SP Electricity North West

NIA ENWL036

LV Predict II

Closedown Report

21/05/2026

Version History

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Review

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Approval

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SP Electricity North West

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Glossary of terms

Acronym	Description
BAU	Business as Usual
CBA	Cost Benefit Analysis
DNO	Distribution Network Operator
ENA	Energy Networks Association
EV / EVs	Electric Vehicle / Electric Vehicles
GIS	Geographic Information System
IPR	Intellectual Property Rights
LCT	Low-Carbon Technologies
LV	Low Voltage
NIA	Network Innovation Allowance
PEA	Project Eligibility Assessment
PILC	Paper Insulated Lead Covered
PoC	Proof of Concept
TRL	Technology Readiness Level
XLPE	Cross-Linked PolyEthylene

Executive summary

Aims

LV Predict II aimed to build on the work completed in the LV Predict I project by refining and extending a probabilistic modelling framework to improve model skill and reliability, expand the model to other Low Voltage (LV) network assets, and enable use of outputs in decision making. The project's outputs should allow networks to move from reactive fault-driven repairs to a targeted proactive LV replacement strategy, including sensitivity testing to replacement volumes and prediction skill. LV Predict II aimed to deliver a Cost Benefit Analysis (CBA) methodology to provide a repeatable, adaptable framework to quantify the net financial benefit of this approach.

Methodology

The project combined detailed physical modelling (demand-to-temperature-to-damage) with statistical modelling trained on simulated outputs, enabling scalable prediction of degradation across realistic network conditions where network information, direct monitoring and failure datasets are limited. The key methodological enhancements from LV Predict 1 include:

- Transient thermal behaviour;
- Cable insulation thermal resistance;
- Temperature-dependent resistivity;
- Local joint heating and contact resistance effects;
- Expanded material and damage mechanisms (including Cross-Linked PolyEthylene (XLPE) and Paper Insulated Lead Covered (PILC) cables);
- Geographic Information System (GIS)-derived network simulation with emulator-supported load flow prediction.

Outcomes

LV Predict II delivered a technically enhanced, end-to-end methodology for assessing the degradation and condition of buried LV cables and joints under present and future demand scenarios. It uses a hybrid framework that combines physically based degradation modelling with statistical models trained (in the absence of input and validation data, i.e. uncertain age, usage, previous failures) on large-scale simulated data. The LV Predict II methodology has progressed beyond a Proof-of-Concept (PoC) through substantive upgrades to the thermal and damage physics, realistic GIS-derived network simulation at scale, and a computational approach that makes large volumes of scenario modelling tractable via load flow emulation.

Key learning

1. Temperature history is a dominant driver of degradation and must be modelled with realistic thermal transients and joint-specific effects.

2. Data scarcity necessitates a hybrid (physical and statistical modelling) approach; however, targeted validation (fault data, post-mortems, monitoring) is critical to progress towards operational deployment.
3. Phase imbalance may be a significant risk factor (investigated but not yet modelled in the core tool) and should be prioritised for future work.

Conclusions

LV Predict II delivered a materially improved and more realistic methodology beyond the PoC stage, supporting more informed risk-based asset management decisions, while clearly documenting assumptions and constraints and recommending further validation and development steps.

Many valuable lessons and learnings have been achieved by the project so far and more development would certainly improve this. However, due to the complexity of the model, it isn't currently cost effective to roll this out into BaU.

Closedown reporting

This project was compliant with Network Innovation Allowance (NIA) governance, and this report has been structured in accordance with those requirements.

This report and the associated documents are available via the Energy Networks Association's Smarter Networks learning portal at www.smarternetworks.org or via the Electricity North West website.

1. Project fundamentals

Project title	LV Predict II
Project reference	NIA_ENWL_036
Funding licensee(s)	Electricity North West Limited
Project start date	May 2024
Project duration	18 months
Nominated project contact(s)	Delroy Ainsworth

2. Project background

LV Predict II was commissioned by SP Electricity North West under NIA project NIA_ENWL_036 to address the growing risk that electrification of heat and transport will increase both the level and volatility of LV demand, accelerating degradation and failure rates in buried LV cables, specifically anticipated to be primarily in the joints. Because buried LV asset condition and failure-rate data are limited, Distribution Network Operator (DNO) LV asset management has traditionally been reactive, with most interventions triggered by faults and associated unplanned outages, creating a need for better visibility of LV asset health to enable risk-based, proactive decisions. Building on the LV Predict I PoC (2021–2023), LV Predict II advances the approach by removing key simplifying assumptions, modelling more realistic network conditions, expanding to older cable/joint types, and scaling up simulation using real network topologies and computationally efficient emulators, informed where possible by real cable/joint examinations shared across industry.

3. Project scope

In the PEA submission, it was proposed that the project was split into two phases. Phase 1 was sprint-based model development, building on the LV Predict I model. Phase 2 was the CBA and reporting.

Phase 1

Task 1.1:

Would improve the predictive skill and reliability of the current framework by:

- Using additional historic data to account for demand changes.

- Generating a larger set of physical model training data for use in training simulations.
- Including other sources of demand, such as non-domestic customer demand and electric heating.
- Demonstrating the use of monitoring data within the modelling framework, including quantification of the possible benefits of deploying this type of monitoring technology.
- Implementing new and innovative data sources (such as LV protection and monitoring devices) to test the validity and reliability of the model.
- Incorporating unstructured data such as fault reports.

Task 1.2:

Would translate the complex modelling framework into a series of replicable steps that could be detailed within a report. This methodology would have defined inputs (such as cable type, estimated age, and number of households served), and a series of equations would be used to establish the probability of failure. Would undertake a sensitivity analysis to understand the prediction ability and define statistically significant thresholds for cable replacement. Would provide confidence that it is possible to use the modelling results in a replicable fashion, and the results would be interpretable.

Phase 2

Task 2.1:

Using the outputs of Phase 1, would generate a methodology report which would detail:

- Step by step guide to the methodology.
- Clear definition of the inputs and outputs required by a user of the methodology.
- Engineering justification for the validity of the methodology.
- Details of any underlying assumptions, limitations, dependencies, and latent conditions to be aware of in the use of the methodology.
- The analysis that would underpin the methodology as an Annex to the report.

Task 2.2:

Would generate a CBA to assess the merit of implementing a proactive LV cable replacement regime in the future. This CBA would use the research undertaken in Phase 1 to quantify the costs and benefits of utilising a proactive maintenance approach compared to the counterfactual of the current reactive approach.

Benefits of LV Predict II

The current asset management approach to LV underground mains cables is reactive sectional replacement upon failure and a proactive replacement of specific types of cable where a safety issue is identified. Spend profiles for LV cables are predominantly based on historic replacement rates, and there is currently no method of assessing LV cable condition, and no consideration of the potentially increased rate of degradation over time related to changing loading. Having a robust method of identifying the diminishing health of LV cables over time supports a new condition-based approach to the LV cable management and the justification of a new investment driver. It was expected that, without intervention, the increase in demand on the LV system would increase the rate of degradation of cables, causing higher failure rates. The project would produce a CBA to quantify the financial benefits of this new approach.

4. Objectives

The objectives were to:

- Produce a methodology for deriving LV cable condition from available data sources.
- Produce a supporting CBA for the methodology.

5. Success criteria

The project intended to deliver a methodology that can be used to determine LV cable condition for asset management purposes.

6. Performance compared to the original project aims, objectives and success criteria

Current LV asset management is largely reactive because condition and failure data are scarce. LV Predict II investigated the problem that rising and more volatile LV demand from electrification of domestic heating and transport is expected to accelerate degradation and failures in buried LV cables (especially joints) may mean that this reactive approach is no longer sustainable. As demonstrated in the Methodology Report, the project investigated and addressed this by developing a practical, scalable modelling framework that predicts joint degradation (as a proxy for condition). It substantially refined the physical modelling linking demand to cable/joint temperatures and damage. It also expanded the damage mechanisms and asset coverage beyond the LV Predict I PoC to include a broader range of cable and joint types, including legacy PILC alongside modern XLPE. This was informed, where possible, by real cable/joint examination evidence. It then scaled this up through statistical modelling trained on physically simulated outcomes and applied it to realistic conditions using real SP ENW network topologies derived from GIS, Monte Carlo sampling of household demand and Low Carbon Technology (LCT) uptake (Electric Vehicles (EVs) and heat pumps). Computational emulators were used to produce very large volumes of network current simulations, enabling degradation predictions across a large asset population under varied future scenarios.

Relative to the project aims and objectives in the Project Eligibility Assessment (PEA), this achieves the scope of Task 1.1 (improving and substantiating predictive skill/reliability by removing key simplifying assumptions, broadening scenarios/asset types, and improving the realism of the physical relationships with better representations of heating and degradation) and Task 1.2 (translating the framework into a clear, stand-alone and replicable methodology suitable for use in decision processes).

Against the PEA success criterion of delivering a methodology that can be used for asset management purposes, the models are sufficiently mature to provide guidance and support decisions. However, there are remaining caveats (notably limited validation/fault data) that currently prevent it being developed and verified to a Business as Usual (BAU) tool standard. This is consistent with the project's research scope and the PEA's framing of this work as a necessary step towards future BAU development.

The outcomes of phase 1 suggested that there would be limited value in producing a full CBA, noting the methodology caveats above. Therefore, it was agreed that the most valuable activity was to document a CBA methodology with a stylised example CBA using illustrative inputs, allowing SP ENW to take the analysis forward and test any proposed future proactive maintenance strategies. The CBA methodology allows the relationship between increasing understanding of network condition (which could be from LV Predict style models, but equally from failure or condition data and more accurate demand data) versus actual condition with cost and benefit of proactive intervention. The illustrative CBA showed a clear net financial benefit from moving to a proactive LV cable replacement strategy compared to a purely reactive approach. This benefit arises even with low skill in fault prediction, and increases as prediction capability improves.

7. Required modifications to the planned approach during the course of the project

Key modifications

1. Additional model development
    - Planned: It was planned to make use of the existing, PoC LV Predict I model.
    - Delivered: During the project it became apparent that further development was required from the LV Predict I model.
2. Planned inclusion of asset age as an input did not materialise
    - Planned: The replicable methodology was expected to have defined inputs including "estimated age" alongside cable type and customers served.
    - Delivered: Asset age data was not available, so the modelling leant on demand-driven degradation and other available features instead that serve as a proxy for asset age, and therefore essentially an implicit assumption that existing cables are in good condition (at least related to thermal stresses).
3. Inclusion of non-domestic demand
    - Planned: Task 1.1 explicitly planned to improve skill by including other sources of demand, such as non-domestic customer demand.
    - Delivered: Demand modelling was using domestic smart meter data plus EV and heat pump time series only, as industrial/non-domestic demand was judged to be insignificant to the majority of secondary ways and difficult to find a reliable source for.
4. Monitoring device data integration was planned, but largely not implemented

- Planned: Task 1.1 included (a) demonstrating use of monitoring data in the framework and quantifying benefits of monitoring deployment, and (b) implementing innovative data sources such as LV monitoring devices to test validity and reliability.
- Delivered: Access to time series demand data with sufficient temporal granularity was difficult. Network monitoring did not provide the granularity required and smart meter data is difficult to obtain due to GDPR considerations and scarcity/cost of datasets. The lack of data for validation purposes remains a key limitation, including more recent datasets to account for current LCT adoption and usage patterns. The findings of this project help define the requirements of datasets to be useful in degradation prediction.

5. Shift from 'probability of failure' framing towards 'damage' outputs that are not yet calibrated to failures
    - Planned: Task 1.2 described producing equations to establish the probability of failure and using sensitivity analysis to define thresholds for cable replacement.
    - Delivered: The final methodology focusses on predicting accumulated joint damage, with explicit caveats that the damage metric is not an exact predictor of failure. Mapping the damage metric to a probability of failure would require validation against real faults which is not currently possible as data is limited.
6. Asset scope refinement: practical focus on joints and selected joint types
    - Planned: Expanding to other network assets.
    - Delivered: The Methodology Report's modelling and outputs focus heavily on joints and the surrounding connected cables, with explicit selection rules, for example excluding service-breach joints and modelling only joints with certain characteristics and known cable properties.

8. Project costs

Item	Category	Estimated costs (£)	Final costs £	Variance
1	Labour	172,058	169,251	3,257
2	Contractor	538,500	520,650	17,850
3	Accommodation	4,250	85	4,165
4	Learning and dissemination	2,000	8,470	-6.470
	Total	**719,000**	**698,456**	**20,544**

9. Lessons learned for future projects

What went well

- The overall approach proved suitable for LV: the work reinforced that a combined physical and statistical modelling framework is appropriate where LV cable and joint condition data is sparse, enabling scalable inference of degradation patterns rather than relying on widespread direct monitoring.
- Improved modelling of thermal behaviour: incorporating transient thermal behaviour (including soil heat-sink effects) and strengthening representations of insulation and joint-specific heating and contact resistance provided a more realistic basis for temperature-driven degradation modelling than steady-state simplifications.
- Damage modelling became more physically representative of considered failure mechanisms: the project broadened damage mechanisms (including creep, fatigue initiation and chemical degradation) and extended applicability from modern XLPE to include legacy PILC assets, improving engineering credibility and relevance to the installed base.
- Scale and tractability were achieved: emulator-based load flow proved an effective route to making the large simulation workload computationally feasible while maintaining accuracy for most assets, enabling wide scenario coverage.

What could be improved

- Validation and calibration remain the critical gap: limited availability of historic fault/failure and condition datasets constrained validation efforts and meant outputs are best treated as guidance rather than BAU-grade predictions for individual assets.
- Some important real-world effects were not incorporated into the core model: phase imbalance was identified as potentially significant but was not included in the main modelling due to complexity and data gaps. Several other plausible degradation mechanisms were excluded or simplified due to limited evidence.
- Model structure and assumptions introduce uncertainty: assumptions such as balanced phases, standardised joint construction, inferred joint filler type, empirical factors in thermal relationships, and linear summation of damage mean that the “total damage” metric is not a direct predictor of failure time or mode.
- Uneven performance across network types: statistical model skill was reported to be lower for “complex” networks (for example those with multiple feeders and strong imbalance between them), which reduces confidence in a single reduced-order approach across all topologies.
- Risk of black-box deployment: using fitted models in isolation without the full methodology, assumptions, and update pathway, because outputs can be sensitive to data quality and modelling limitations.

Further possible improvements

- Prioritise data improvements to enable BAU readiness: focus on targeted collection of failure histories, joint post-mortems with contextual information, and better records of asset attributes and installation practice to enable calibration and validation.
- Address known high-impact modelling gaps: develop an approach to incorporate phase imbalance where feasible, improve treatment of soil/backfill and local conditions, and progress beyond independent, linearly summed mechanisms towards representing interactions where they materially affect failure outcomes.
- Adopt a tiered implementation strategy: use the current methodology for triage and prioritisation (relative risk) while establishing governance that prevents over-interpretation of absolute failure timing until calibration evidence exists; apply fuller simulation or enhanced handling for complex networks where reduced-order performance is weaker.

10. The Outcomes of the project

LV Predict II delivered a substantially more mature and better evidenced methodology for inferring LV underground joint condition from commonly available data, addressing the PEA problem that increasing and more volatile LV demand is expected to accelerate degradation and failures while current practice is largely reactive. The principal output is a stand-alone Methodology Report that documents an end-to-end, repeatable modelling framework and CBA methodology report. The framework combines an improved physical model of cable and joint temperatures and degradation mechanisms with a statistical model trained on physically simulated outcomes to enable scalable prediction of joint damage across large asset populations using realistic network topology and customer/LCT inputs. In terms of quantitative outcomes, the project increased the realism and simulation coverage, including modelling on real SP ENW network topologies with large-scale Monte Carlo sampling.

Key technical performance improvements attributable to the project include:

- Increased realism in the temperature modelling through inclusion of transient thermal behaviour and refined treatment of insulation/soil thermal resistance and joint heating effects, improving the plausibility of temperature histories used for damage calculation.
- The expansion of degradation mechanisms and asset coverage (including modern XLPE and legacy PILC joint and cable types), improving relevance to the network.
- The use of emulator-based load flow to make high-volume simulations tractable, with reported strong performance for supporting sub-models such as soil temperature prediction and high emulator accuracy for most cables.

Alongside the technical methodology, the project produced a CBA methodology that sets out a repeatable framework (including a worked demonstration) to quantify the net financial benefit of adopting proactive replacement strategies that are informed by model outputs, and to test sensitivity to both replacement volumes and prediction skill, enabling SP ENW to re-run the analysis as assumptions and trajectories change.

With respect to performance against the PEA aims, objectives and success criteria, the project demonstrably delivered against the objective to produce a methodology for deriving LV cable condition from available data sources. It provides a documented, replicable process that outputs joint-level degradation (as a condition proxy) driven by available network, demand and LCT information, supported by transparent assumptions and limitations. It also partially delivered the second PEA objective, a supporting CBA for the methodology, by providing a structured CBA approach designed for repeatability and future use, rather than a single fixed business case. Against the PEA success criterion, the methodology framework is now beyond PoC and capable of informing asset management decisions, although there are still remaining limitations, most notably the lack of comprehensive fault/failure validation data and several necessary modelling assumptions that limit verifiable skill.

The increase in maturity beyond the earlier, LV Predict I PoC stage, despite the identified outstanding gaps in model capability, validation, and assurance, and deployment within a development environment using a representative SP ENW network topology dataset, is consistent with Technology Readiness Level (TRL) 6. To enable BAU deployment on SP ENW systems, requirements must be formally defined to determine whether further methodology and model development is beneficial. In addition, the methodology would need to be implemented as formally controlled software and supported by appropriate software validation and assurance processes.

Finally, the project highlights several opportunities to develop learning further to increase model skill and methodology deployability:

- Prioritised collection and structuring of LV fault/failure and asset attribute data for calibration and validation.
- Incorporation of phase imbalance effects. This was investigated but not incorporated in the core model due to a lack of data.
- Refinement of soil and backfill representation.
- The development of an integrated BAU tool.

11. Data access & quality details

No network or consumption data has been gathered during this Project.

12. Foreground IPR

SP ENW and Frazer-Nash Consultancy own the foreground Intellectual Property Rights (IPR) they independently created but SP ENW owns all joint foreground IPR. Foreground IPR from LV Predict II independently created by Frazer-Nash Consultancy (owned jointly with their subcontractor TNEI) comprises of the methodology and supporting artefacts for deriving LV cable and joint condition from available data. This includes, but is not limited to, the documented step-by-step method, physical/statistical modelling approach, simulation workflow using SP ENW topology and demand/LCT sampling and supporting analysis.

13. Planned implementation, recommendations or next steps

Improvements could be made to the modelling with a further work, such as understanding and incorporating the effects of phase imbalance.

One the main contributors to improving the outcome of the model would be higher quality and more granular available data (mainly fault data quality). Should this data become available then significant progress could be made in the project but that cannot be delivered by the project itself.

Therefore, there is no plan to implement the project into BaU at this stage, but this may change as new data becomes available. This is a very realistic possibility as DNO's are increasingly focused on LV asset monitoring and data collection.

14. Other comments

15. Standards documents

Not applicable

16. Net Benefits Statement

The project did not deliver any quantitative net benefit as the analysis showed that whilst it is possible to model the damage to cable joints over time under various conditions, the statistical relationships are complex and not easily scalable for application across a network. As such, it was not possible to progress the solution beyond TRL6. Obviously, this in itself is useful learning.

However, there were several learnings from the project which can be taken forward into future asset strategy, and to inform the development of future asset health models for LV cables:

- The most likely point of failure for cable network is at the joints, so irrespective of other factors, the probability of fault on a given LV circuit is likely to be proportionate to the number of joints on that circuit.
- The probability of failure is more strongly related to the load on the network, rather than the age of cable, and damage can occur at loads significantly below the cable thermal rating. In addition, cable damage is more closely related to sustained load rather than short term peaks.
- The soil type and cable depth can have a significant effect on the load required to cause damage to the cable.
- Different EV charging regime (i.e. naïve charging versus smart charging) have limited impact on the level of damage to the LV network, largely due to the large peak in demand at the start of any ‘off-peak’ period.