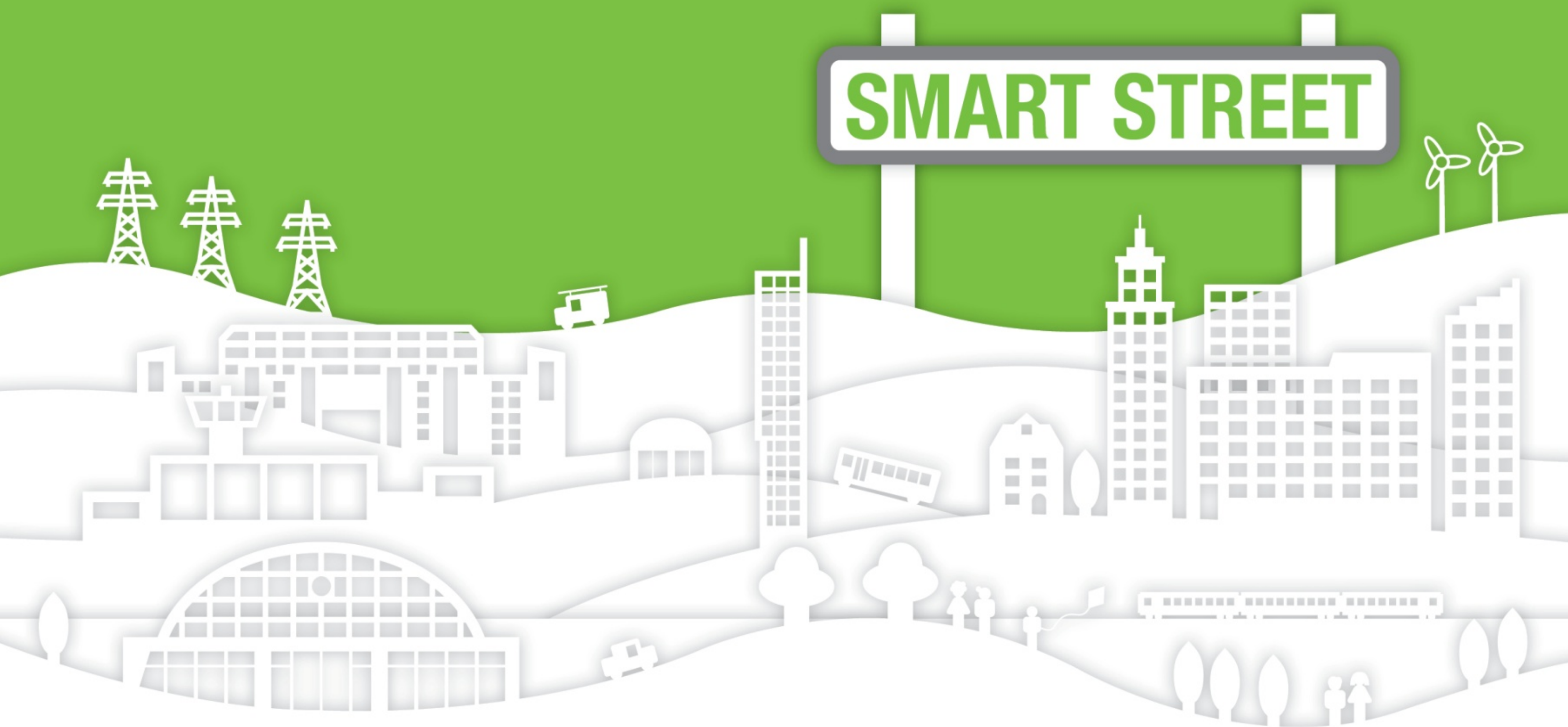
electricity north west

Bringing energy to your door

Smart Street

Interim Design and Operation of Interconnected LV Networks Study

28 February 2017



VERSION HISTORY

Version	Date	Author	Status	Comments
First Draft	21/02/17	Ben Ingham	1.0	

LIST OF ACRONYMS

Abbreviation	Term
CLASS	Customer Load Active System Services (LCNF Tier 2 project)
COP	Codes of practice
CRMS	Control room management system
CVR	Conservation voltage reduction
DG	Distributed generation
DSSE	Distribution system state estimator
HV	High voltage (11kV / 6.6kV)
LCT	Low carbon technology
LCNF	Low Carbon Networks Fund
LV	Low Voltage (400V / 230V)
NMS	Network management system
OHL	Overhead line
OLTC	On load tap changer
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition system
SP5	Spectrum Power 5 (Siemens optimisation software)
THD	Total harmonic distortion
VVC	Volt/Var control

CONTENTS

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 an interim Design and Operation of interconnected LV Networks Study report on the Smart Street website by February 2017.**

This document describes the methodology employed and simulation work carried out to assess the impact of interconnecting the LV network and quantify the optimum operational procedures. The effects are quantified in terms of reduction in voltage, energy consumption and energy losses. An analysis is also made of the potential power quality impact of applying the Smart Street techniques.

1.2 What is Smart Street

Smart Street aims to utilise advanced real time optimisation software to simultaneously manage HV and LV network assets to respond to customers' changing demands. Voltage management on HV networks will look to reduce network losses while Conservation Voltage Reduction (CVR) on the LV networks will look to reduce energy demand. Capacitor banks on the HV network are being utilised to help manage network losses by adjusting the networks power factor. On the LV network, a mix of capacitor banks and controlled meshing of networks will be integrated to flatten the voltage profile and improve energy efficiency. The meshing of LV networks will also aim 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 230 to 220volts. This equipment can, however, operate adequately at voltages in the region of 200volts. If power is delivered at voltages higher than these optimum levels, then energy will be 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 the customer's equipment. Smart Street proposes 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 proposes to optimise the voltage by utilising on-load tap changing (OLTC) transformers. These transformers will be able to regulate the voltage along the feeder while maintaining statutory limits. This will allow for the peak load to be reduced, hence reducing the annual energy consumption.

Additionally Smart Street will utilise shunt capacitors on the LV feeders to allow for a voltage boost at the end of the circuit to reduce voltage drop. This will allow 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 will assess the benefits of meshing LV networks to balance load while releasing network capacity at times of high demand.

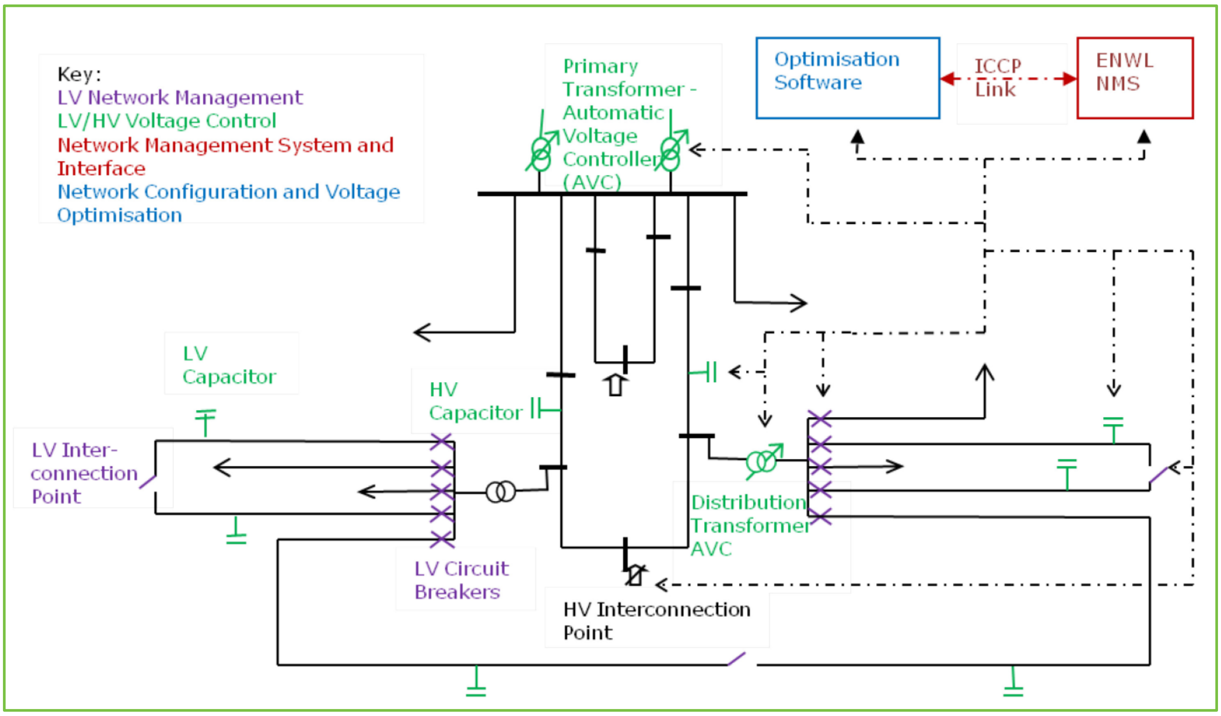
Our project partner, Kelvatek, has developed new controllable retrofit vacuum switching devices especially for this project. These devices are to be utilised at the existing distribution boards and in link boxes across the LV trial circuits. The devices will have the capability to be remotely controlled allowing both 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 will be installed across the trial networks. The optimisation will include the ability to optimise for violations, losses and to minimise load as a single VVC function. The opportunity to mesh the trial networks will also be included in this function, but radial configurations will be the preferred running arrangement. This is specified to minimise customer outages during electrical faults. Therefore the switching equipment shall be closed (create loop or mesh networks) if the objective-function results in positive changes to the network above a set threshold.

The optimisation application calculates the optimal procedures to reach the optimisation objectives, which may be different for HV and LV depending on the chosen function. The user can select if the switching equipment shall be included or inhibited in the optimisation scheme and only specified remote controlled switches will be included in the optimisation.

Figure 1: Smart Street network management



1.6 Overview of the Smart Street test regimes

A summary of the Smart Street trials is shown in Figure 2 below.

Figure 2: List of Smart Street trials

Smart Street Trial	Test Regime
Trial 1: LV voltage control	T1.1 On-load tap changing distribution transformer only
	T1.2 On-load tap changing distribution transformer and capacitor(s) on LV circuits
	T1.3 Capacitors at distribution substation only
	T1.4 Capacitors at distribution substation and on LV circuits
	T1.5 Capacitor(s) on LV circuits only
Trial 2: LV network management & interconnection	T2.1 LV radial circuits
	T2.2 LV interconnected circuits
Trial 3: HV voltage control	T3.1 Voltage controllers at primary substation only
	T3.2 Voltage controllers at primary substation and capacitors on HV circuits
Trial 4: HV network management & interconnection	T4.1 HV radial circuits
	T4.2 HV interconnected circuits
Trial 5: Network configuration & voltage optimisation	T5.1 Losses reduction
	T5.2 Energy consumption reduction.

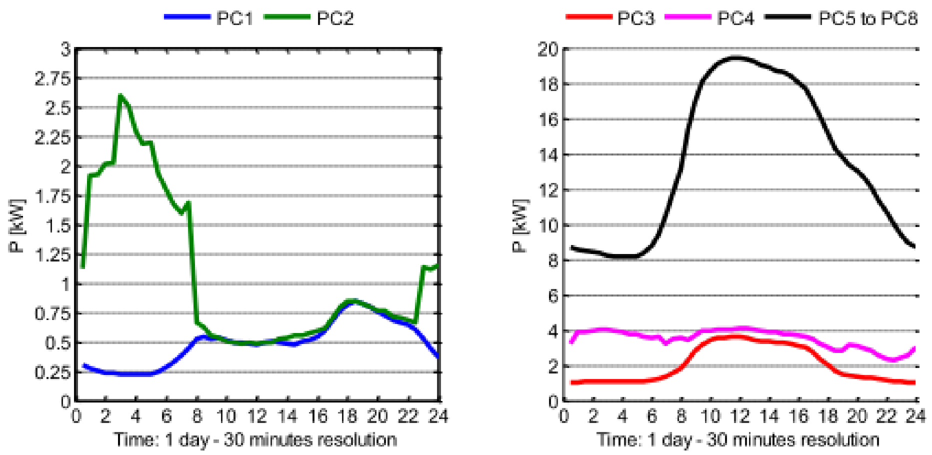
The Smart Street trials will take place over a two year period using an off/on test regime which will result in one year's worth of data for both network normal running configurations and for Smart Street operation. This will allow for the two scenarios to be compared and analysed enabling the overall benefits of Smart Street to be calculated.

2 NETWORK MODELLING

An extract of network data was taken from Electricity North West's Control Room Management System (CRMS) and provided to the project's academic partners in an XML format. This was used to create network models in OpenDSS, these models used Meter Point Access Number (MPAN) data to build up the customer connections per phase. These customers were assigned a load profile consistent with the ELEXON classes, described in Figure 3 below. Street light connections were also built into the model to fully capture the loadings on the trial networks. The full breakdown of how the models were built up is detailed in the University of Manchester (UoM) report WP2 Deliverable 2.1: Initial Modelling and Simulation Framework

Figure 3: ELEXON profile class descriptions and average load profiles for a winter weekday

Profile Class (PC)	Descriptive name
PC1	Domestic Unrestricted Customers
PC2	Domestic Economy 7 Customers
PC3	Non-Domestic Unrestricted Customers
PC4	Non-Domestic Economy 7 Customers
PC5	Non-Domestic Maximum Demand Customers. Peak Load Factor (LF) of less than 20%
PC6	Non-Domestic Maximum Demand Customers. Peak LF between 20% and 30%
PC7	Non-Domestic Maximum Demand Customers. Peak LF between 30% and 40%
PC8	Non-Domestic Maximum Demand Customers. Peak LF over 40%
PC0	Non-Domestic. Maximum Demand above 100 kW



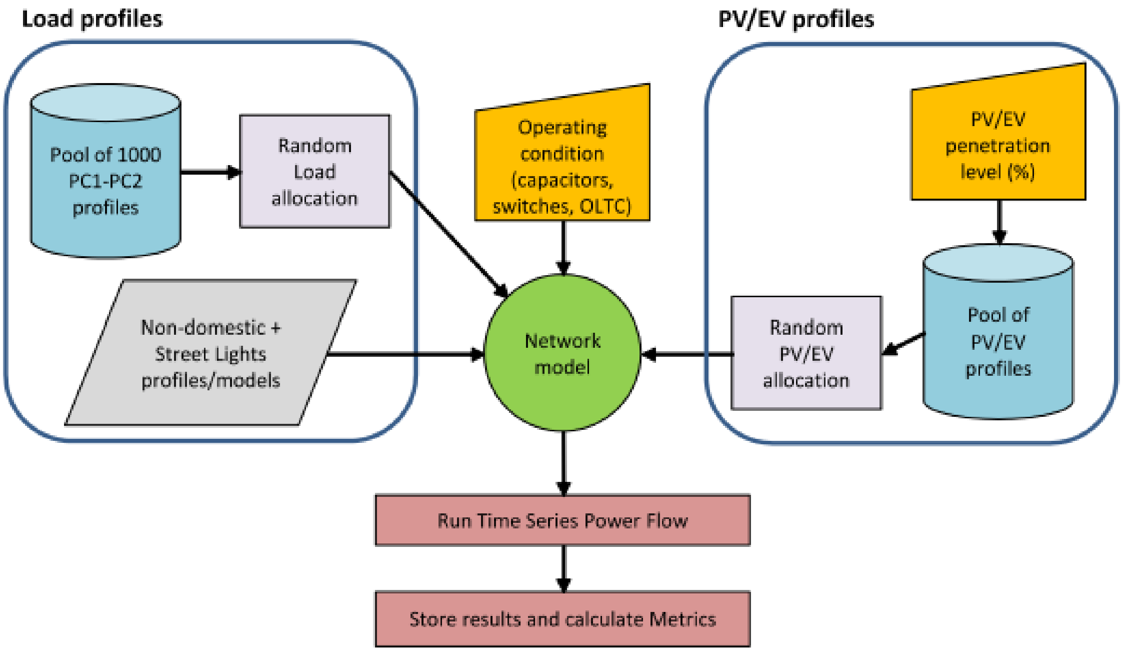
To model Photovoltaic Cells (PV) a data set comprising the 30 sunniest radiation curves as recorded at the Whitworth Meteorological Observatory of the University of Manchester over the course of 2012. From this set one of the profiles is randomly selected and applied to the networks, with the sizes of the installation distributed based on UK statistics.

The load profiles representing Electric Vehicles (EVs) were based on the data collected from the Low Carbon Network Fund (LCNF) tier two project 'My Electric Avenue' which was run by EA Technology Ltd. From this data a set of 1,000 charging profiles were generated to cover variations in state of charge, number of connections and connection times. Full details of the build up of the load models for both EV and PV can be found in UoM report WP2 Deliverable 2.2: Assessment of LV Interconnection benefits for different LCT penetrations

3 BENEFITS OF INTERCONNECTION

The network models built up to represent the trial areas have been used to the effect of differing penetrations of LCTs on the trial areas. Initially this was done by considering only various penetrations of either EV or PV only and ensuring that all Smart Street devices, ie Lynx or capacitors, were switched out. A simulated power flow was then run using a randomly selected profile from those created via the above methodology to cover the selected penetration level. This methodology is described in detail in UoM report WP2 Deliverable 2.2: Assessment of LV interconnection benefits for different LCT penetrations.

Figure 4: Graphical representation of the Monte Carlo methodology



Following the simulation of the standard network this process was repeated with the interconnecting Lynx devices modelled as closed to mesh the networks and the impact of this interconnection was compared to the standard running. As expected this simulation demonstrated that EV penetrations caused issues at different levels of penetration depending on the network type, ie dense urban, urban or rural; with transformer loading issues being seen from around the 40% level upwards. Initial simulations on these networks also indicated that the benefits of ring operation were influenced by the customer composition of the circuits being meshed.

For PV the modelling indicated that from around the 40% penetration levels that reverse power flows on the distribution transformers was likely to become an issue. As part of the Smart Street Trial any interconnection is carried out between circuits from the same distribution substation limiting the ability to resolve these issues.

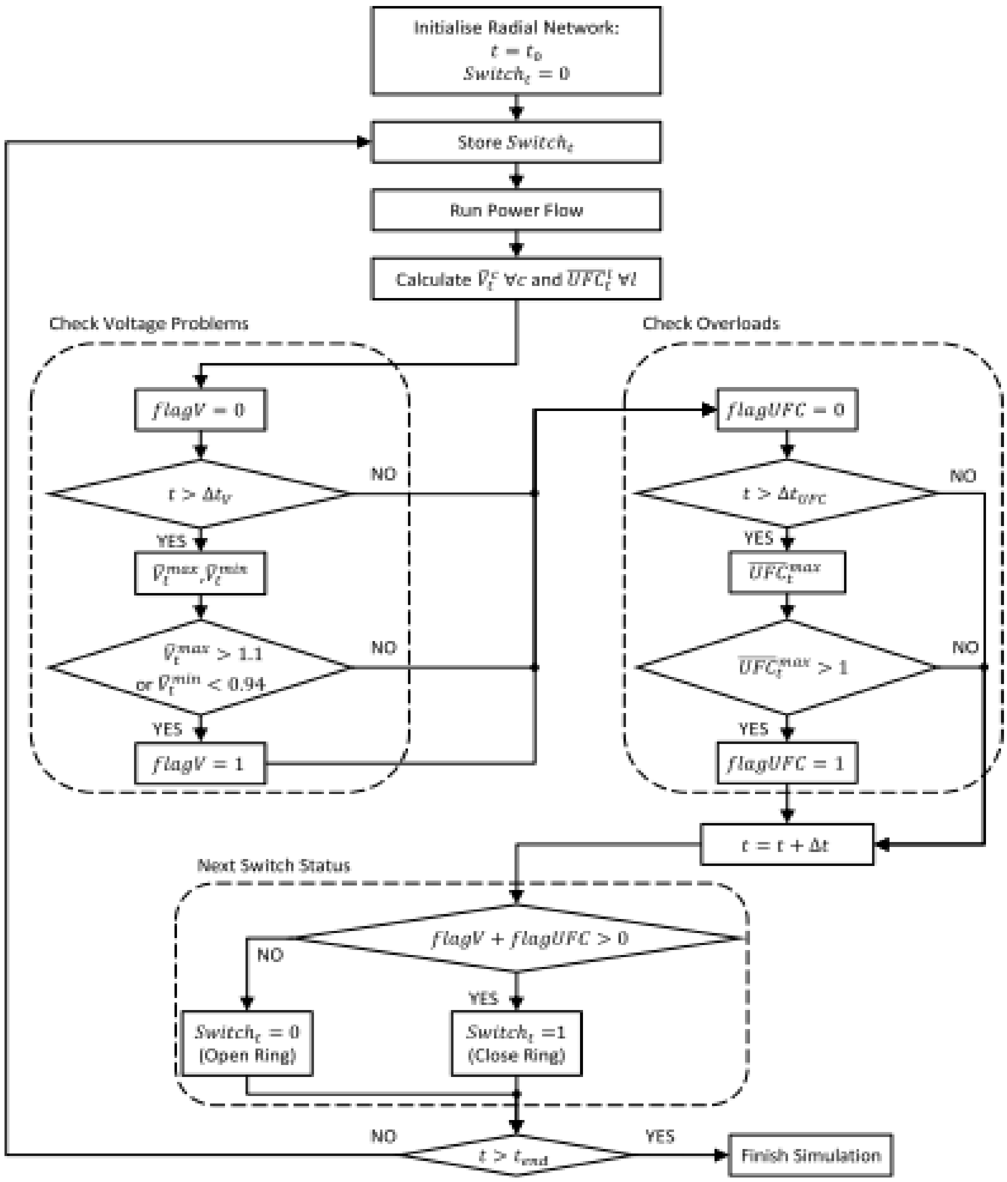
In both cases ring operation was observed to reduce the overloads experienced by cables at the head of the circuits. Meshing the circuits also led to over and under voltage issues caused by LCT penetration being mitigated due to the change in network impedance. The initial studies also indicated that the benefits of ring operation were influenced more by customer composition on the circuits in question rather than the type of network being studied, ie dense urban, urban or rural.

For these initial simulations it is important to note that a uniform penetration level for each LCT was applied to all the circuits being studied and so the benefits of ring operation may have been underestimated. Once the data collected from the trials is used to refine these models the overall improvements for ring operation may be greater than these initial simulations suggest

4 TIME LIMITED INTERCONNECTION

As the lynx devices being used to mesh networks during the Smart Street trials are vacuum switches, and as such have no protection capabilities, running with circuits interconnected means that more customer are at risk for a fault than would be for standard operation. In order to mitigate this risk the Lynx devices are designed to automatically open following a loss of volts, such that when the Weezaps reclose the healthy side should be re-energised within a minute of the initial loss. However Electricity North West policy is to avoid this risk where possible, therefore the studies into ring operation were then extended to include a time/ load element in order to determine if there were periods when the benefits of ring operation were low enough to allow for the network to be returned to a radial configuration. This study is detailed in UoM report WP2 Deliverable 2.3: Most Beneficial Types and Times of LV interconnections with LCTs. In order to study this process for modelling the networks was modified as shown in Figure 5 below.

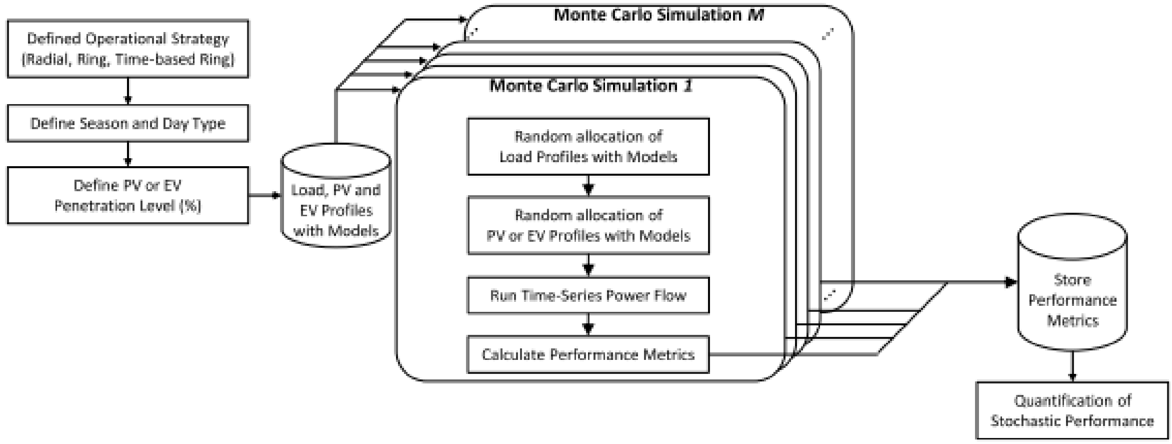
Figure 5: Revised process for assessing ring operation



- t_0: Initial simulation time.
- t_{end}: Final simulation time.
- Δt: Simulation time step (e.g., 1, 5, 30, 60 min).
- Δt_V: Time window to calculate moving average of voltages at each customer node. This cannot exceed 10 min due to the standard BS EN50160.
- Δt_{UFC}: Time window to calculate moving average of utilization factor at each main cable section. Values over 30 min have been normally used to account for thermal problems [3, 4].
- $\bar{V}_t^c$: Moving average voltage of customers c at time t.
- $\bar{V}_t^{max}$: Maximum $\bar{V}_t^c$, c considering all customers.
- $\bar{V}_t^{min}$: Minimum $\bar{V}_t^c$, c considering all customers.
- $\overline{UFC}_t^l$: Moving average utilization factor of cable section l at time t.
- $\overline{UFC}_t^{max}$: Maximum $\overline{UFC}_t^l$, l considering all main cable segments (excludes service cables).
- $flagV$: Flag to indicate the presence of voltage problems (1 indicates problem, 0 otherwise).
- $flagUFC$: Flag to indicate at least one overloaded cable (1 indicates problem, 0 otherwise).
- $Switch_t$: Switch status at time t (1 when closed and or 0 otherwise).

Again a Monte Carlo method was used to assign a random profile from the generated set to cover LCT penetrations on the networks. Following each simulation run the results are studied to find the initial switch on time and the last switch off time, which are then rounded to the closest hour.

Figure 6: Methodology for performance assessment of the operational scheme



These simulations demonstrated that time limiting the meshed operation of the networks could result in near identical benefits to continuous ring operation. For various penetrations of LCTs the optimal times for meshing the networks were found to be:

i. 09:00 – 15:00 for 50% PV penetration
ii. 07:00 – 17:00 for 100% PV penetration
iii. 18:00 – 21:00 for 100% EV penetration

Again the customer composition rather than the network type had more bearing on the benefits of ring operation. Going forward the intention is to utilise the real data generated by the trials to compare against these simulations to give an assessment of the benefits of ring operation on real world networks.

Future work into this will also look at the potential power quality impacts of both interconnection of the networks and the application of CVR.

5 REFERENCES

i. UoM Deliverable 2.1: Initial Modelling and Simulation Framework
ii. UoM Deliverable 2.2: Assessment of LV Interconnection Benefits for Difference LCT Penetrations
iii. UoM Deliverable 2.3: Most Beneficial Types and Times of LV Interconnection with LCTs