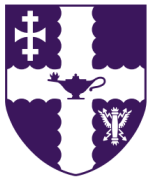
HV Pilot Follow-on Project Report

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Contents

- The first three slides in this document summarise a new proposal – the PHASEWISE project
- Following slides summarise the outcomes from HV Pilot and from SMITN, and next steps to develop this work as an enabling technique in PHASEWISE
- The final slides give further detail on the PHASEWISE proposal and explain how phase balancing would be achieved, and how the benefits would be assessed and costed

PHASEWISE

Phase-Aware Network Planning and Investment Strategy

ENIT ALIGNMENT

PRIMARY: INNOVATION CHALLENGE 3
INSTANT USE DOMESTIC ENERGY DEVICES

Enabling phase-aware assessment of plug-and-play LCT connections and proactive identification of resulting network constraints.

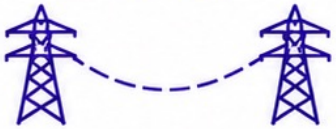
SECONDARY: INNOVATION CHALLENGE 2
FASTER BUILD AND MAINTENANCE

Supporting targeted intervention, improved asset utilisation and alternatives to reinforcement.

PHASEWISE builds on HV Pilot, SMITN and existing planning processes to transform phase intelligence into actionable connection, planning and investment decisions.

1 FOUNDATION PROJECTS

HV PILOT



- HV phase identification
- Machine vision
- Smart meter analytics

SMITN



- LV phase identification
- Feeder identification
- Smart meter insights

PHASE SWITCH SYSTEM



- Dynamic balancing concepts
- Capacity release understanding

DFES / NDP / DNOA



- Future demand forecasting
- Constraint identification
- Investment planning

2 PHASEWISE PROJECT ACTIVITIES

Developing a scalable phase-aware planning capability for NGED.

IDENTIFY CAPACITY OPPORTUNITIES



- Quantify phase imbalance
- Identify hidden capacity
- Assess capacity constraints
- Identify balancing opportunities
- Target priority areas for intervention

INTERVENTION ASSESSMENT



- HV balancing options
- LV balancing options
- Phase Switch System opportunities
- Alternatives to reinforcement
- Economic assessment (cost, benefit & capacity impact)

PHASE-AWARE FUTURE PLANNING



- DFES-informed forecasting
- Future constraint identification
- Asset investment planning
- Reinforcement deferment assessment
- Integrated planning with other processes

3 SUPPORTING TECHNICAL ACTIVITIES

SCALE & VALIDATE



- Apply HV Pilot methodology across a much wider range of network configurations
- Establish confidence and repeatability
- Assess network-wide applicability

IMPROVE NETWORK OBSERVABILITY



- Existing aerial imagery
- Existing drone imagery
- Drone thermal imaging
- Targeted drone surveys where required
- Machine vision enhancement

DEVELOP PHASE-AWARE NETWORK MODELS



- Integrate smart meter analytics
- Integrate machine vision outputs
- Improve topology understanding
- Improve network records

4 OUTPUTS

OUTPUT 1
CONNECTIONS & CAPACITY ASSESSMENT

- Phase-specific headroom
- Capacity assessments
- Alternative network solutions
- Capacity release opportunities
- Customer complaint identification (anticipate issues, identify at-risk areas and provide evidence for targeted intervention)

OUTPUT 2
SYSTEM PLANNING, FORECASTING & INVESTMENT SUPPORT

- Reinforcement optioneering
- Asset investment planning
- NDP support
- DNOA support
- Secondary System Planning support

OUTPUT 3
PHASEWISE BAU TOOL & PROCESS

- Combine HV Pilot and SMITN capabilities into a single PHASEWISE BAU tool and process
- Joint delivery with IT&D to develop and implement the operational solution
- Embed PHASEWISE into day-to-day planning processes

5 BUSINESS BENEFITS

- Improved Network Assumptions
- Improved Asset Utilisation
- Capacity Release
- Deferred Reinforcement
- Improved Investment Decisions
- Higher Confidence in Planning Qutputs
- Reduced Customer Complaints
- Lower Whole-Life Network Costs
- Better Customer Outcomes

PHASEWISE builds on HV Pilot, SMITN and existing planning processes to transform phase intelligence into actionable connection, planning and investment decisions.

HV Pilot – Smart meter method

- Phase identification using the smart meter method works well
- Phase voltage variations are sufficiently consistent to enable phase identification, by correlation of smart meter voltages, between distant substations on an HV feeder
- The method performs better where substation LV monitoring is available, but also works without this
- If there is no substation monitoring, identified phases are clusters rather than actual phases L1, L2, L3
- Errors in phase identification appear to be due, at least partly, to voltage drops on LV feeders that are specific to local groups of customers
- Phase identification accuracy is therefore limited more by the LV feeder voltage drops than by the separation distance of substations along the HV feeder

HV Pilot – Machine vision method

- Conductor connections are detected, even when human interpretation is less certain
- Images for many feeders were found to be unusable, and many junctions were not covered by the helicopter survey
- There were few examples in the available images of single-phase transformer connection onto three-wire feeders, and there are fewer images of two-wire junctions than of three-wire junctions
- Given the gaps in the aerial survey and the presence of underground cable sections, it is not possible to trace end-to-end conductor connectivity, so phase identification relies on conventions to determine the left-to-right conductor sequence on overhead lines
- These conventions appear to be respected for most overhead lines, but uncertainty limits the confidence of phase identification, even though conductor topology can be determined
- Conductor topology at junction poles can be determined for three-wire connections, in addition to the two-wire HV spurs originally intended for the analysis

HV Pilot – Combined method

A proposal for a combined method, where data for both methods exists

1. Machine vision identifies and confirms single- or three-phase transformers and two-wire spurs
2. Voltage data analysis identifies phases of smart meters
3. Phases of confirmed single-phase transformers determined by weighted voting of individual smart meters
4. Phases of transformers on two-wire spurs without smart meter customers assigned based on neighbouring transformers with smart meters
5. Conductor sequence determined at two-wire and single-phase transformer connection by machine vision analysis, using phases derived from smart meter method
6. Where there is confidence that the conductor sequence remains unaltered, phases of transformers or two-wire spur on three-wire sections without smart meters determined using machine vision analysis

HV Pilot – Further work

- Apply the methods to more HV feeders to ensure common design practices can be accommodated
  - The analysis should ensure a sufficient range of asset types have been encountered. For example, voltage regulators are installed on only a few feeders so may not have been found in a smaller test sample. Future analysis needs to allow for these, and other asset types not yet discovered. We are aware that some HV feeders include transformers, for example from 11 kV to 6.6 kV.
- Improve statistical representation of phase identification results
  - The smart meter analysis uses threshold parameters, for example to reject spurious voltage values. These have been configured based on a few unusually long feeders so further work is needed to develop parameters that work more generally. The machine vision method may also have parameters to be generalised. Results so far indicate a high confidence for phase identification, but these are based on only a few feeders.
- Improve aerial survey images
  - Higher resolution images would improve results from the machine vision method. This could include more frequent captures for better spatial resolution along the flight path, giving multiple captures for each transformer or junction, or images captured using drones flying nearer to the connections and with observations from multiple angles.
- Demonstrate the combined method
  - The steps to integrate the smart meter and machine vision methods have been proposed but not demonstrated in full. On some feeders, both methods provide a phase identification so there is scope to generate a combined confidence metric. Where the smart meter results are ambiguous, an automated phase selection process is needed.
- Interpret network state from PowerOn
  - Email information from HV planners has been used in HV Pilot to avoid applying data analysis when data would be inconsistent due to network topologies, or when open points are moved for maintenance work. Avoiding this manual process, the analysis could compare the network configuration from PowerOn with the normal state from Electric Office to ensure aerial survey and smart meter data are consistent.

SMITN – Further work

- SMITN project developed four use-cases of smart meter data
  - Planning profiles
  - LCT detection
  - Phase identification
  - Substation and feeder identification
- These user-cases were considered somewhat independently, each assuming the success of the others
- There is still a need for a clearly defined end-to-end process
  - Calculations of unbalance require an estimate of the demand profile (with the resolution to be determined), and so must only include MPANs that connect to the feeder. Phase identification involves clustering, also requiring that the correct MPANs for the substation are already known. However, feeder identification requires correlation of MPANs that are on the same phase, so an iterative method is needed.

Summary of innovation project background

- We have good techniques to identify phases of LV customers and single-phase transformers
  - SMITN developed LV phase and feeder identification
  - HV Pilot developed single-phase transformer and HV spur phase identification
- These techniques can be combined with consumption data or load profiles to quantify unbalance
- Phase Switch System provides dynamic phase balancing
- Other projects are investigating interventions such as static tap changes and dynamic OLTC installations manage voltage on all phases

- The obvious next step is to define the decision-making process that determines which methods to use, and where to deploy them

PHASEWISE proposal

- ‘PHASE WISE’ will release capacity by optimising phase balance
- The need for this additional capacity is triggered by new connection requests, by customer voltage complaints, or by thermal overloading
- Integrated HV and LV modelling will compare benefits of phase balancing will consider options at HV and LV
- Future LCT uptake will be considered probabilistically, based on DFES, allowing for the stochastic variation between customers
- Aim: to develop a business tool, integrated within NGED IT systems to quantify the capacity release from HV and LV phase balancing, with estimated costs and deferment duration, as an alternative to more costly reinforcement

Capacity release process

- Identify HV feeders at risk as a trigger to initiate analysis
  - High incidence of customer complaints, smart meter voltages near limits, new connection requests, connections with constraints, LV feeder and substation demand high relative to rated capacity
- Phase identification
  - Apply the methods from SMITN and HV Pilot to determine phases at LV and HV
- Phase demand assessment
  - Create custom aggregation groups to determine LV feeder demand per phase
  - Identify constraints at transformers and on LV and HV conductors, relative to thermal ratings
- Phase balancing and tap setting optimisation
  - Identify incremental changes to phase connections at HV and LV
  - Compare capacity release using aggregated headroom metric to quantify released capacity
  - Summarise balancing interventions and cost of implementation
- Recommendations for field operations
  - Cost benefit analysis of balancing options against alternative reinforcement methods
  - Assess probabilistic LCT growth based on DFES to estimate how long released capacity will remain

Customer complaints

- Mostly relate to over-voltage
  - Could be caused by export power, high voltage at the primary substation, or unbalanced demand on other phases
- Response is typically reactive rather than proactive
  - Smart meter data could allow over- and under-voltages to be detected ahead of customer complaint. A risk assessment approach would be needed to target smart meter voltage reads.
- Customer complaints appear to be treated on an equal basis without prioritisation based on severity or frequency of over-voltages
- Business as usual response
  - Confirm voltage issues using smart meter data, or additional monitoring if no smart meter available
  - Over-voltages may be persistent over time and common to multiple LV customers, or intermittent and localised. We understand that all are treated equally, though the frequency of occurrence could be very different. There is limited visibility of phase connections.
  - On rural substations, transformer tap settings may be changed to reduce voltage ranges
  - If this does not, or cannot, provide a resolution, rural pole-mounted transformers may be upgraded
- Without phase identification, the response to voltage complaints does not consider phase unbalance
  - Phase balancing could provide a lower cost response and avoid the need for a transformer upgrade
- The response to complaints mostly focuses on LV assets, without considering HV voltage management

HV connection phase balancing

HV voltage drops are typically lower, by proportion, than LV voltage drops, but corrections to unbalance at HV could release capacity for all the transformers connected to the feeder. Demand on HV feeders has more aggregation than at LV so more likely that one-off changes can be deployed.

Assumed for HV Pilot:

- Two-wire HV spur connections to three-wire overhead line
  - This could have a high impact in terms of demand, as a spur can connect many single-phase transformers. Spurs can have very different numbers of transformers and connect to the three-wire line at different places, so a perfect balance may not be possible. Where a good balance can be achieved, it may only be balanced locally.
- Single-phase or split-phase transformer connections to three-wire overhead line
  - Individual transformer connections could allow a more granular balancing but individually have less impact on the overall HV feeder balance.

Additional:

- Three-phase transformer connection to three-wire overhead line
  - Although the LV connections of three-phase transformers may be balanced, results suggest that this is not always the case. Even lower levels of unbalance may at a high-capacity transformer may have similar demand magnitude to the total demand from a single-phase transformer. Where three-phase transformers have been installed to upgrade a previous single-phase transformer, the LV connections are unlikely to be balanced. Reconfiguring connections on the HV side may offer a simple fix, though does not address the impact of unbalance within the transformer.

LV connection phase balancing

LV voltage drops can be high, especially on long rural overhead line. Corrections to unbalance could release useful capacity, though the impacts are limited to individual feeders or transformers and so costs may be more difficult to justify. LV phase unbalance is likely to be greater than HV unbalance due to the reduced demand aggregation, but variations in unbalance are more dynamic.

Static:

- Single-phase customer connections to three-phase line
  - Individual customer phase connections via overhead line could be reconfigured, especially for high-demand commercial customers. Disruption is limited to individual customers. We assume that changes to underground service cable connections to mains are cost-prohibitive.
- Single-phase LV spur connection to three-phase feeder
  - Groups of customers on single-phase spurs from overhead lines could be re-balanced.
- LV feeder connections to transformer LV busbar
  - Where transformers have been upgraded to three-phase, single-phase feeders could be assigned to different phases on the LV side. Transformers with multiple three-phase feeders could be re-balanced at the busbar connection on the LV side. Feeder cable insulation colouring would differ between feeders, so care would be needed if feeders could join at link-boxes.

Dynamic:

- Phase Switch System
  - Switching dynamically selects one of three routing configurations -straight, rotated +120°, rotated -120°
  - PSS installed at a cabinet mid-way along an LV feeder so relatively high cost to install
  - Current sensors installed at the cabinet and at the substation
  - Routing configurations selected at the cabinet with the objective of balancing demand at the substation
  - Switching is selected to optimised balance on the first feeder cable from the substation. This is likely to be the most critical cable for many LV feeders but not necessarily the case for tapered feeders or where faults have been repaired with lower rated cable sections
  - Likely to be less viable for highly branched LV feeder topologies
  - Further work is needed to assess where and when to deploy PSS

Rural overhead lines

- Limits to capacity appear more likely to occur on rural overhead lines
- Low carbon technology uptake may be higher than in urban areas
  - Increased mileage for EVs in rural areas, and fewer commercial charge-points
  - Heat pumps have a greater financial advantage for customers not on gas grid
  - Some areas have customer demographics with more ability to invest in LCTs
  - Long line lengths and higher impedances on overhead lines
- Stochastic LCT adoption is a greater concern for smaller numbers of customers connected to smaller transformers and with lower line ratings
  - With a uniform distribution of LCTs, smaller transformers will have a less even uptake rate. Some will have higher than average LCTs, possibly exceeding capacity, and others will have lower than average numbers. Conversely, growth in LCTs at larger ground-mounted transformers will tend to be closer to the average.
- Evidence to assess this is available from voltage complaint data, but so far has not been investigated in detail

LCT connection growth

- For any given mean uptake rate of LCTs, growth on an LV feeder or transformer is stochastic, biased by demographic trends and clustering effects
- Future mean uptake is uncertain, as seen with multiple DFES scenarios
- Historical connection data analysis
  - Using CROWN LCT connection data, define localised uptake statistics, eg. probability of $n + 1$ LCTs, given n existing LCTs. Overall statistics can be calibrated for current local LCT uptake where connected data is corrected using SMITN LCT detection.
- LCT demand analysis
  - Large-scale regression modelling from feeders with varying numbers of LCTs per customer to quantify half-hourly demand impact
- Future demand growth modelling
  - Scale historical uptake statistics for future LCT growth from DFES
  - Apply probabilistic LCT growth to customers on HV feeder
  - Differential power-flow analysis to find voltage and thermal load power-flow

Benefits

- Avoided customer complaints
- Transformer replacement deferred where balancing provides an alternative solution
- Fast response to over-voltage, avoiding transformer lead times
- Disruption reduced to those on affected phases or connections
- Reduced losses
- Releases headroom for new connections
- Updates network data for improved modelling accuracy

Method

- WP1 – Site selection
  - Suggest to aim for 100-200 HV feeders, selected for network topology rather than machine vision data availability
  - Drone surveys could be commissioned
- WP2 – Phase identification
  - Uses a combined smart meter and machine vision method
  - Identifies custom aggregation groups of customers, providing phase-specific demand data to identify thermal constraints
- WP3 – Balancing algorithm definition
  - Defines machine-learning optimisation to allow for phase balancing, incorporating combined effects at HV and LV
- WP4 – End-to-end phase balancing
  - Applies the balancing methods, aiming for optimisation with minimised cost of changes
  - Identifies locations for static phase balancing or for dynamic deployment of Phase Switch System
- WP5 – Demand growth modelling
  - Develops statistical models for growth in LCT connections and the associated impact on demand
- WP6 – Integrated phase balancing recommendations
  - Develop CBA process to recommend interventions for the selected project feeders, with phase balancing options, with costs and confidence that benefits will be sustained
- WP7 – Develop Business-as-Usual process
  - Work with NGED business stakeholders and IT&D to define an end-to-end process, initiated by triggers from planning, or customer complaints, defining a CBA for recommended interventions, and transfer for review and implementation

Next steps

- Initial data needed on locations of customer complaints to assess whether numbers on overhead lines, and clustering impacts
- Data also needed on costs of existing process to resolve customer complaints, including fixed tap changes and transformer upgrades