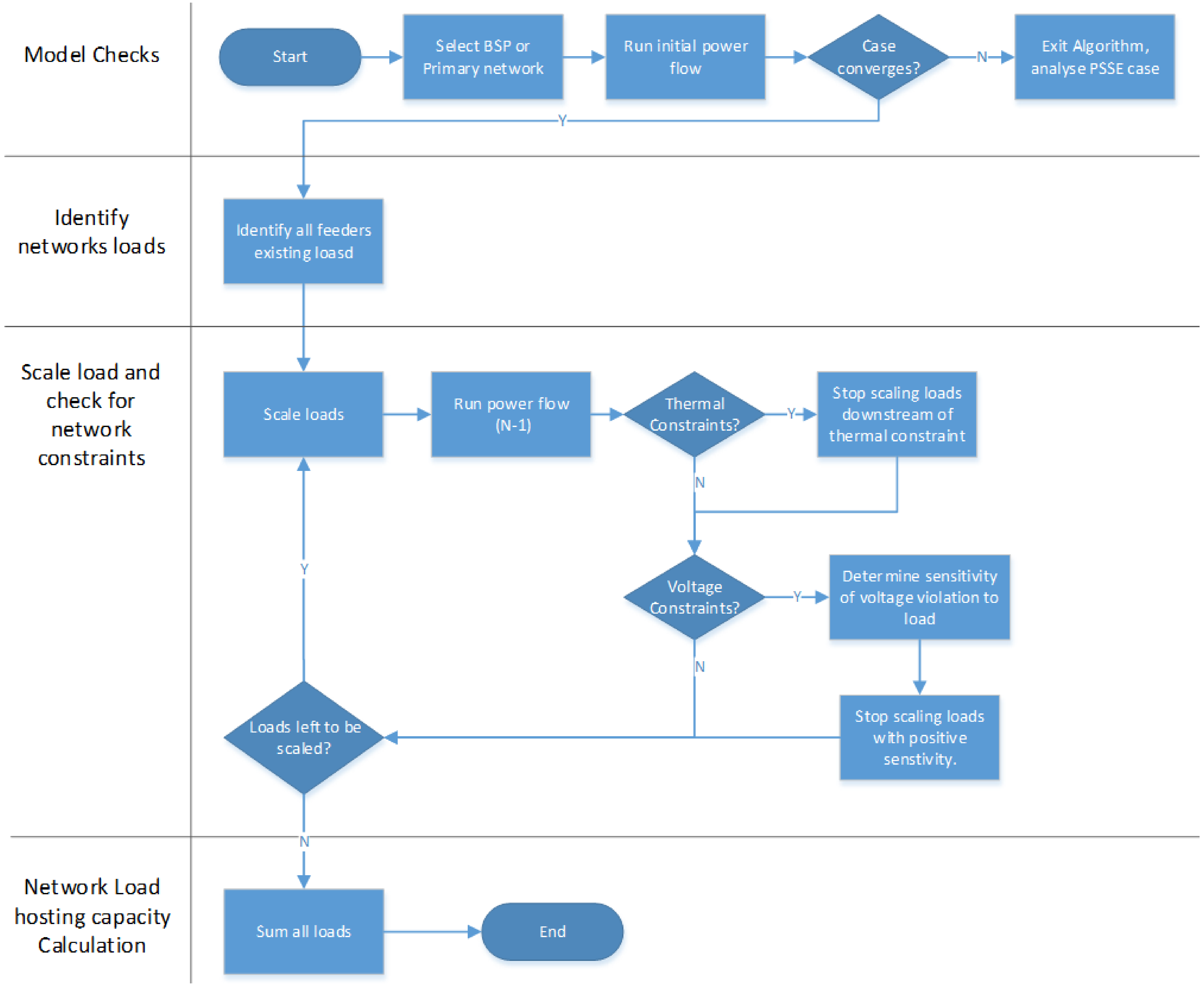
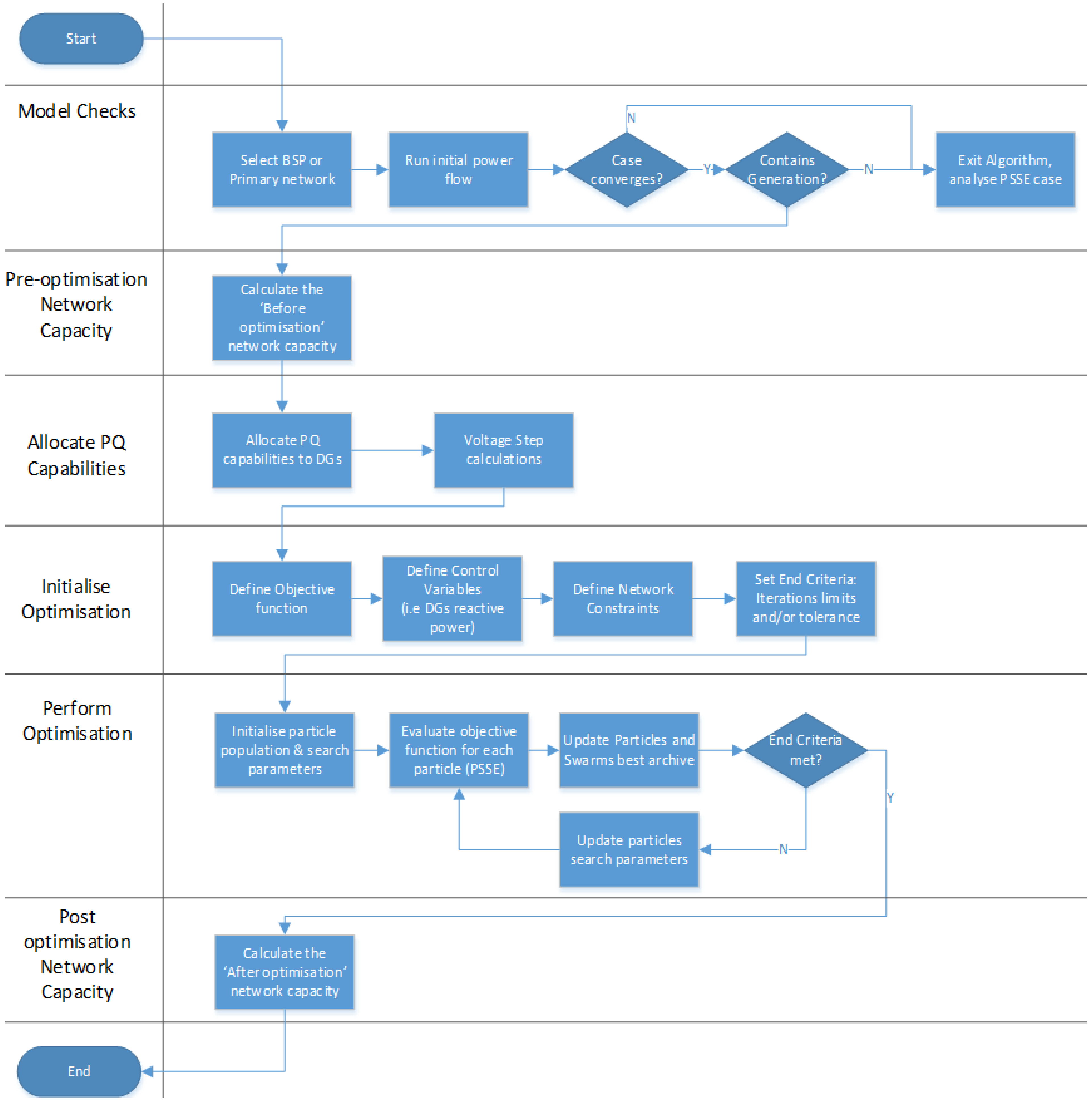
NETWORK HOSTING CAPACITY ALGORITHMS (LOAD)



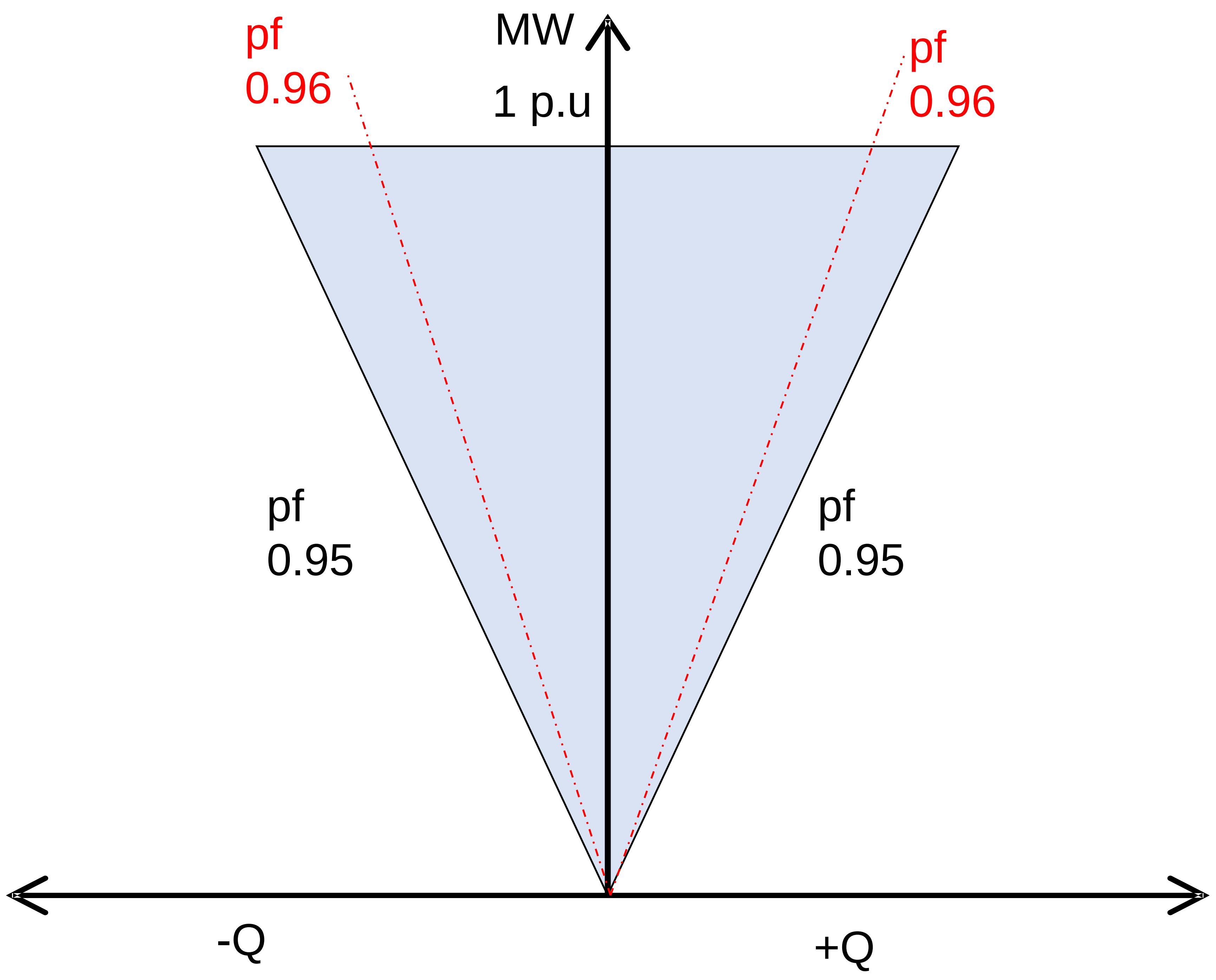
VIRTUAL STATCOM OPTIMISATION ALGORITHM



VIRTUAL STATCOM OPTIMISATION ALGORITHM

Allocation of PQ capability

- Initially algorithm will apply a PQ capability of
  0.95 p.f exporting – importing.
- Voltage step calculations may reduce the PQ capability.



WP2 – POWER FLOW SIMULATIONS & VIRTUAL STATCOM ALGORITHM UPDATE

- Capacity Hosting Algorithm development
- Initial generation hosting capacity results/observations

CAPACITY HOSTING ALGORITHM DEVELOPMENT

Challenges so far:

- Placement of ‘dummy’ generators
- Dynamically identifying T-circuits for contingencies

```
bsp_gen_totals, primary_gens_totals, bsp_dgen_totals, primary_
    PCT.gen_totals(sid, mach_id)

print("  Generation @ 33kV: " + str(bsp_gen_totals[0]) + " MW
      str(bsp_gen_totals[1]) + " MVAR ")
print("  Generation @ 11kV: " + str(primary_gens_totals[0]) +
      str(primary_gens_totals[1]) + " MVAR ")
print("  Dummy Generation @ 33kV: " + str(bsp_dgen_totals[0])
      str(bsp_dgen_totals[1]) + " MVAR ")
print("  Dummy Generation @ 11kV: " + str(primary_dgen_totals[
      str(primary_dgen_totals[1]) + " MVAR ")

# initialise Data frames/lists
therm_violate = pd.DataFrame()
rpf_violate = pd.DataFrame()
v_hi_violate = pd.DataFrame()
v_lo_violate = pd.DataFrame()
v_step_violate = pd.DataFrame()

if case_voltage == 33:
    mw_increment = float(1)
elif case_voltage == 11:
    mw_increment = float(0.01)

print('Scaling Generation...')
```

CAPACITY HOSTING ALGORITHM DEVELOPMENT

Placement of ‘dummy’ generators

- Goal is to make sure all capacity in a network is realised.

- Methods trialled
  - Impedance path
  - Sink bus

- The sink bus method was preferred as has better results for meshed networks.

VIRTUAL STATCOM PROJECT

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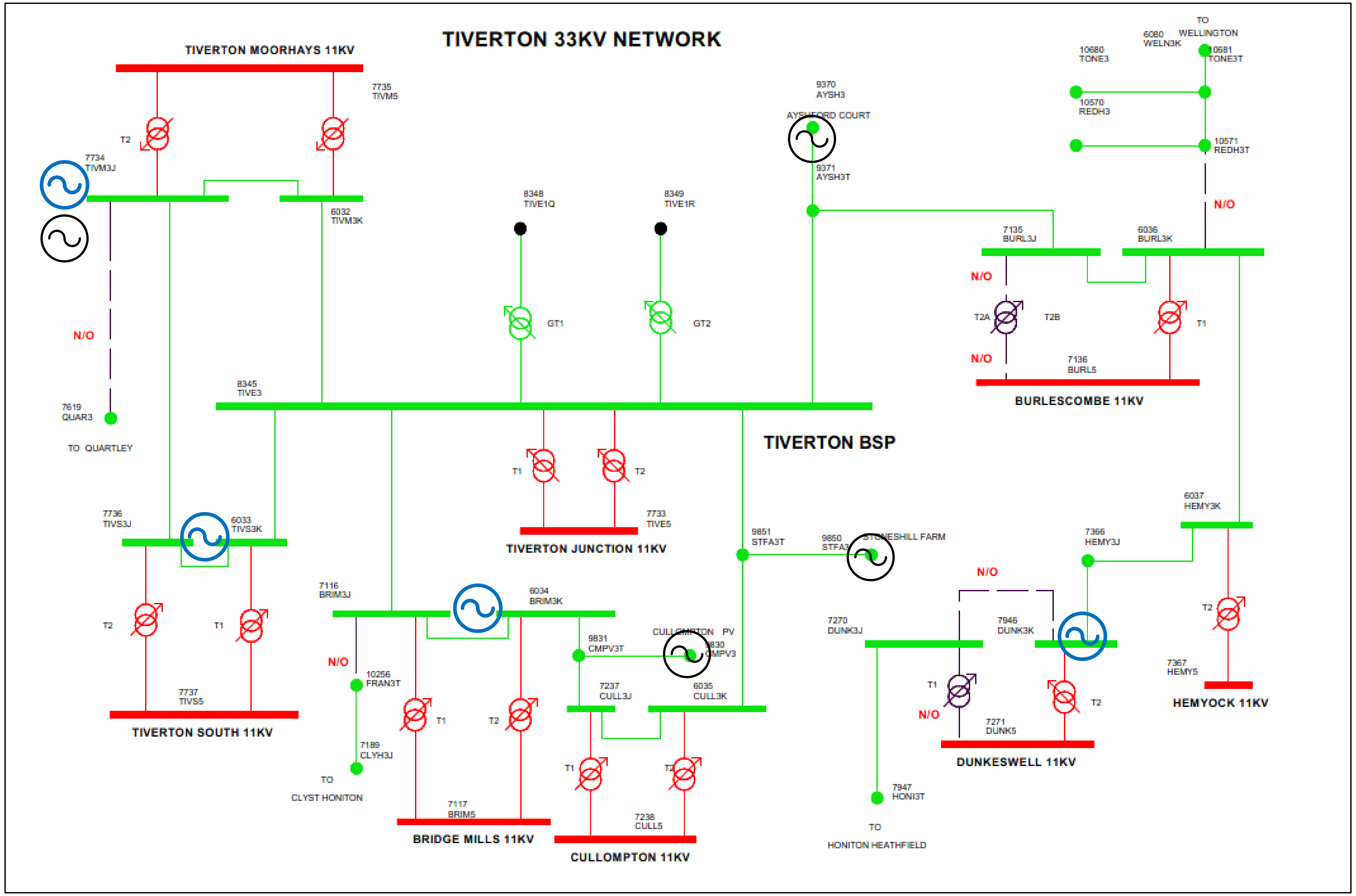
PLACEMENT OF 'DUMMY' GENERATORS



VIRTUAL STATCOM PROJECT

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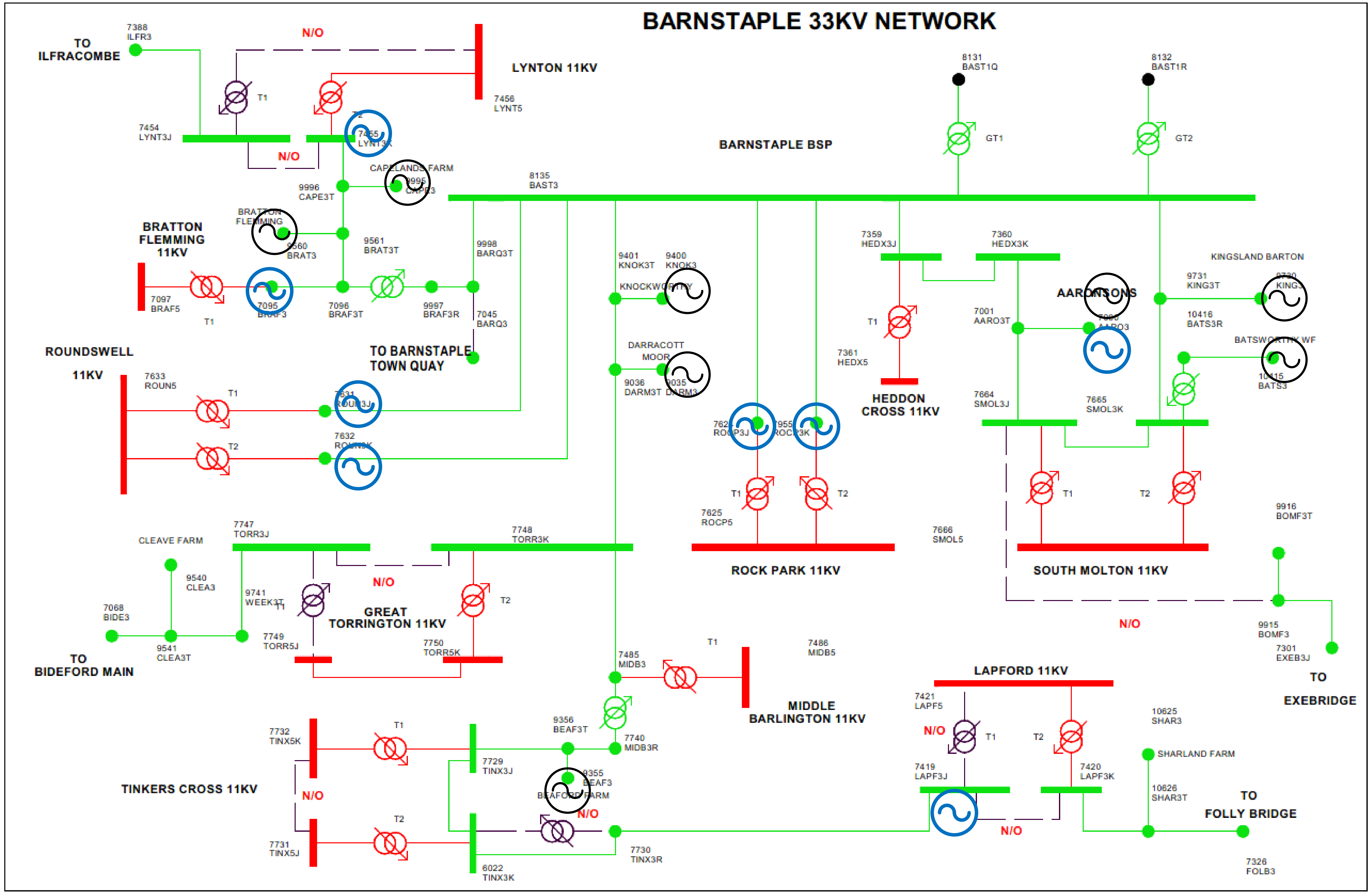
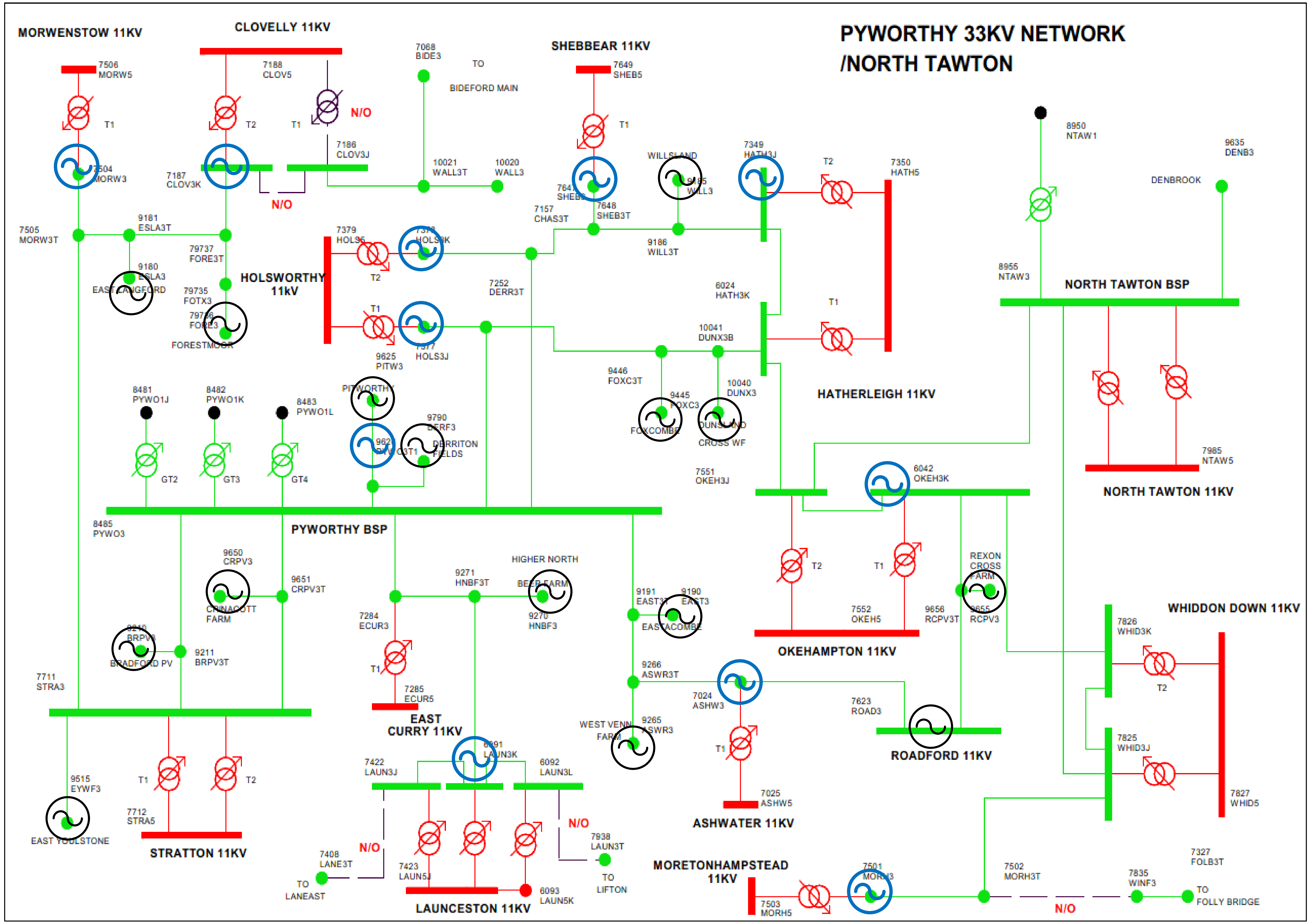
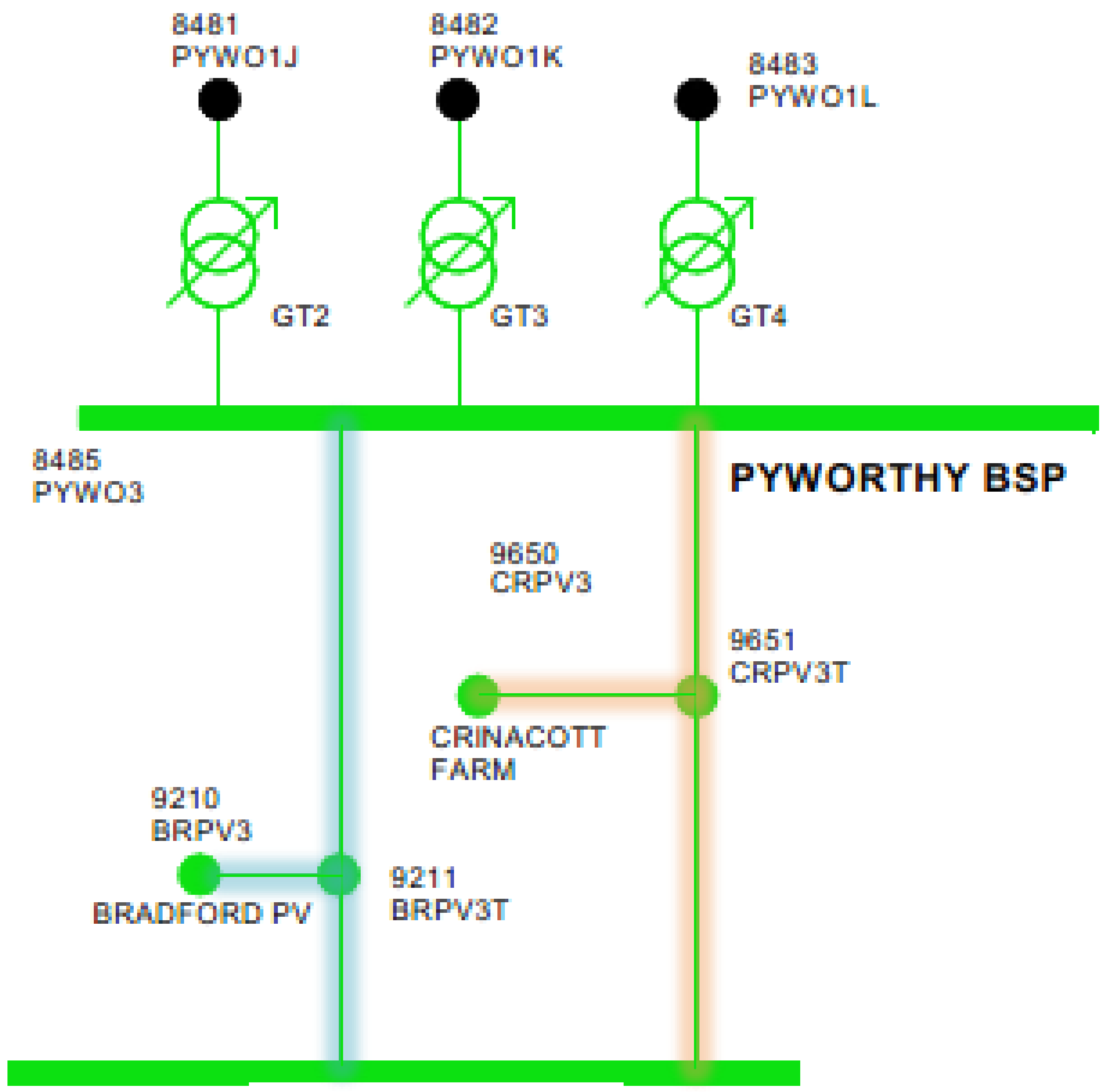
PLACEMENT OF ‘DUMMY’ GENERATORS

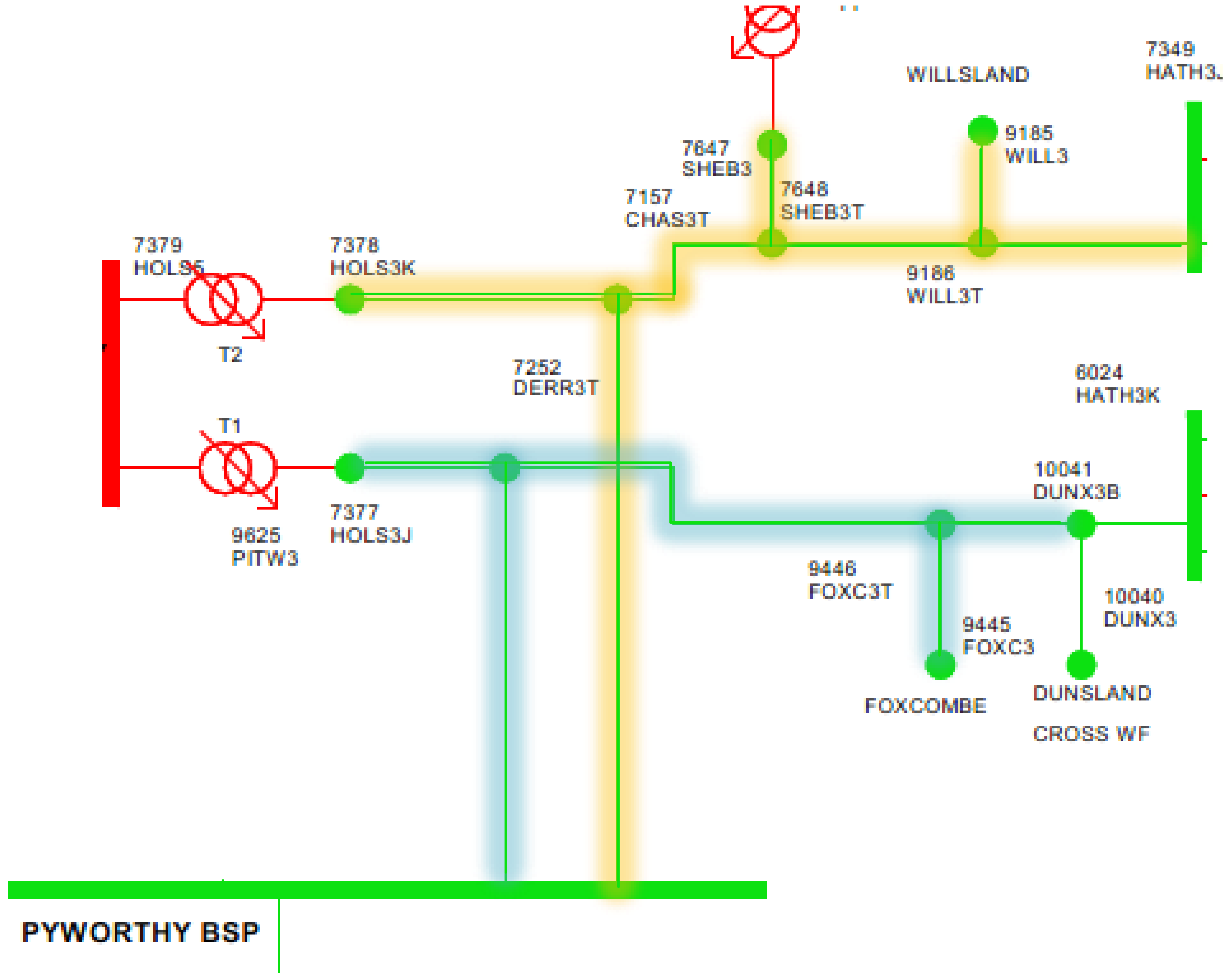


PLACEMENT OF ‘DUMMY’ GENERATORS



DYNAMICALLY IDENTIFYING T- CIRCUITS FOR CONTINGENCIES





INITIAL GENERATION HOSTING CAPACITY ALGORITHM RESULTS/OBSERVATIONS

- Network hosting capacity is affected by the location of generation, e.g.
  - Scaling existing generator
  - Scaling ‘dummy’ generators
  - Scaling both existing and ‘dummy’ generators.

- Scaling both existing and ‘dummy’ generators at the same time in early cases appear to provide the highest hosting capacity.

NEXT STEPS…

1. Develop and Virtual Statcom algorithm to optimise hosting capacity
2. Build a GUI for the tool
3. Run timeseries studies

THANK YOU FOR LISTENING

ANY QUESTIONS?

GRANT McCORMICK
PSC UK LTD - POWER SYSTEM ENGINEER

PSC
Specialist Consultants
to the Electricity Industry

WESTERN POWER DISTRIBUTION
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WESTERN POWER DISTRIBUTION INNOVATION TEAM

REFRESHMENTS BREAK

RESUME AT 14.45

WESTERN POWER DISTRIBUTION INNOVATION TEAM

LOSSES INVESTIGATION

BALANCING ACT CONFERENCE

20th JUNE 2019

CHRIS HARRAP
WPD - INNOVATION AND LOW CARBON NETWORKS ENGINEER

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

PROJECT OVERVIEW

Background

- Losses are a important issue on electricity networks
- Licence obligation to operate efficient and economic networks

Aims

- Further our understanding of technical losses; and
- Provide information to help cost effectively manage losses

Outline project approach

- Install monitoring on sample HV and LV feeders, gather data
- Use data to design HV and LV feeder loss estimation methods
- Use data to validate preferred estimation methods
- Produce HV & LV feeder loss estimates

Project Partners

Loughborough University

manxutilities bun shirveishyn vannin

GRIDKEY

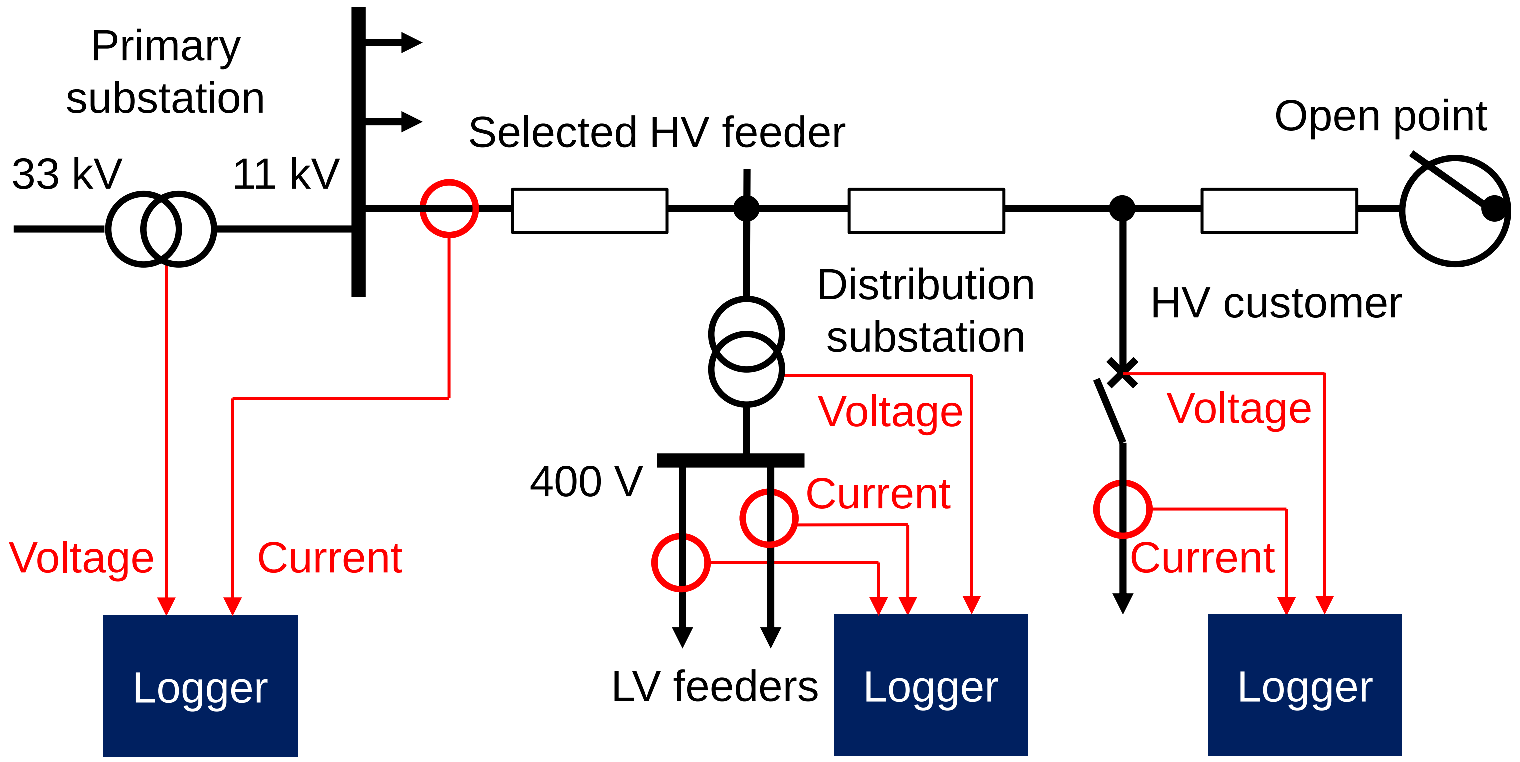
Project Metrics

- NIA project
- April 2015 – May 2019
- £1.9m spend

FEEDER MONITORING

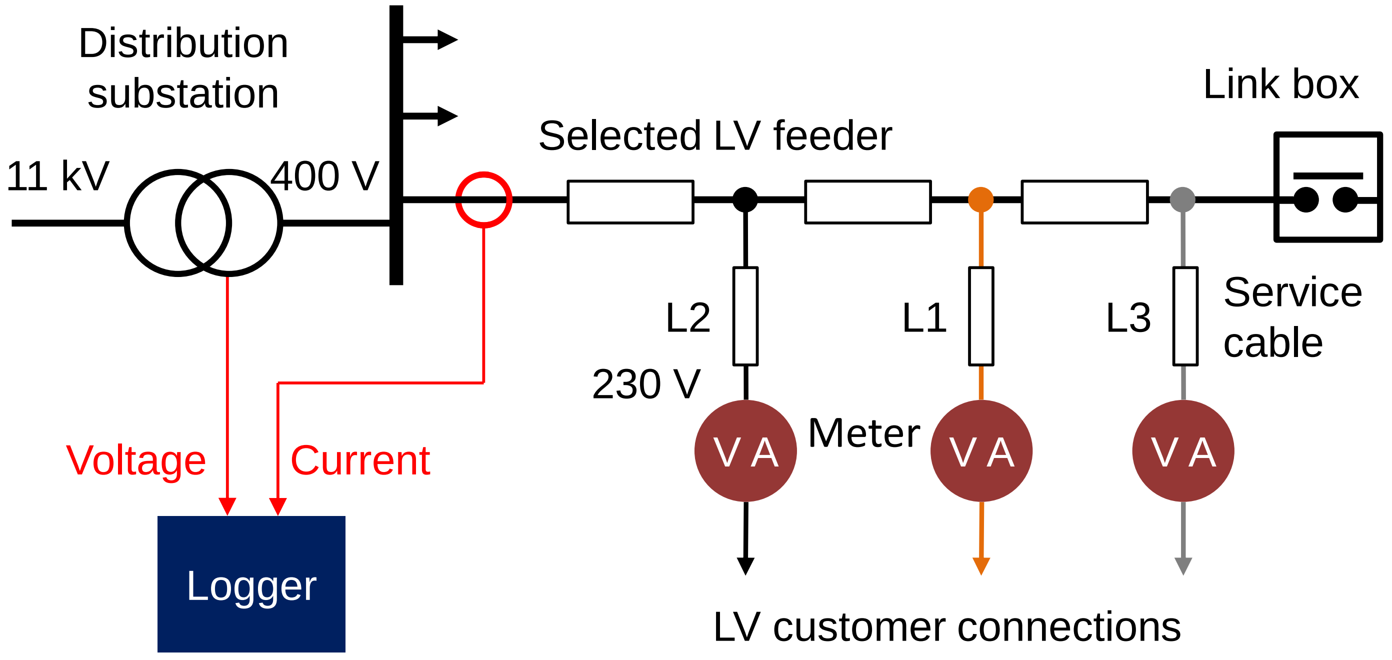
HV Monitored Feeders

- 11 feeders – urban / rural; cables / overhead
- Monitoring at 183 entry and exit points
- Primary Subs / Dist. Subs / HV Connections



LV Monitored Feeders

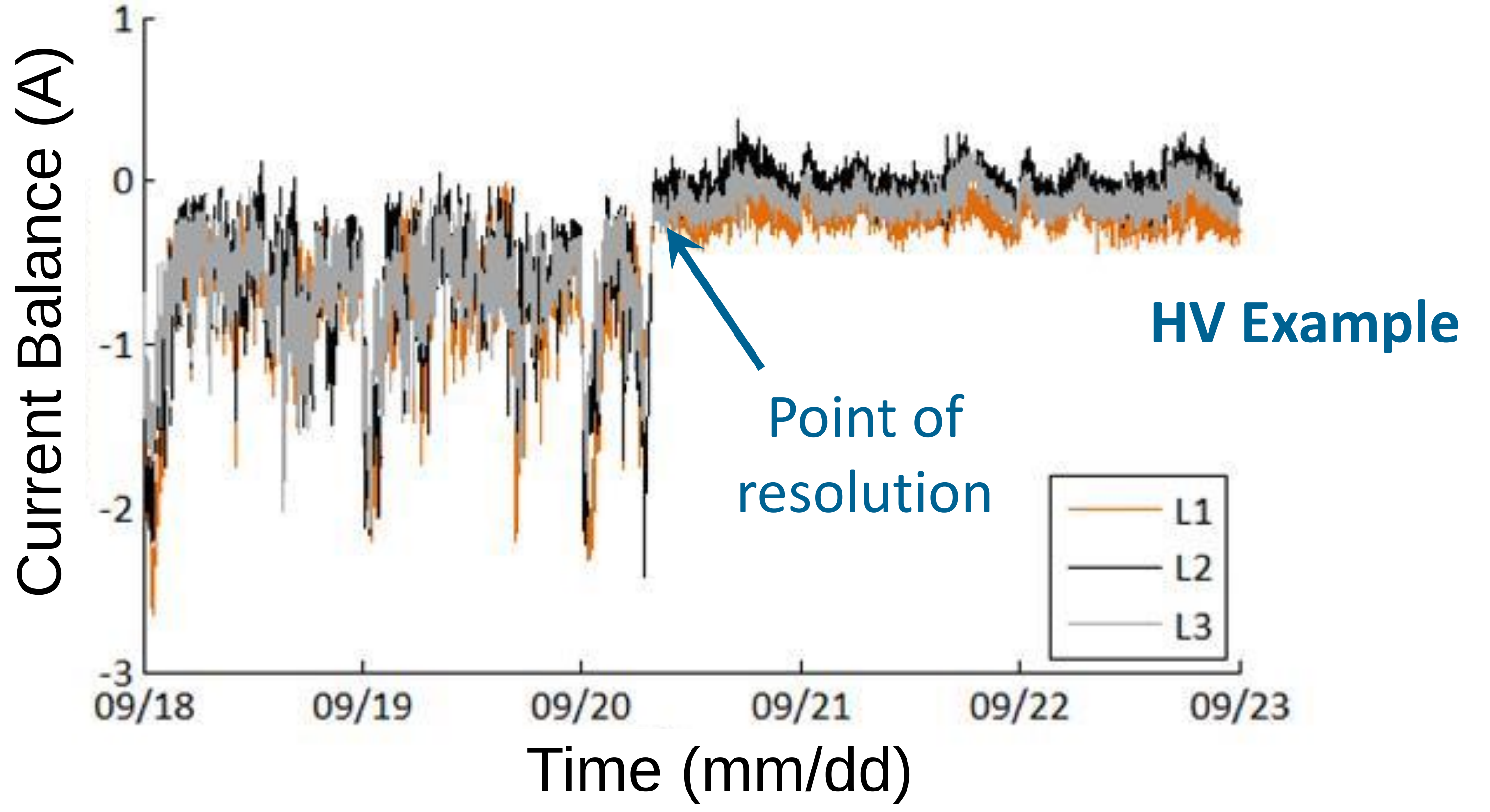
- 11 feeders – domestic / industrial and commercial; cables / overhead
- Monitoring at 360 entry and exit points
- Gridkey at substations / NOPs
- Advanced meters at customer connections



MEASUREMENT CONSISTENCY TESTING

Complete Monitoring

Current balance checks confirm that all entry and exit points on the feeder are monitored (both HV & LV), the sum of currents is zero.

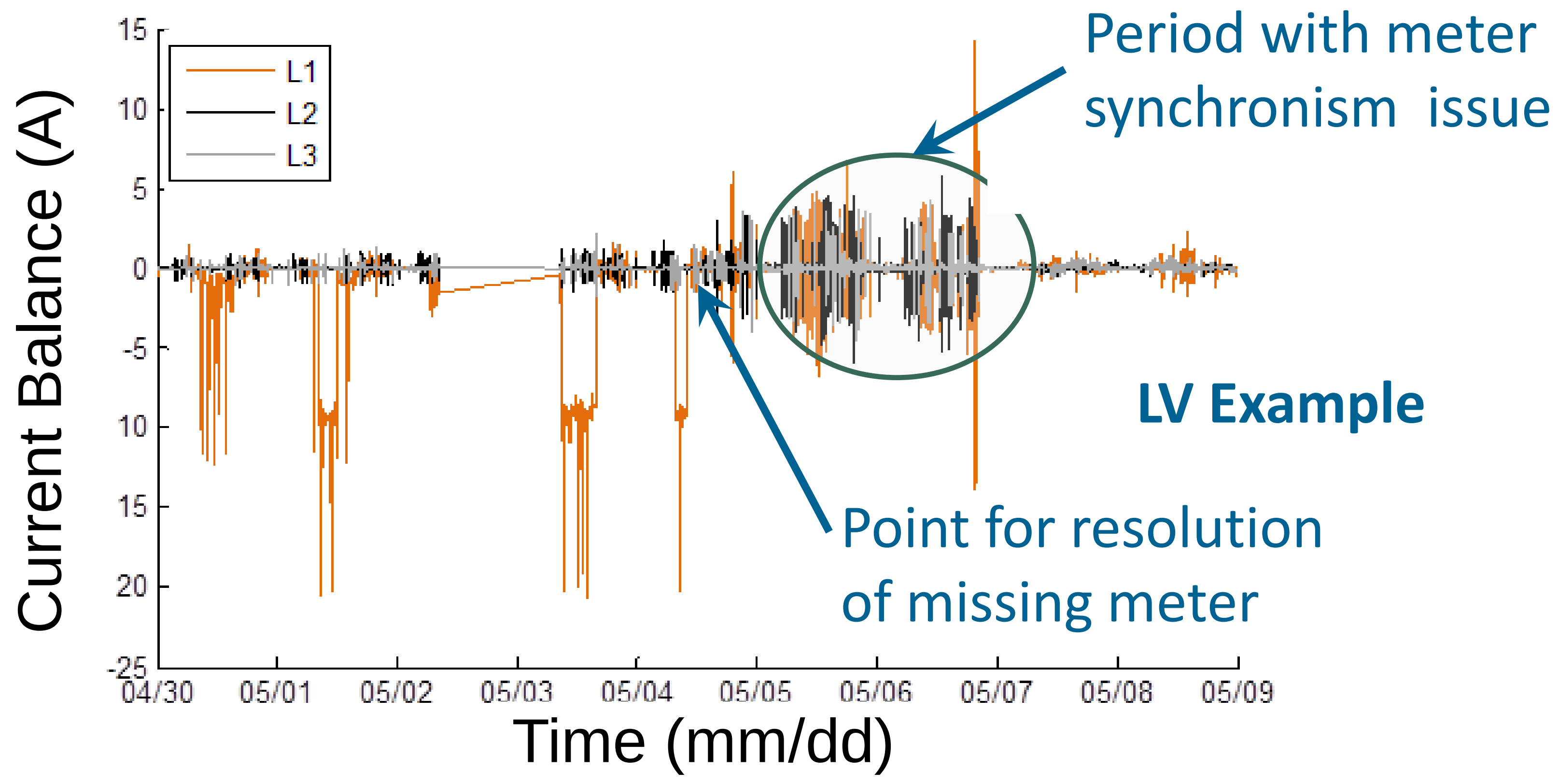


Phase Connection

Voltage checks confirm phase connection of single-phase loads.

Synchronisation of Measurements

Voltage checks identify meter synchronisation issues.



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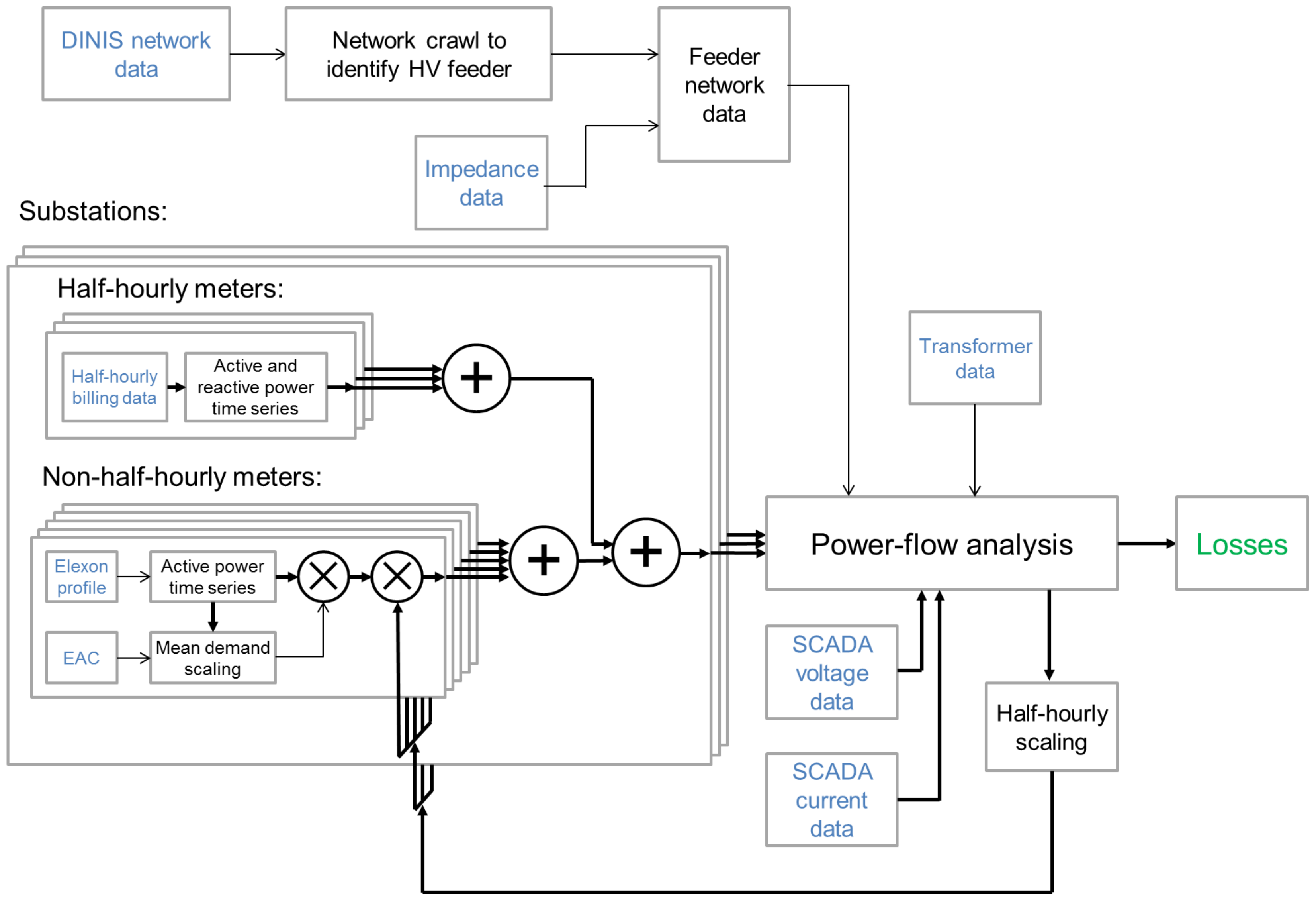
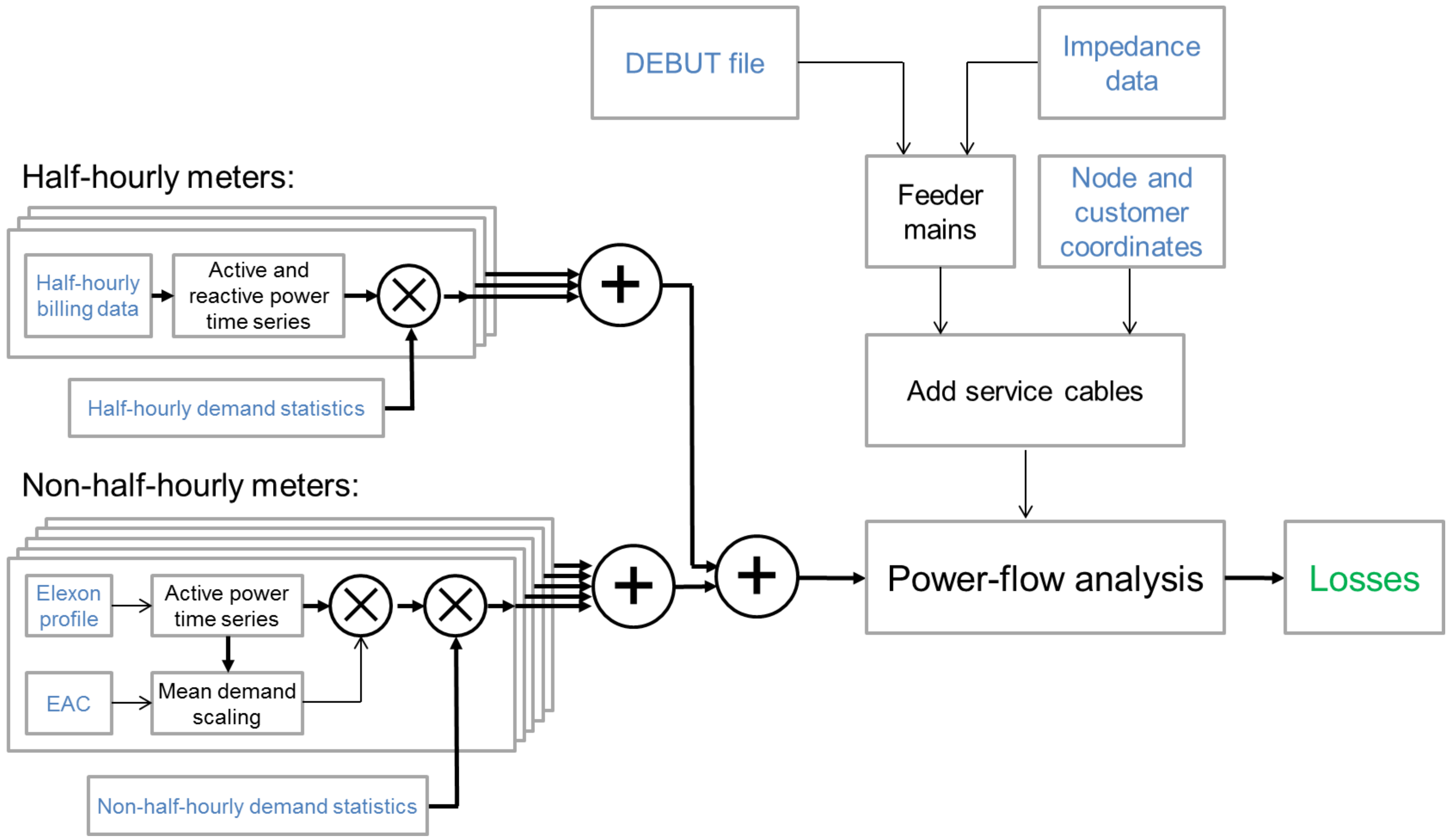
LOSS ASSESSMENT – HV & LV METHODS



HV Feeder Loss Assessment process



LV Feeder Loss Assessment process

Losses for individual feeders can be assessed using business-as-usual data, these assessments doesn't need any additional monitoring to be installed

LOSS ASSESSMENT – HV & LV METHODS COMPARED

HV Loss Assessment

- HV line and distribution transformer losses
- Half-hourly resolution OK with minimal loss of accuracy
- Demand can be modelled as balanced
- Reactive power included
- Network data is highly reliable
- Some uncertainty in NOP locations
- Multiple databases for consistency checking

LV Loss Assessment

- LV mains, services and meter losses
- 1-minute sample resolution, but only 1 in 30 samples are needed
- Unbalance is included
- Reactive power included
- Network models depend on input data quality
- Some feeders are extended through link boxes
- Consistency checks based on planning rules

Software customised separately for HV and LV. Iteratively developed for core calculations, extended input data & result storage, and volume optimisation

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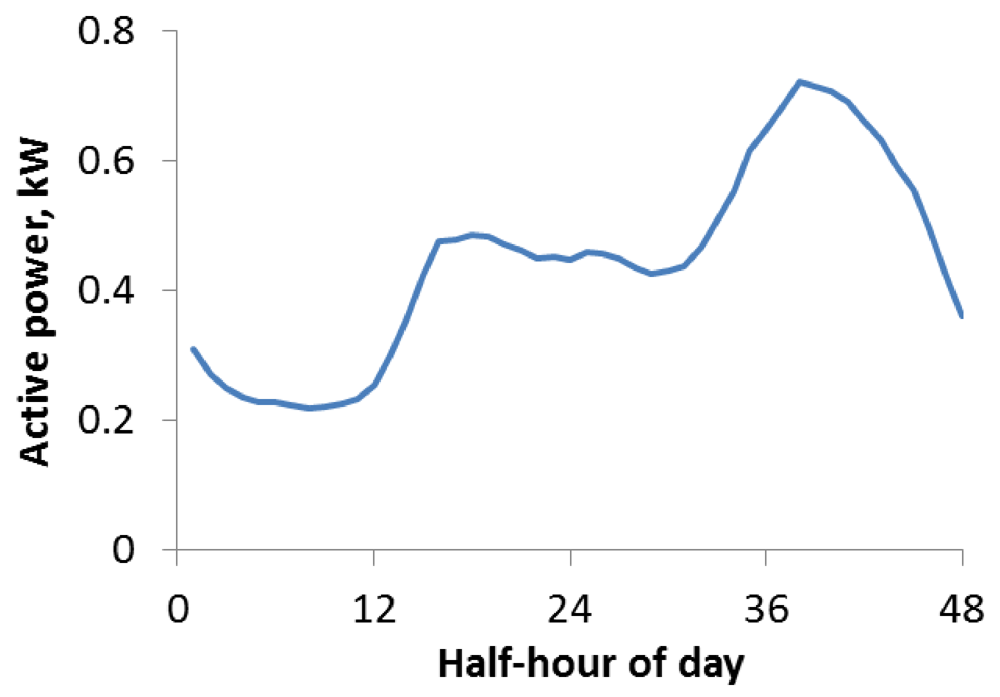
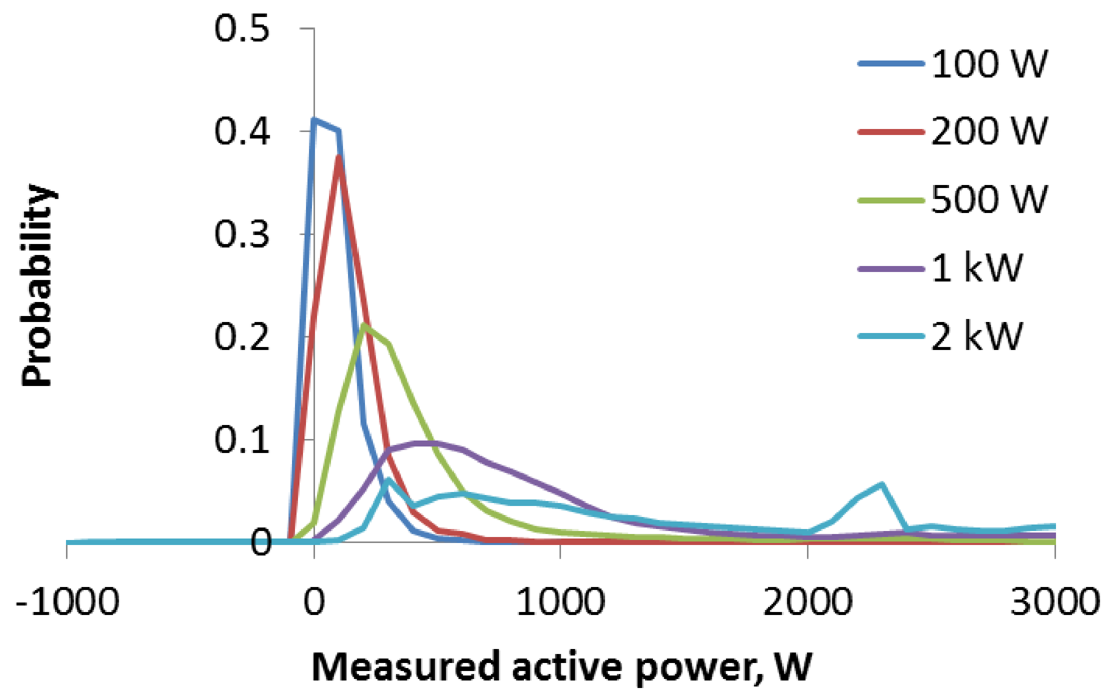
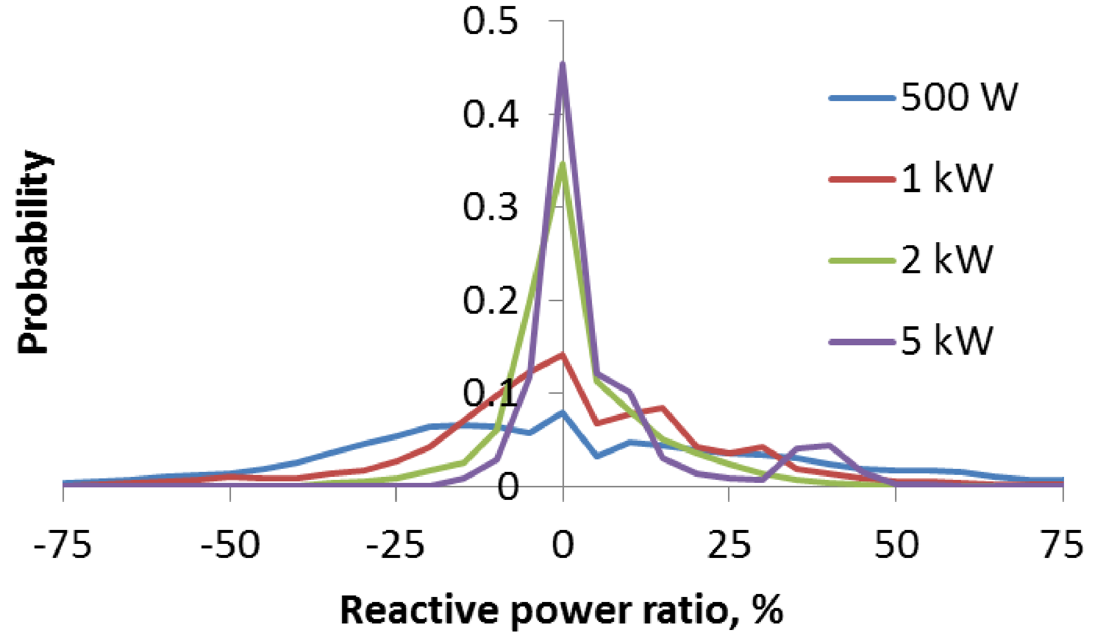
LOSS ASSESSMENT – MODELLING LV DEMAND







Half-hourly profile

- From demand data and Elexon Profiles

Add time variation and unbalance

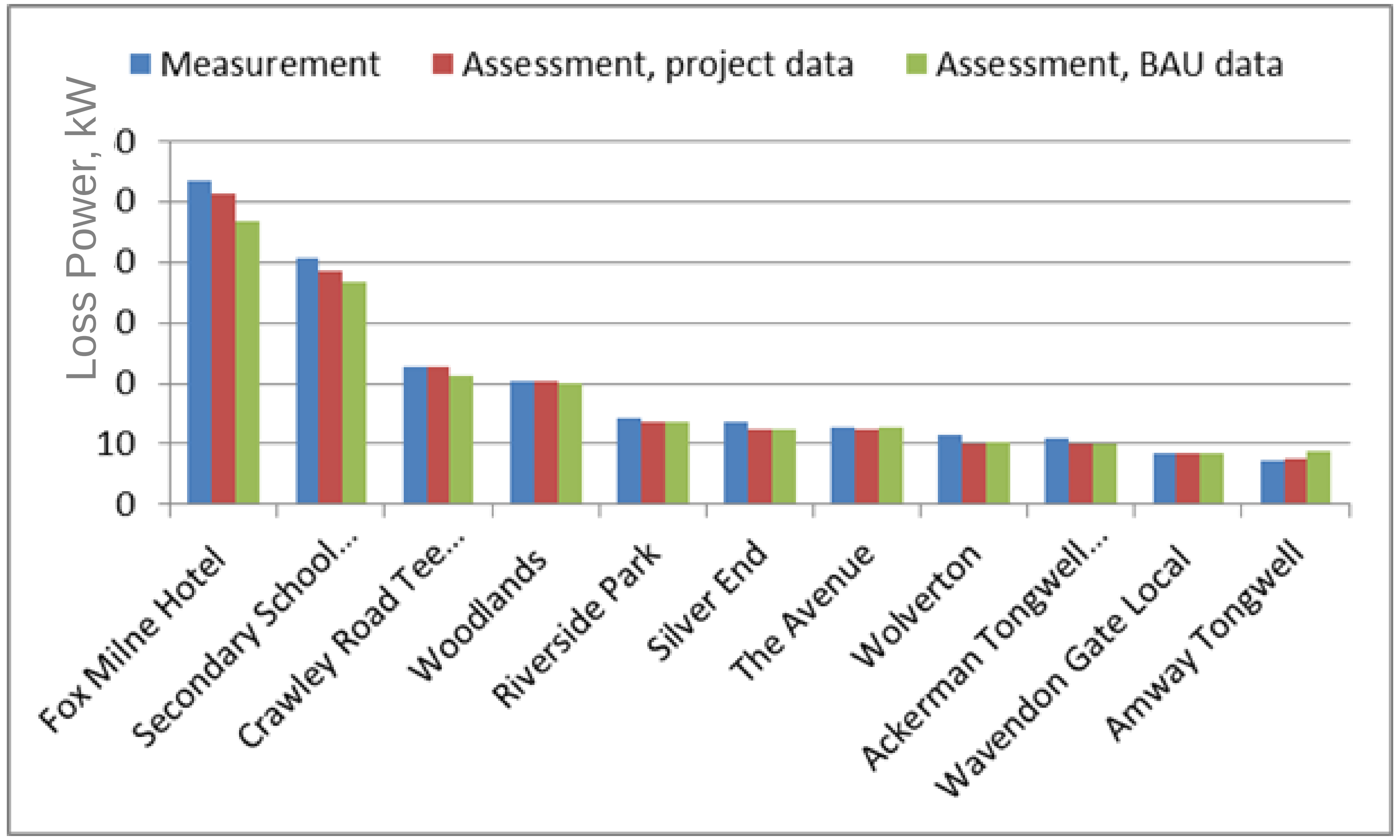
- Variation of 1-minute demand per phase for a given half-hourly demand

Add reactive power

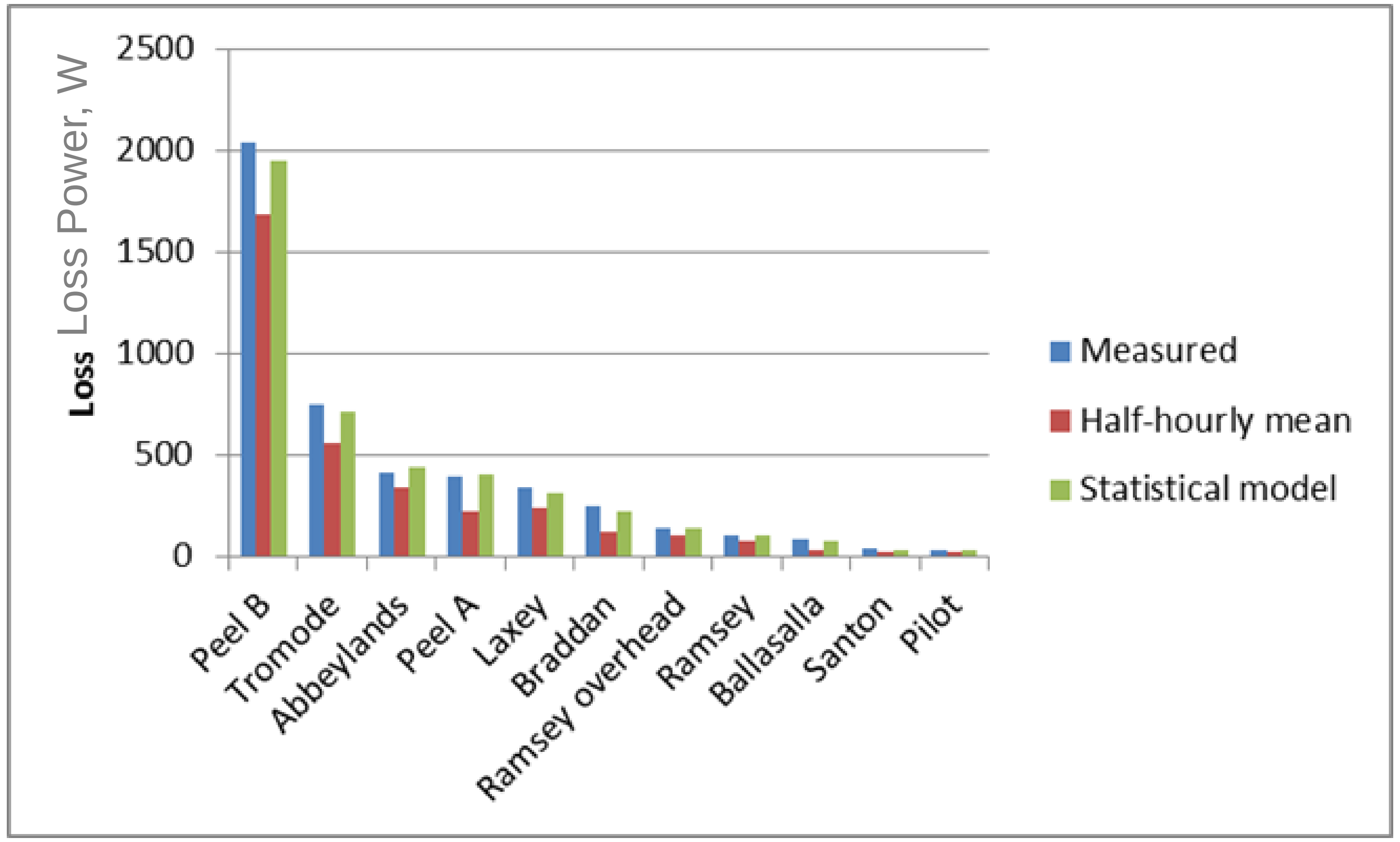
- Variation of reactive power for a given active power

Detailed analysis of the results from the Isle of Man monitoring provided the underlying statistical models that have been used for LV feeder assessments

LOSS ASSESSMENT– VALIDATION AGAINST MONITORED FEEDERS



HV Feeder Loss Assessment Validation



LV Feeder Loss Assessment Validation

Assessment method provides assessment of feeder-specific losses that agree well with full monitoring data

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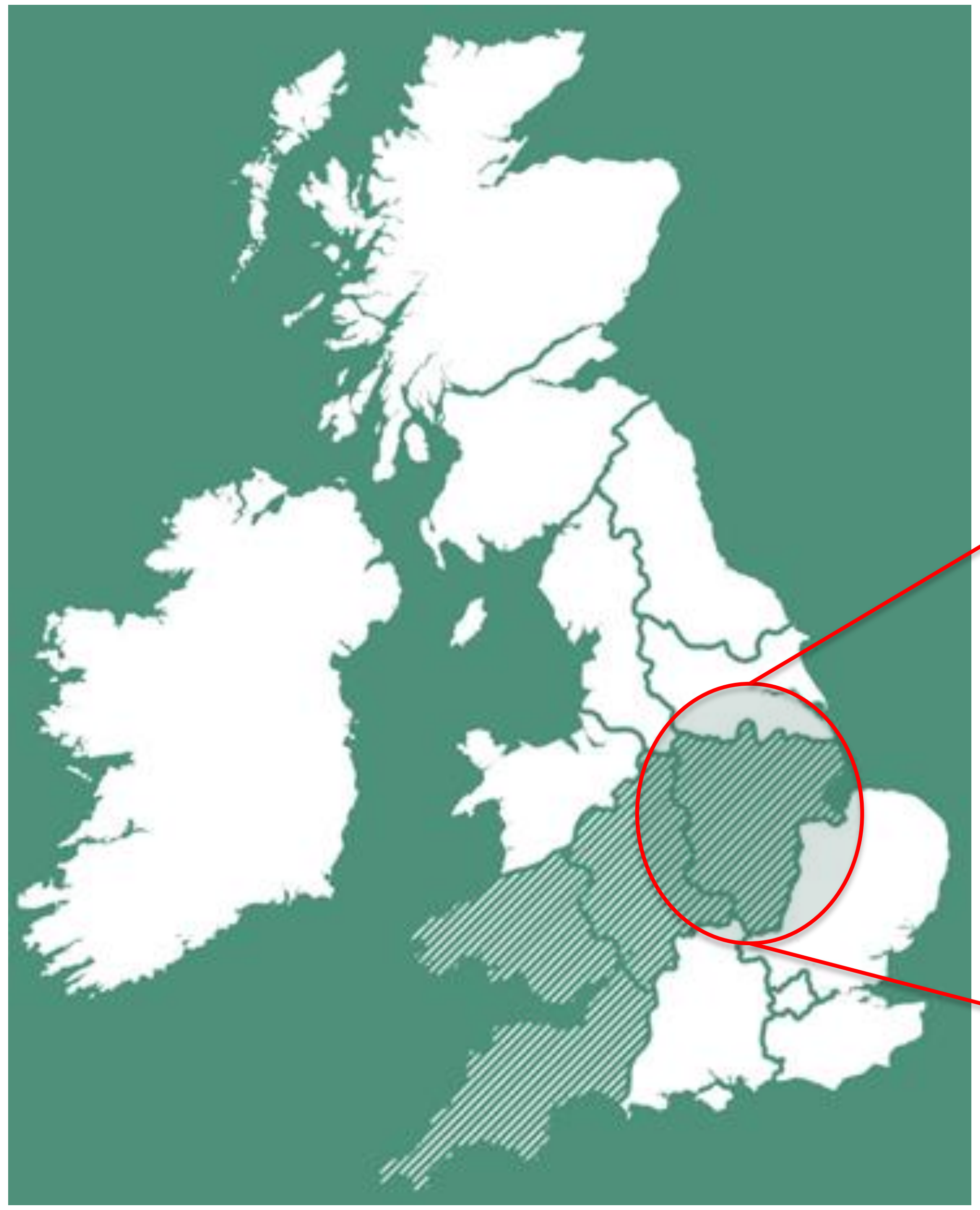
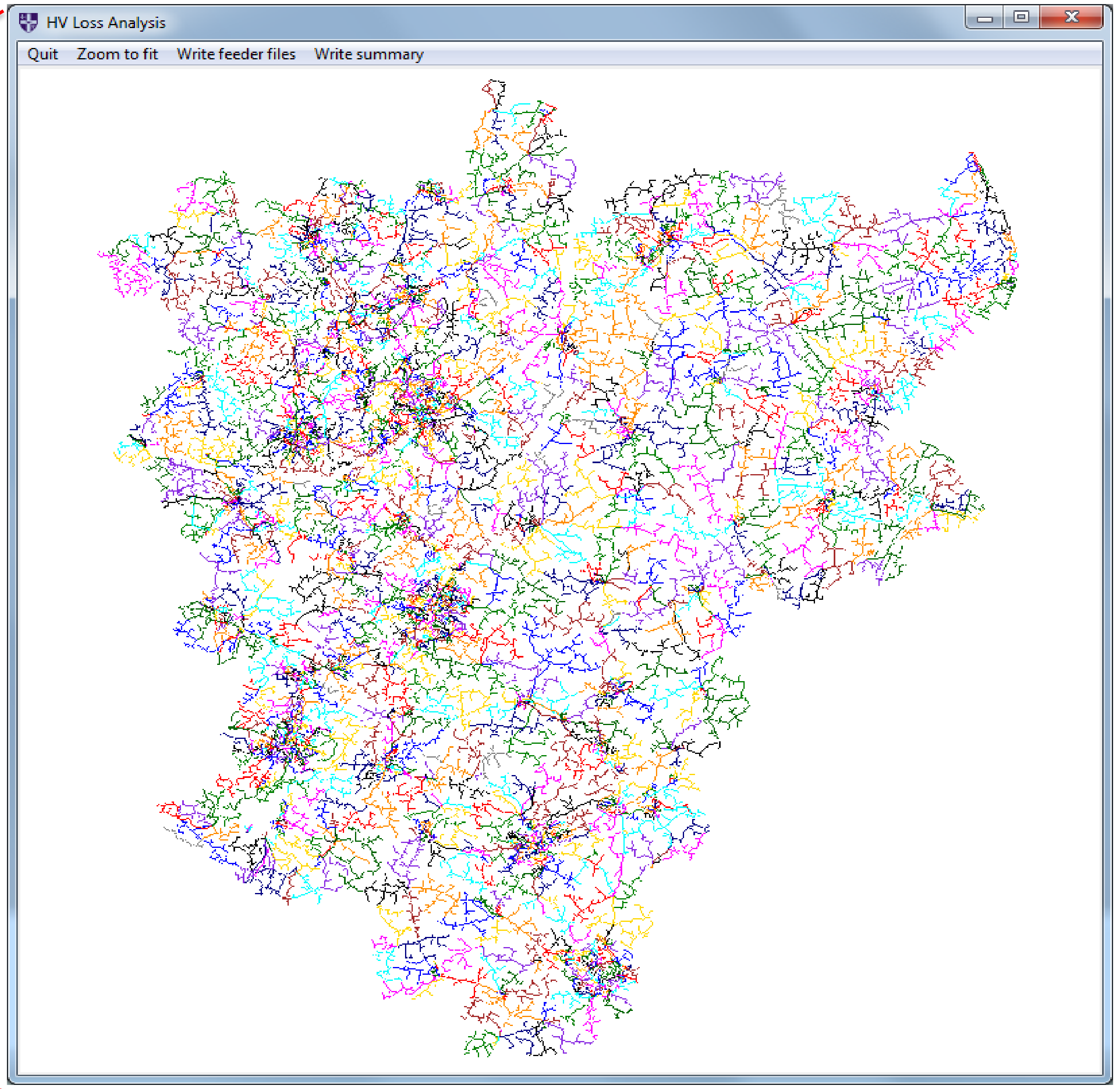
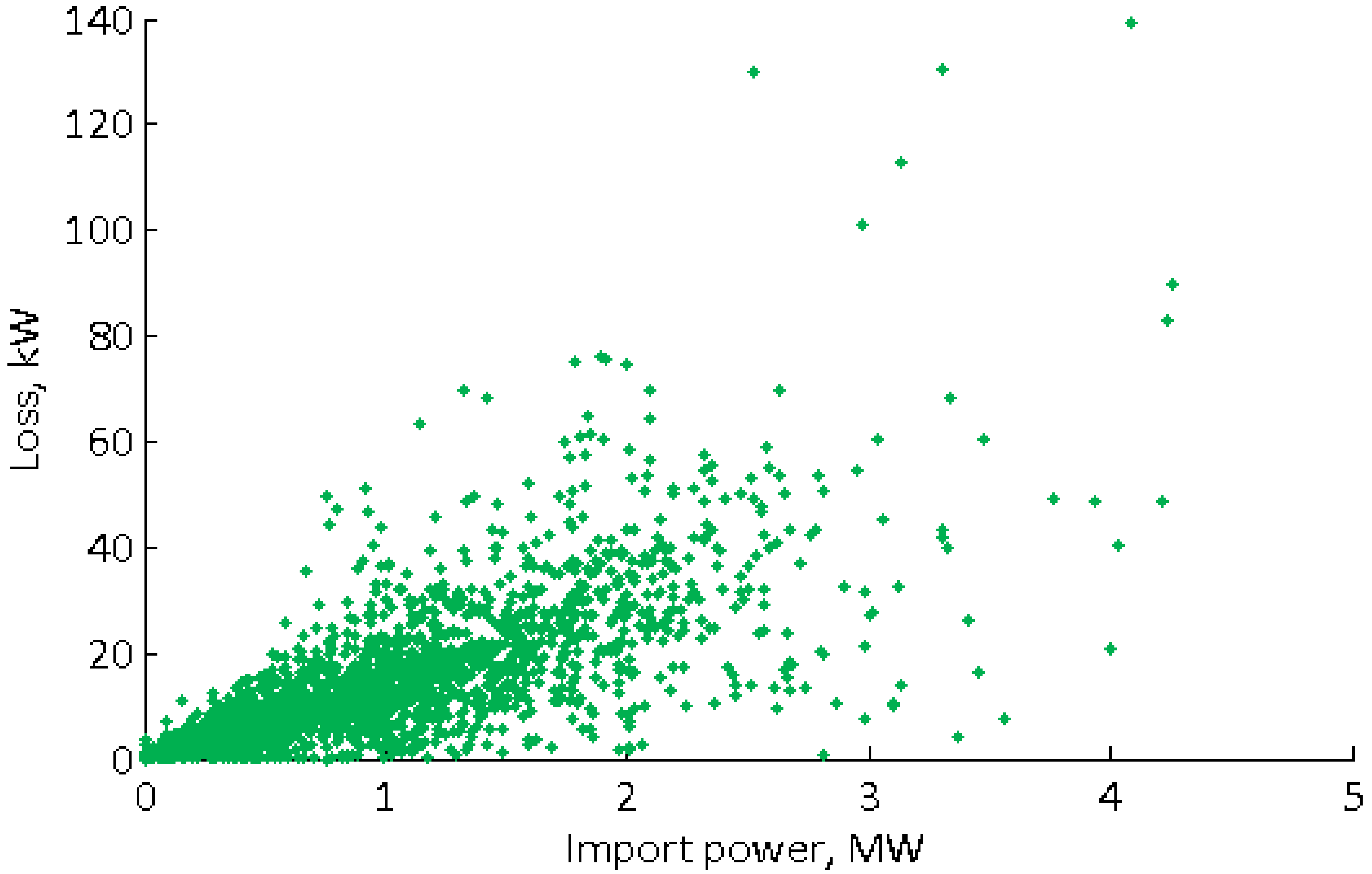
LOSS ASSESSMENT – LARGE-SCALE APPLICATION





Successfully applied to over 2,100 HV feeders and 69,000 LV feeders in the East Midlands region

LOSS ASSESSMENT – HV FEEDER RESULTS (1)



2,130 HV feeders assessment results

Scatter plot shows the range of results, though it contains significant overlay of individual feeder result points for lower mean demand / mean loss results

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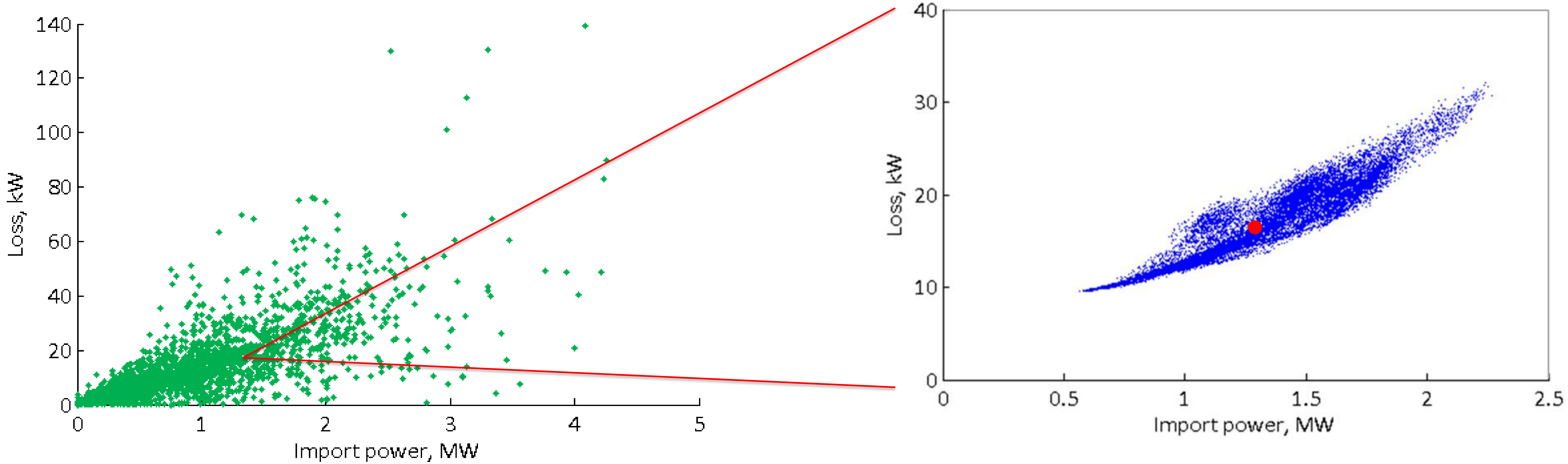
LOSS ASSESSMENT – HV FEEDER RESULTS (2)



2,130 HV feeders assessment results

Annual loss assessment for a single HV feeder

Behind each mean HV feeder result lies an assessment of a feeder's loss performance over an annual period

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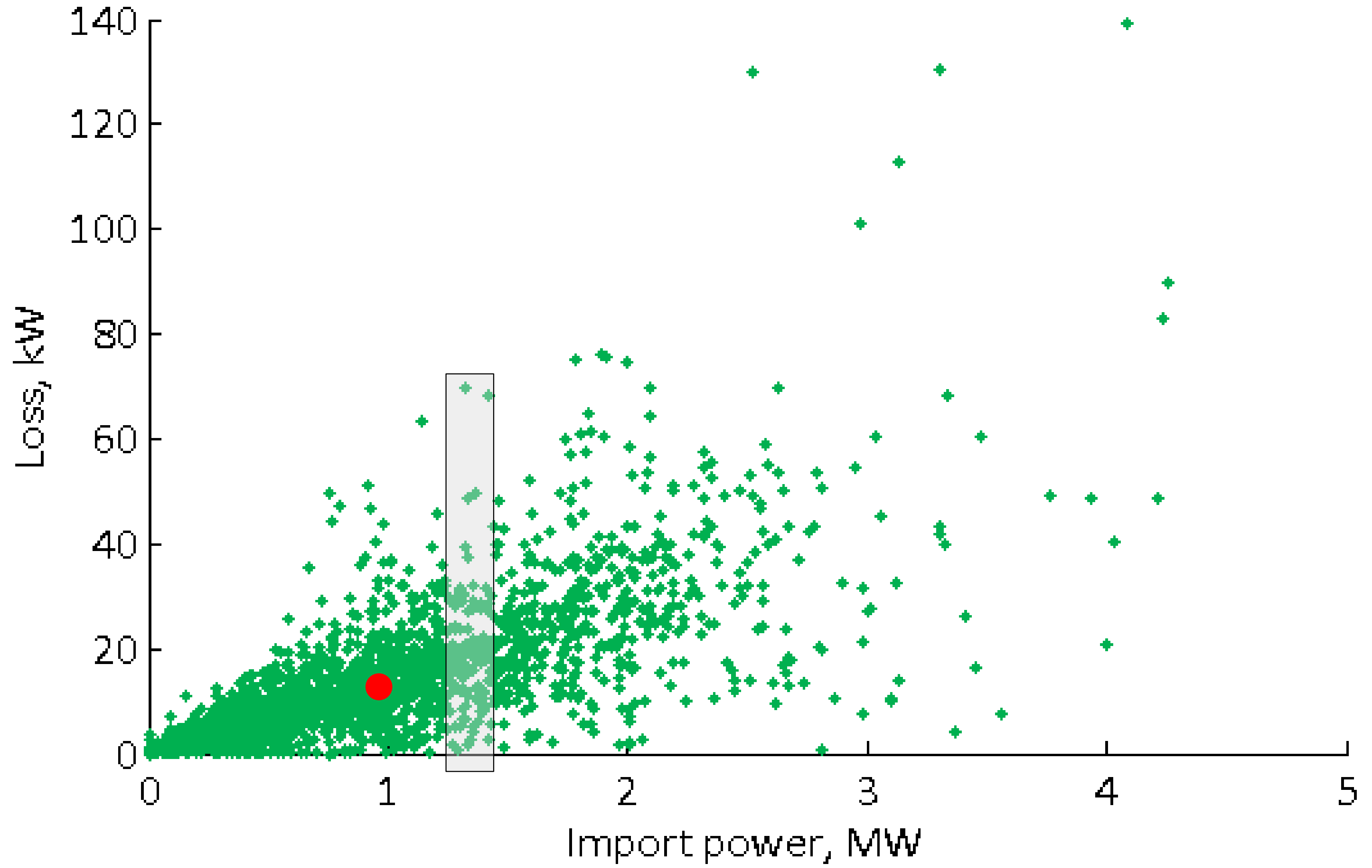
LOSS ASSESSMENT – HV FEEDER RESULTS (3)



2,130 HV feeders assessment results

Factors driving variation in losses

- Feeder resistance (length and cross sectional area)
- Numbers of distribution transformers / number of HV connections
- Load factor
- Location and relative magnitude of the load along the feeder
- Reactive power, particularly for industrial loads

Mean HV result: 1.47% loss, with significant diversity in individual feeder results

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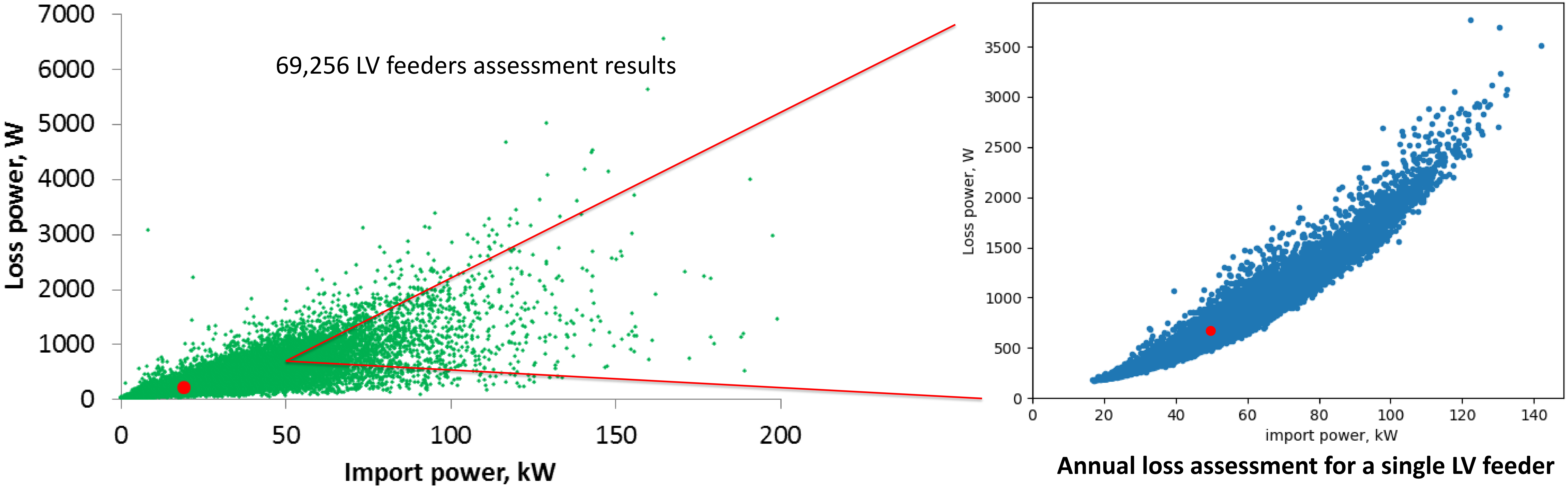
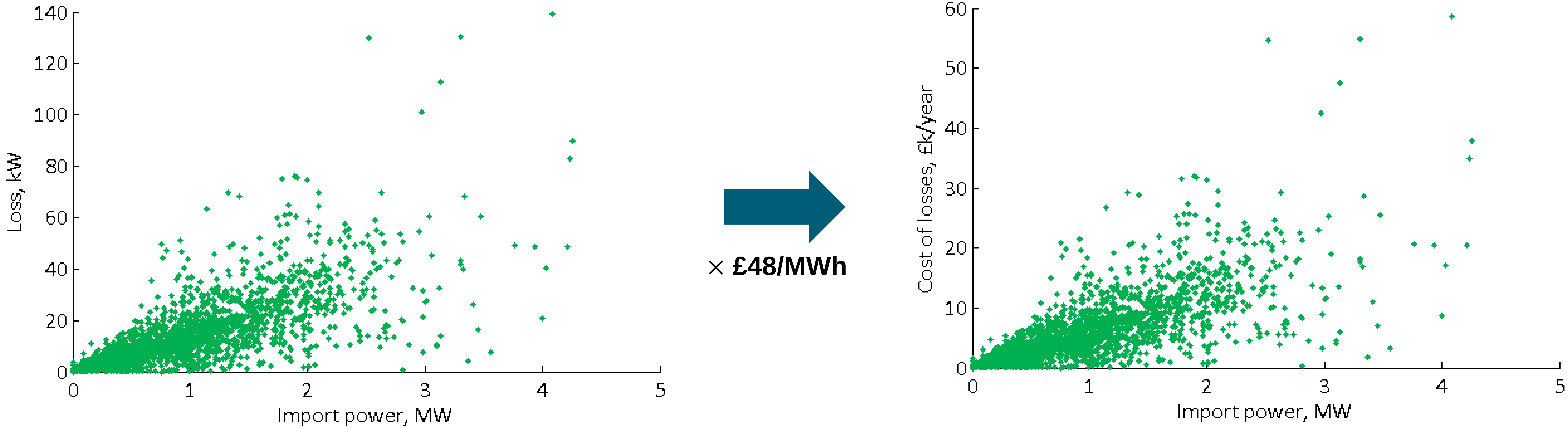
LOSS ASSESSMENT – LV FEEDER RESULTS



Annual loss assessment for a single LV feeder

Mean losses: 1.06% LV, with significant diversity in individual feeder results

LOSS ASSESSMENT – COST OF LOSSES



2,130 HV feeders assessment results

Assessment of technical loss power can be translated into an annual cost

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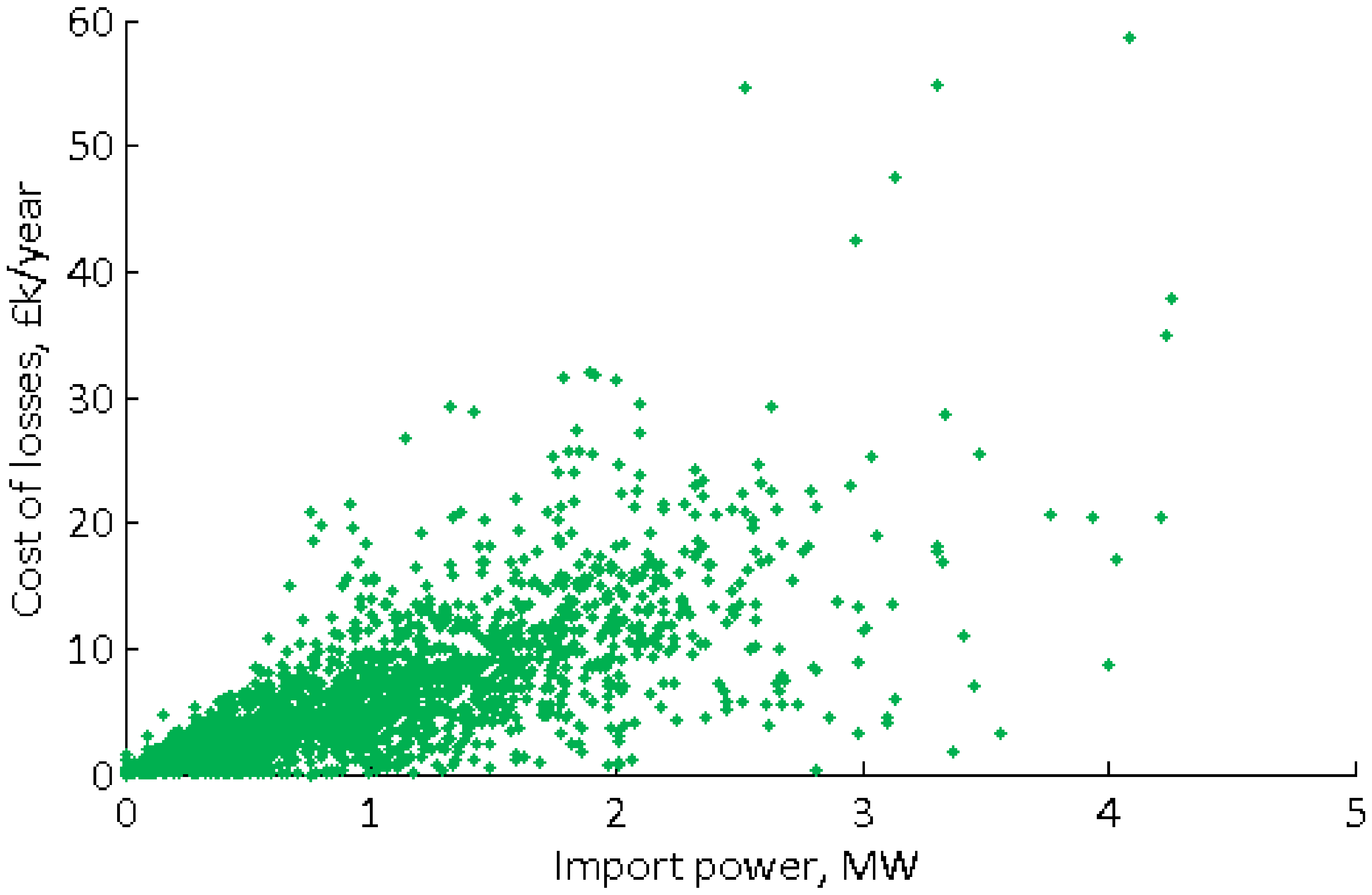
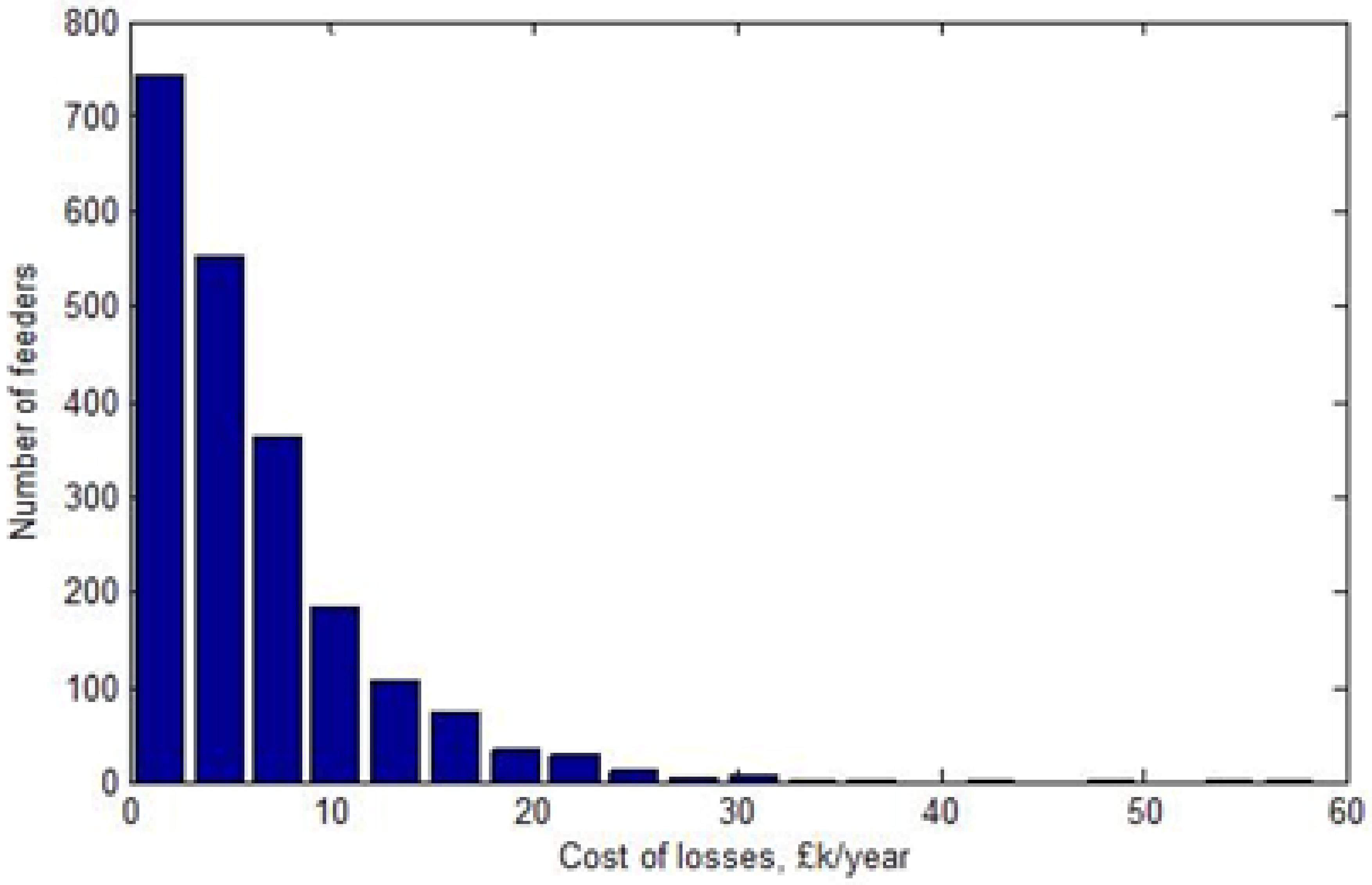
LOSS ASSESSMENT – COST OF HV FEEDER LOSSES

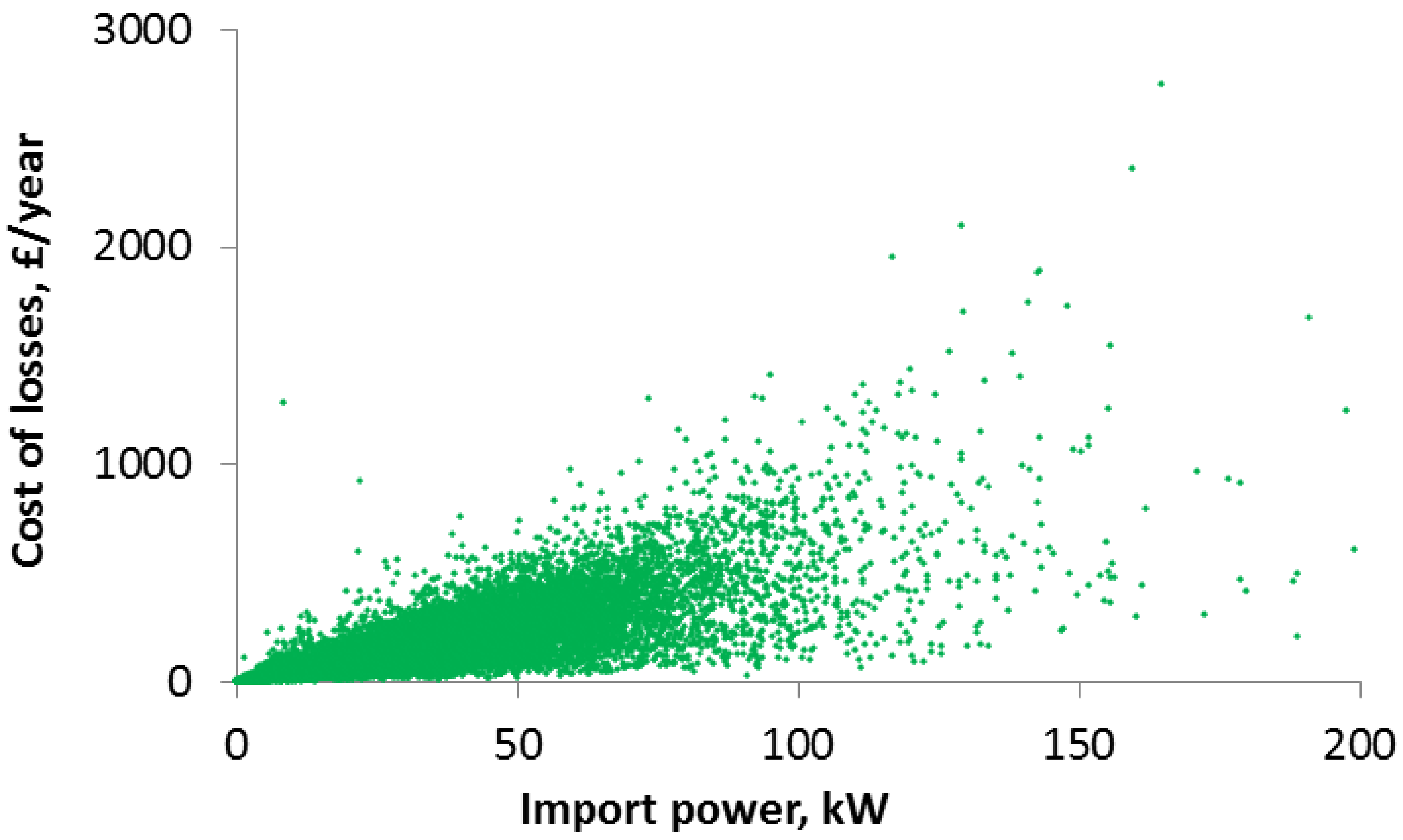


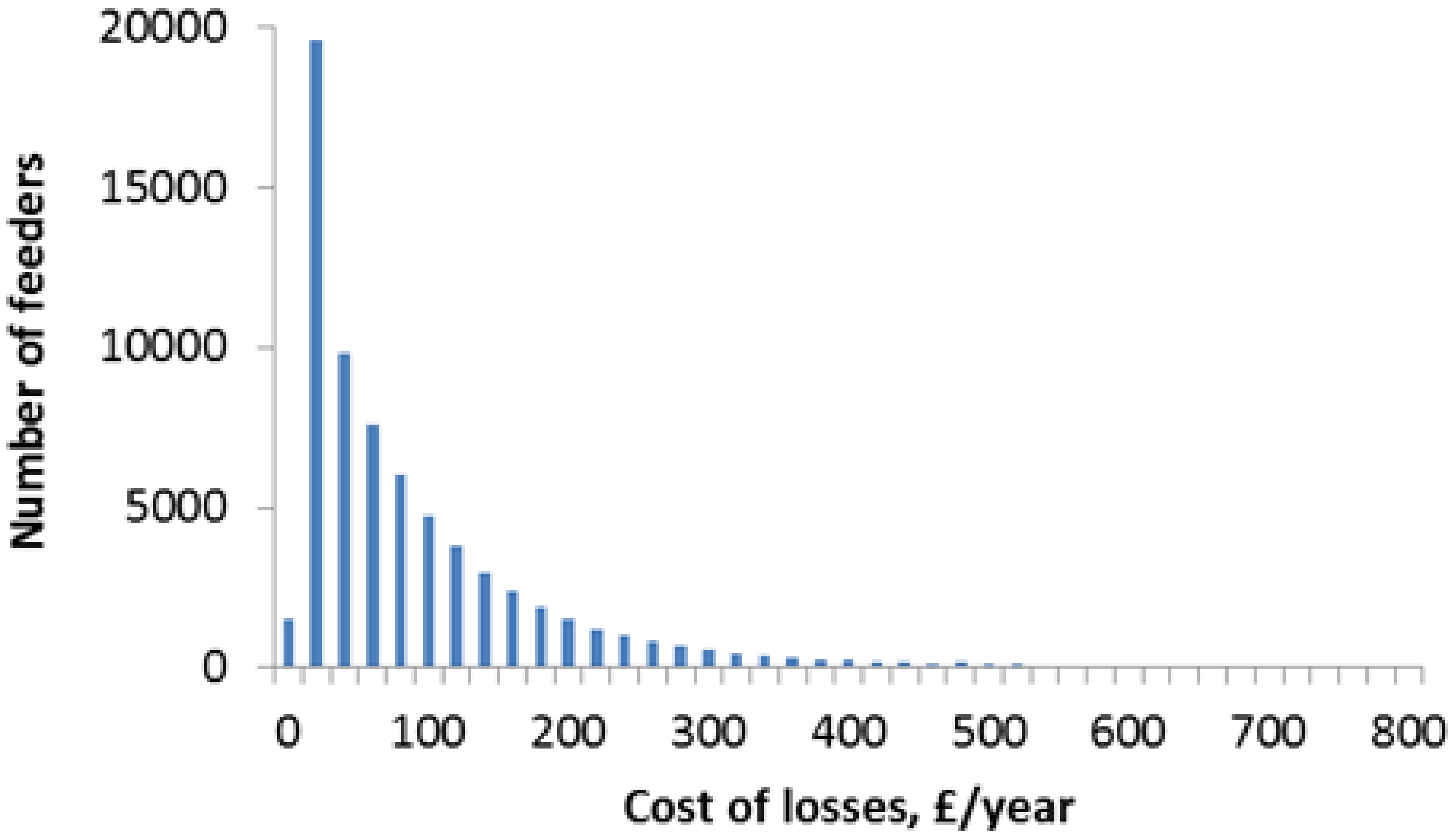


2,130 HV feeders assessment results

Small numbers of HV feeders have high cost of losses

LOSS ASSESSMENT – COST OF LV FEEDER LOSSES





2,130 HV feeders assessment results

Cost of losses per LV feeder is substantially lower than for HV feeders

CONCLUSIONS

1. Provides a Baseline

Project has a provided a baseline for assessed HV & LV technical losses for EM region.

2. Some Significant HV Feeder Loss Costs

Individual HV feeder loss costs can be significant, targets have been identified for possible mitigation action

3. High Volume, Lower Cost for LV feeders

Cost beneficial retrospective mitigation action on individual LV feeders is significantly more challenging than HV.

4. Evidence Supporting Policy Changes

Loss assessments provide further evidence of the benefit of recent WPD policy changes on future LV system design.

WESTERN POWER DISTRIBUTION INNOVATION TEAM

THANK YOU FOR LISTENING

ANY QUESTIONS?

CHRIS HARRAP
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WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

WESTERN POWER DISTRIBUTION INNOVATION TEAM

NEW PROJECTS & CLOSE

BALANCING ACT CONFERENCE

20TH JUNE 2019

JONATHAN BERRY
WPD - INNOVATION TEAM MANAGER

WESTERN POWER DISTRIBUTION
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WESTERN POWER DISTRIBUTION
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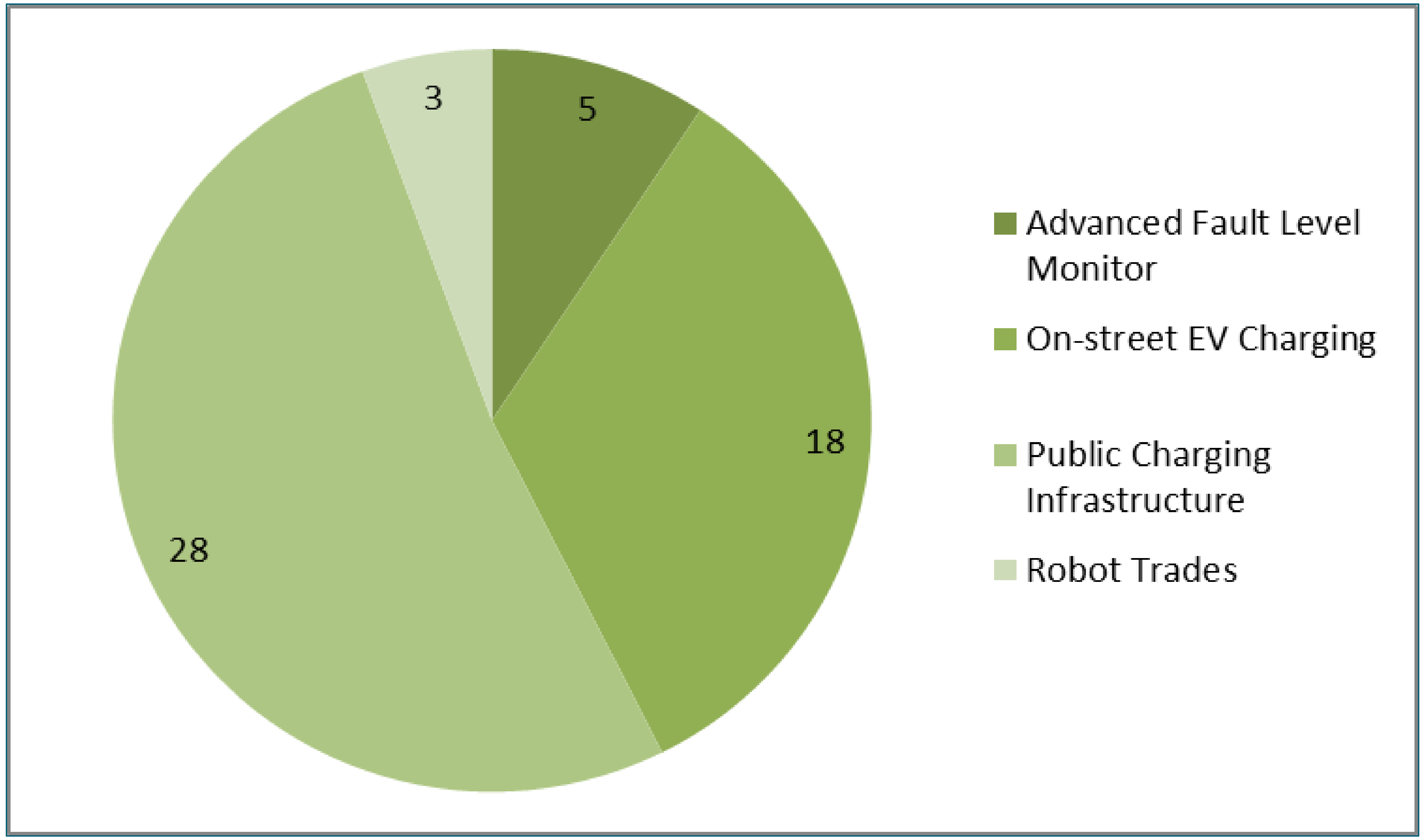
NIA THIRD PARTY CALL 2019

- 54 submissions across four themes
- Project value between £40k and £2.5M
- 11 taken forwards to meetings
- 2 developing in to NIAs



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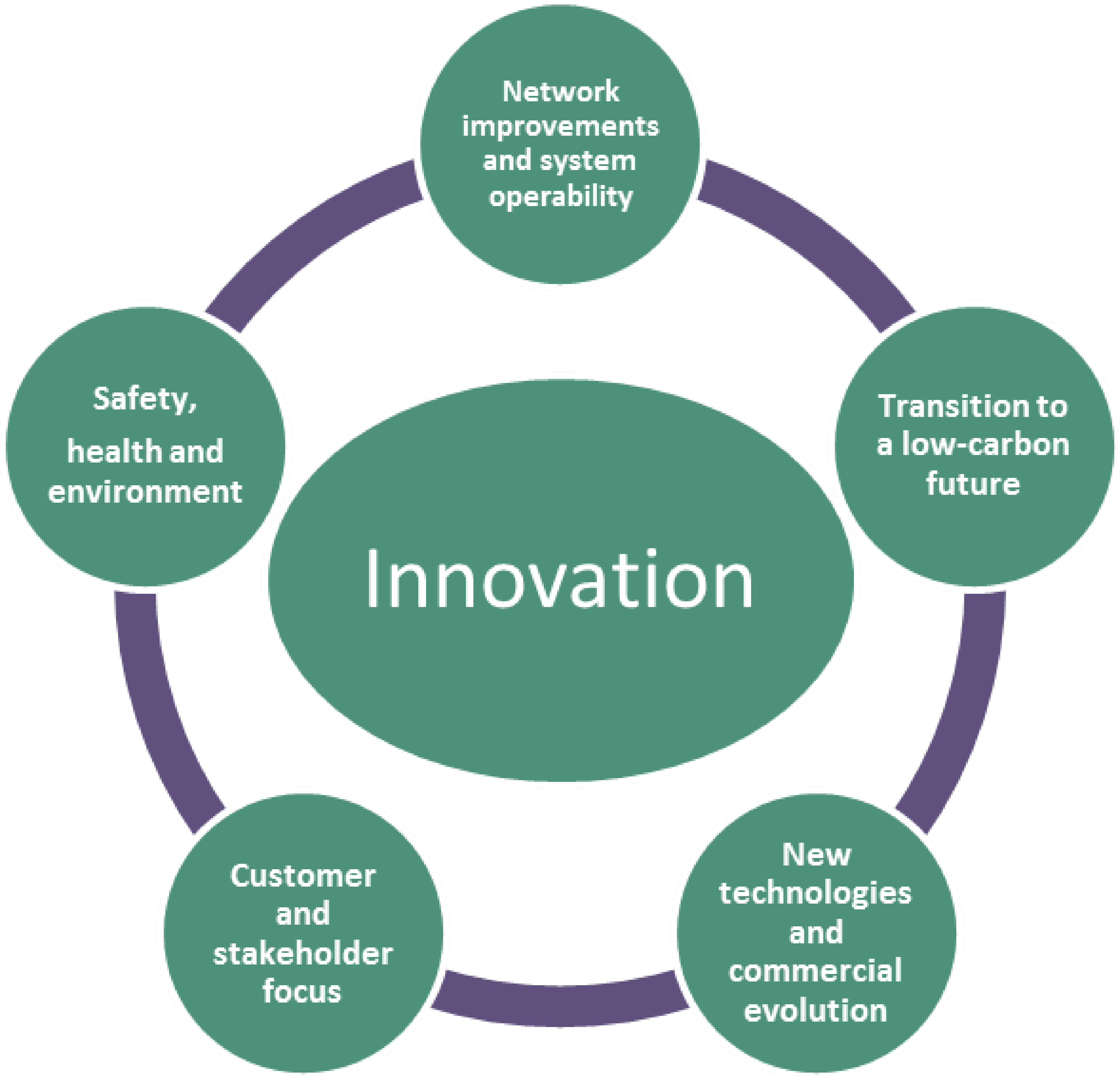
INNOVATION STRATEGY AND FORWARD PLAN



- WPD's Innovation Strategy aligned with ENA's Electricity Innovation Strategy
- Update end July 2019
- Forward Plan to be developed following Strategy update and consulted on

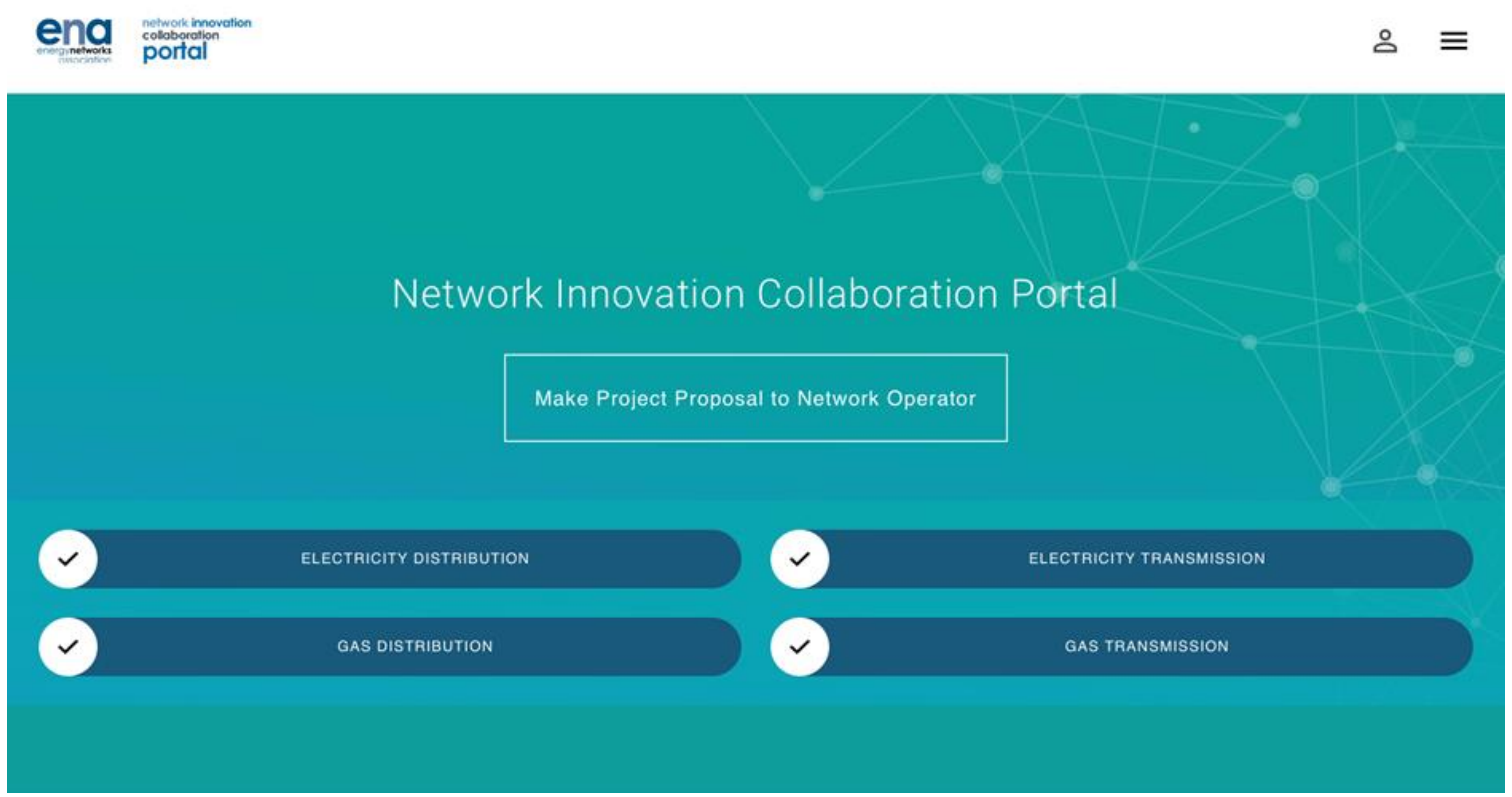
INNOVATION STRATEGY AND FORWARD PLAN

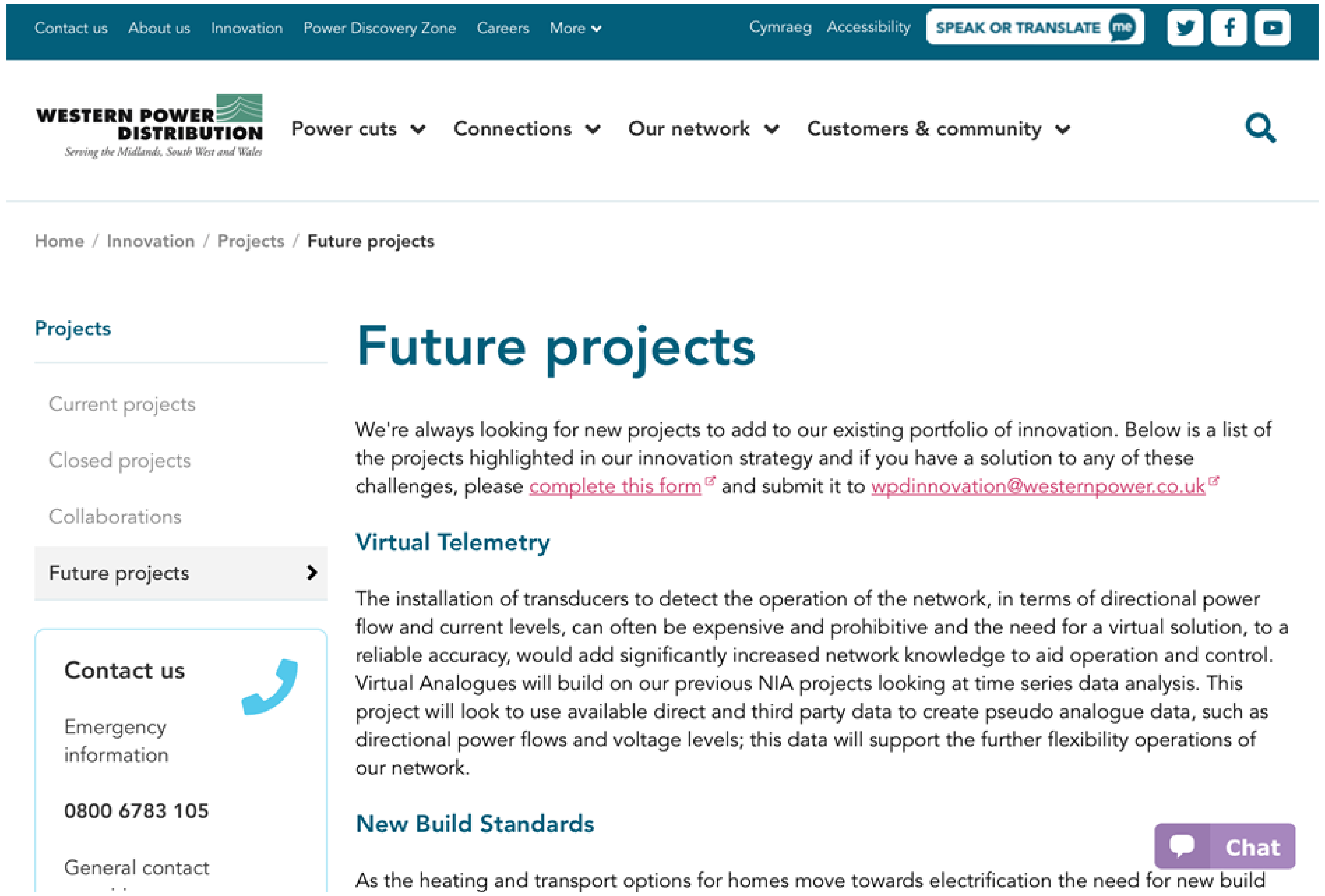
- In year aims and priorities
- Programme and portfolio building
- Link to longer term strategy aims
- Drive focus for NIA and NIC calls

Innovation Forward Plan

NEW PROJECTS & CLOSE

NEW PROJECT PROPOSALS





WESTERN POWER DISTRIBUTION INNOVATION TEAM

THANK YOU FOR ATTENDING

HAVE A SAFE JOURNEY

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales