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SMART STREET

Retrofit Design and Operation of Interconnected LV Networks Study

25 April 2018

VERSION HISTORY

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First draft	21 March 2018	B Ingham	0.1	
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CONTENTS

LIST OF ACRONYMS

Acronym	Explanation
CVR	Conservation voltage reduction
EV	Electric vehicle
HV	High voltage (11kV / 6.6kV)
LCT	Low carbon technology
LCN Fund	Low Carbon Networks Fund
LV	Low voltage (400V / 230V)
NOP	Normal open point
OLTC	On load tap changer
PV	Photovoltaic cells
VVC	Volt/Var control
XML	Extensible markup language

1 INTRODUCTION

1.1 Purpose of document

The purpose of this document is to achieve the associated deliverable related to the following Smart Street **SDRC 9.4.2 – Publish a final Retrofit Design and Operation of Interconnected LV Networks Study on the Smart Street website by April 2018.**

This document aims to set out how to cost effectively transform the radial LV network as an interconnected system, including consideration of any protection changes required.

1.2 What is Smart Street

Smart Street aimed to utilise advanced real time optimisation software to simultaneously manage high voltage (HV) and low voltage (LV) network assets to respond to customers' changing demands. Voltage management on HV networks aimed to reduce network losses while conservation voltage reduction (CVR) on the LV networks aimed to reduce energy demand. Capacitor banks on the HV network were utilised to help manage network losses by adjusting the network's power factor. On the LV network, a mix of capacitor banks and controlled meshing of networks were integrated to flatten the voltage profile and improve energy efficiency. The meshing of LV networks also aimed to release additional network capacity.

1.3 Conservation voltage reduction (CVR)

Electrical equipment made for the European market, including household appliances and lighting, is designed to operate most efficiently in the region of 220 to 230 volts. This equipment can, however, operate adequately at voltages in the region of 200 volts. If power is delivered at voltages higher than these optimum levels, energy is consequently wasted. Excess voltage can shorten the useful life of electrical equipment, since the excess energy is dissipated as heat. Therefore, optimising network voltages reduces overall energy consumption, improves power quality and extends the life of customers' equipment. Smart Street proposed to optimise network voltages by using CVR on the LV trial networks.

CVR on a distribution network is defined as a reduction of energy consumption resulting from a decrease in feeder voltage. Smart Street proposed to optimise the voltage by utilising on-load tap changing (OLTC) transformers. These transformers were able to regulate the voltage along the feeder while maintaining statutory limits. This allowed for the peak load to be reduced, hence reducing annual energy consumption.

Additionally Smart Street utilised shunt capacitors on the LV feeders to allow for a voltage boost at the end of the circuit to reduce voltage drop. This allowed for a flatter voltage profile, allowing for the OLTC to tap closer to the lower limit.

1.4 LV network meshing

In addition to the proposed CVR techniques, Smart Street assessed the benefits of meshing LV networks to balance load while releasing network capacity at times of high demand.

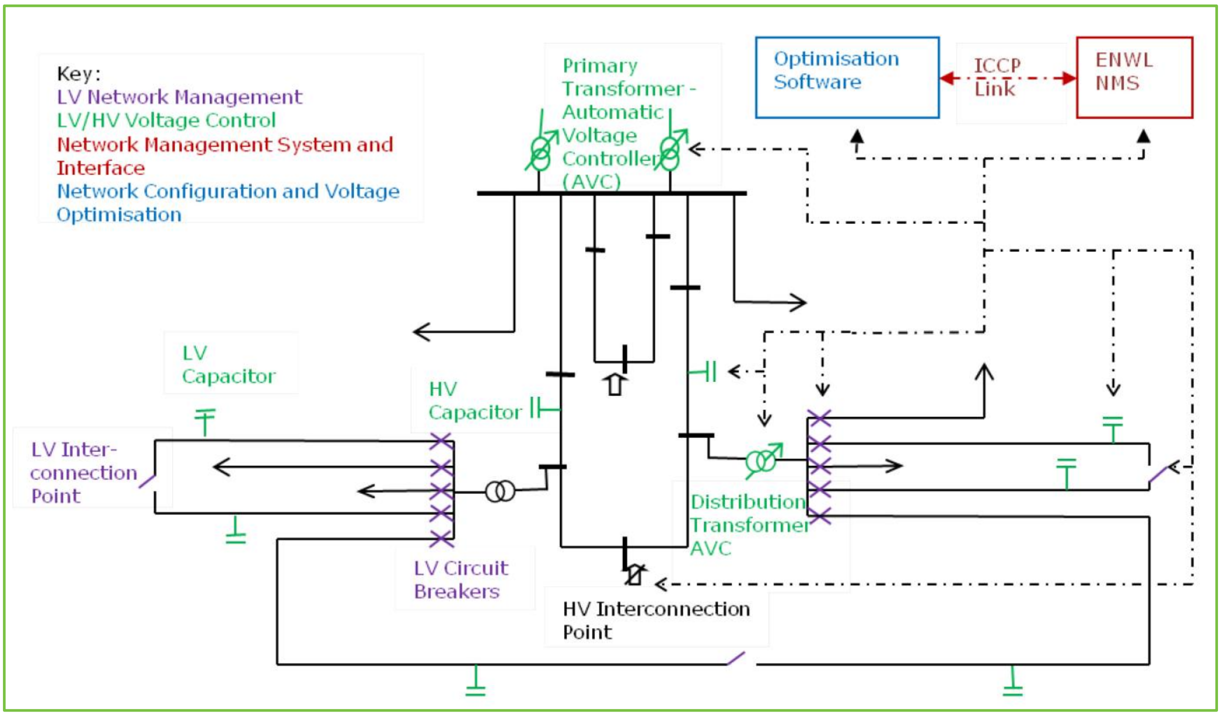
Project partner, Kelvatek, developed new controllable retrofit vacuum switching devices especially for this project. These devices were utilised at the existing distribution boards and in link boxes across the LV trial circuits. The devices have the capability to be remotely controlled allowing sensing of feeder flows and reconfiguration of the LV network.

1.5 Control systems

Figure 1 shows an example of how the various Smart Street technologies were installed across the trial networks. The optimisation included the ability to optimise for violations, losses and to minimise load as a single Volt/Var Control (VVC) function. The opportunity to mesh the trial networks was also included in this function, but radial configurations were the preferred running arrangement. This was specified to minimise customer outages during electrical faults. Therefore the switching equipment was closed (creating loop or meshed networks) if the objective-function resulted in positive changes to the network above a set threshold.

The optimisation application calculated the optimal procedures to reach the optimisation objectives, which could be different for HV and LV depending on the chosen function. The user could choose if the switching equipment was included or inhibited in the optimisation scheme; and only specified remote controlled switches were included in the optimisation.

Figure 1: Smart Street network management

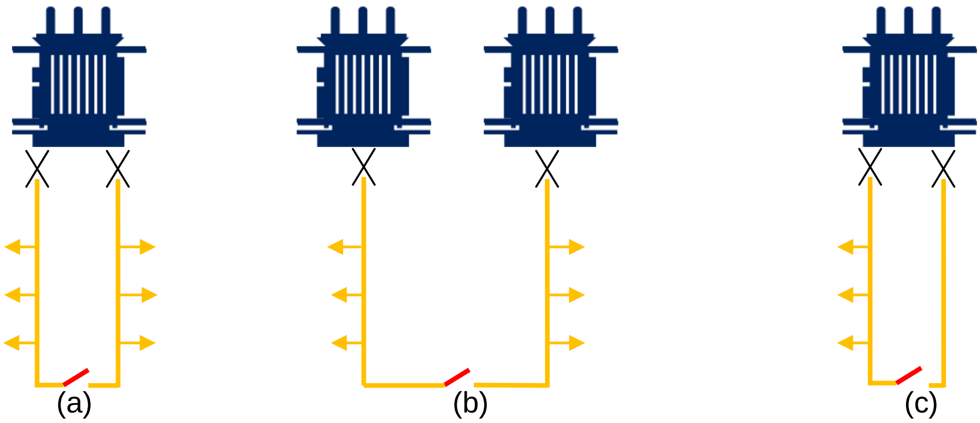


2 INTERCONNECTION TYPES

For the purposes of this study three types of interconnections have been defined as follows:

- *Ring operation:* where two LV feeders fed from the same distribution transformer have the ability to interconnect
- *Meshed operation:* where LV feeders from two distinct distribution transformers have the ability to interconnect
- *J connection:* Where a separate dedicated feeder is laid to interconnect with an existing circuit.

Figure 2.1: Modes of operation – Ring (a), Meshed (b) and J Type (c)



From the above it is clear that ring operation is the simplest to implement as it does not lead to any considerations about high voltage (HV) issues affecting the LV. Meshed operation is somewhat more complicated as the HV network above and the running conditions on the interconnecting LV networks must be considered. J type connections are included for completeness as it is highly unlikely that any benefits from this arrangement would outweigh the cost of laying a dedicated feeder for interconnection purposes. In all cases it is assumed that the normal open point (NOP) in the link box will have remotely operable switches retrofitted to allow control of the network. The fuses at the distribution substations are also assumed to have been replaced with telemetered circuit breakers.

3 MODEL DEVELOPMENT

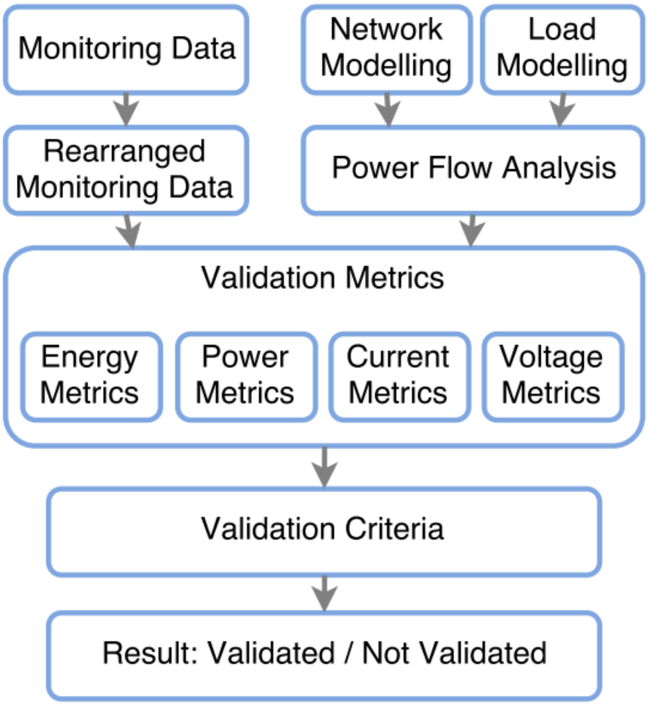
The network data for the trial areas was extracted from the Electricity North West Control Room Management System and Geographical Information System and presented to the university in extensible markup language (XML). These files contained connectivity and technical data such as ratings, impedances, line lengths, etc. From this data the University of Manchester converted the relevant data from these files to a readable OpenDSS format. OpenDSS was the software selected to model the networks as it allowed representation of unbalanced three-phase plus neutral and time-series power flows. Following the input into OpenDSS a series of checks were carried out to ensure that all the data was correct and complete.

The Smart Street assets were added to the model as well as the relevant one-minute resolution load profiles of the connected customers. The load profiles were created using the ELEXON profile classes and a modified version of the CREST tool.

4 MODEL VALIDATION

The validation method compared the monitoring data with the power flow results simulated in the OpenDSS. The flow chart of the overall validation model is shown in Figure 4.1.

Figure 4.1: Validation process



The validation metrics and criteria developed in the Electricity North West First Tier project Low Voltage Network Solutions were applied. This validation method compared percentage differences/errors between the monitoring data and the simulation data from the following aspects:

- Percentage error of energy consumption through the day
- Percentage error of energy consumption during peak time (5pm – 8pm)
- Mean percentage errors of single-phase current
- Mean percentage errors of single-phase voltage
- Percentage errors of three-phase active power.

The following four criteria were used to decide whether a feeder or network passed the validation:

- The model was valid if both energy metric errors were equal or smaller than 20%
- The model was invalid if one energy metric error was equal or greater than 70%
- The feeder/network was valid if the energy error metrics were between 20% and 70%, there were up to 30 customers, and the current and active power error metrics were similar
- The feeder/network was not valid if the energy error metrics were between 20% and 70%, there were more than 30 customers, and the current and active power error metrics were different.

Using this methodology highlighted some feeders which were not valid and investigation showed errors in the customer numbers and topology. Once these errors were corrected all feeders were deemed valid.

5 DATA ANALYSIS

The analysis of the data was based on a Monte Carlo approach, which caters for the stochastic nature of demand and generation and for tackling the unknown location of low carbon technologies (LCTs) on distribution networks. The Monte Carlo method can be defined as a computational algorithm that depends on repeated random sampling of unknown parameters to acquire numerical results. Monte Carlo methods are usually used in mathematical problems such as optimisation and the generation of draws from a probability distribution. It is very useful in situations where the application of a deterministic algorithm is not representative, such as in the case of unknown locations/sizes/behaviour of photovoltaic panels (PVs) or electric vehicles (EVs) in the network.

Two pools of 1,000 individual domestic profiles were randomly generated for the type of day (season/day of week) to be assessed with their corresponding time-varying load models using the CREST tool. Non-domestic loads were represented by ELEXON profiles.

In order to model PV profiles, a set comprising the 30 sunniest irradiation curves of 2012 from the Whitworth Meteorological Observatory of The University of Manchester was considered. It was assumed that all systems will get the same irradiation as the length of the LV networks does not exceed 1km. Statistics from 2014 showed that the domestic scale PV panels currently installed in the UK have a distribution of 1%, 8%, 13%, 14%, 14%, 12% and 37% of 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0kW, respectively. This distribution of sizes was used for power flow simulations when allocating PV panels.

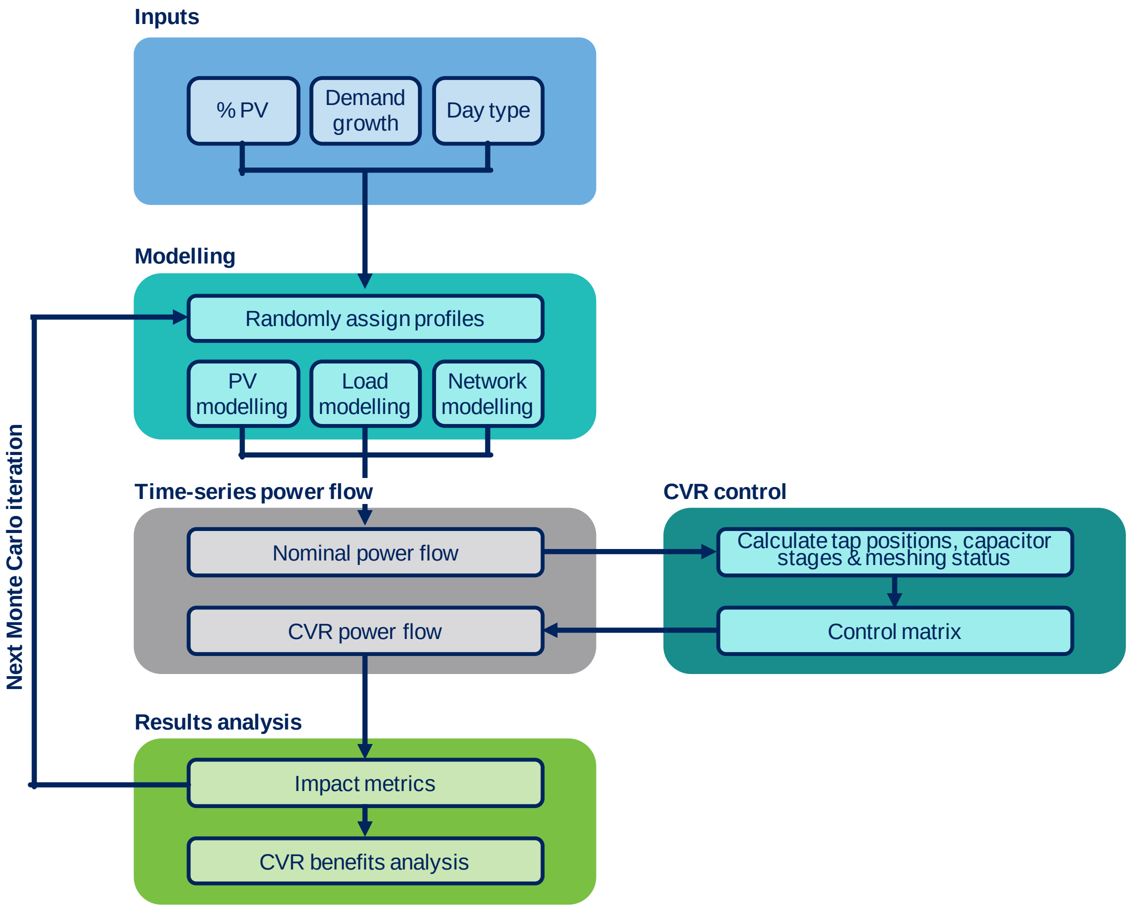
SSE's Second Tier LCN Fund project "My Electric Avenue" produced real data on EV charging. This data was coupled with statistical analysis on when the car is charged, how many cars are being charged as well as the initial and final state of charge to give a range of profiles for this analysis. A representative pool of 1,000 EV profiles was generated using this methodology.

The Monte Carlo method was then applied to the 38 LV networks of Smart Street to assess the impact of LCTs and benefits of operational actions. The steps to carry out the Monte Carlo analysis are listed below and summarised in Figure 4.1:

- The operational statuses of capacitors, switches and tap changers were set
- Random demand profiles were selected from the pool and allocated to each domestic customer respecting their profile class

- A random irradiance from the pool of 30 days was taken
- A percentage of the total customers were randomly assigned a PV panel. All the customers share the same irradiance
- A percentage of the total customers were randomly assigned an EV profile
- A one-minute resolution time series power flow was performed using OpenDSS
- Impact metrics were calculated from power flow results
- When assessing the impact of an operational action (eg tap position for CVR) the process was repeated from step 2 to give the same initial conditions
- The process was repeated from step 1 a predefined number of times.

Figure 4.1: Flow chart for modelling process



The metrics listed below were calculated after every Monte Carlo simulation. The median and standard deviation were obtained for each metric when all the simulations are complete. The latter contains the required information to conclude about any impact and benefit.

- Percentage of customers with voltage problems
- Utilisation factor of transformers
- Percentage of overloaded cables/lines
- Location of overloaded cables/lines
- Energy losses
- Total energy
- CVR factor.

6 OUTCOMES

The analysis indicated that ring operation was beneficial in mitigating the impacts of PV and EV penetrations up to a point, after which further measures became necessary. The combination of loadings and impedances was shown to be more influential on the effectiveness of ring operation than the network type, ie urban, rural etc.

For increasing amounts of PV installations the ring operation of the LV network can delay the occurrence of overvoltage issues at customer premises for an additional 10% of penetration. From around the 40% PV penetration level we start to see reverse power flows. For rural networks, ring operation can reduce losses by up to 46% at 100% penetration levels.

For high EV levels the first issue is generally the overloading of the transformer against which ring operation is ineffectual. Voltage issues are postponed by ring operation as it lowers the equivalent impedance of the circuits. Also the presence of overloads is reduced by allowing the circuits to share the current flows needed to supply the load.

In both cases having a disparity in loadings and impedance results in the most effective cases of ring operation as this gives the maximum capacity to share the power flows.

Based on disparate pairs of circuits it was shown that time limited ring operation produced benefits equivalent to permanent ring operation, while still minimising the risk of faults affecting additional customers.

7 ELECTRICITY NORTH WEST DESIGN AND OPERATION PHILOSOPHY

Following the outcome of the Smart Street project, Electricity North West haS proposed a number of changes to its internal policies to allow the deployment of the technologies and techniques trialled. This has been published on the project website as the Management of LCT Clusters document.

Once monitoring of the circuit loadings determines that ring operation would be beneficial, the existing link box with the normal open point (NOP) between two adjacent circuits should have telemetered controllable switches retro-fitted. Where possible the circuits to be interconnected should be fed via the same distribution substation; where this is not achievable they should not be interconnected if the two substations straddle an HV NOP.

Ring operation should be carried out on either a time-limited basis or as part of an integrated actively-optimising network solution. In both cases telemetry and control of the switch states is needed to ensure that operators are aware of the state of the network prior to commencing any work and can isolate as needed.