Impact Assessment of LCTs on LV Networks

Appendix I

Alejandro Navarro Espinosa

alejandro.navarroespinosa@manchester.ac.uk

Supervised by Dr Luis(Nando) Ochoa

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The University of Manchester, Manchester
Outline

- Objectives
- Problem Description
- Profiles Creation
- Network Creation
- Impact Assessment
- Multi-Feeder Analysis
- Conclusions
Objectives

- **Project objective:**
  - Understand the characteristics, behaviour, and future needs of Low Voltage Distributions Networks with high penetration of low carbon technologies.

- **Research objective:**
  - Maximise the penetration of low carbon technologies minimising the impacts on LV networks.

- **Presentation objective:**
  - Analyse the impacts of different LCT penetration on real low voltage distribution networks under different scenarios.
Problem Description

Different behaviour and sizes of loads and LCT along the day

Electric Vehicles (EV)

Photovoltaic Panels (PV)

Electric Heat Pumps (EHP)

Micro combine heat & power (uCHP)

Residential Loads
Problem Description


- Requirements for solving the problem:
  - Monte Carlo analysis to cope with the uncertainty (LCT size and location, sun profile, heat requirements, EV utilization, load profile, etc.)
  - Time Series Analysis – 5 min synthetic data.
  - Three-phase unbalanced power flow – OpenDSS.

- Inputs data:
  - Load and LCT profiles.
  - Real UK networks (topology and characteristics).
Problem Description: Methodology

This process is repeated 100 times for each feeder and penetration level (% of houses with PV panels).

- Random allocation for each customer node.
- Random allocation of sites and sizes.
- Time Series Simulation.
- 3 Phase four wire power flow

Therefore, for the random allocation process, we need to create thousands of individual residential profiles.
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Profile Creation: Loads

- Synthetic data from: “Domestic electricity use: A high-resolution energy demand model” (Richardson et al, 2010).
  - Making an automatic process, it is possible to create N individuals profiles (probabilistic model) to be used in the simulations.
Profile Creation: Winter and Summer Loads

- A diversified profile is created from a pool of 1000 profiles for each month.
  - Summer profile: July (PV analysis)
  - Winter profile: February (EV, EHP, uCHP analysis)
Profile Creation: PV

- Real daily profiles for 2012
- Measured by The University of Manchester (Sackville Building)
- The size of the PV panels is allocated according to UK statistics.
- Sunny scenarios: The 30 sunniest profiles are considered in the simulations.
Profile Creation: EV

- **Information Source:** “Impact of Electric Vehicle Charging on Residential Distribution Networks: An Irish Demonstration Initiative” (CIRED, 2013).

- **Input Data (from field trial):**
  - Probability distribution function of EV connection times.
  - Probability distribution function for the daily EV energy requirement.
Profile Creation: EV

- Creation of one EV profile:
  - Random selection of the connection time following the previous distribution.
  - The amount of energy required is randomly selected by following the probability distribution.
  - This energy is divided by the battery capacity (3 kW/24kWh – Nissan Leaf) to calculate the number of periods required.
  - The charging time is between the connection time and the (connection time + the periods required)

Examples – EV Profiles
Profile Creation: µCHP

- Information Source: Carbon Trust, it is possible to extract the energy consumption for different types of houses and different regions (north Ireland, north west, etc.) for different days (different outside temperatures).
- Real µCHP production – North West of England (20/12/2006): cold day (min: -4°C max: +3°C).
Profile Creation: EHP

- From the same database, it is also possible to obtain the heat requirement for each of the houses measured.
- This heat requirement information allows us to build the EHP profile for each home.
Profile Creation: EHP

1. Heating period identification

2. Heat to be supplied by AH or EHP

3. EHP Operation by using Manufacturer Data

4. Cycling Operation
Profile Creation: Diversified Profiles

- Diversified maximum demand for groups of 100 profiles for each technology: Histogram and one sample profile for the central bin.
Profile Creation: Diversified Profiles

- Diversified maximum demand for groups of 100 profiles for each technology: Histogram and one sample profile for the central bin.
Profile Creation: Sensitivities

- **EV:**
  - Fast Charging: 6kW, peak consumption as in the original data.
  - Peak Shifted: 3kW, moving the peak consumption from 21:00 to 19:00.

Median average profile for 100 loads from 1000 groups
Profile Creation: Sensitivities

- PV: Maximum irradiance data (without any cloud)
- EHP and uCHP: Coldest day.
Profile Creation: Diversified Profiles

- Diversified Maximum Demand Histogram for 1000 groups of 100 profiles for each technology.
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Network Creation: Information Received

- The LV networks were provided in GIS format.
- Examples:

  - Dunton Green
  - Edge Green
  - Greenside
  - Howard St
  - Landgate
  - Leicester
Network Creation: Stages

- To understand the LV network behaviour, the GIS data need to be transformed into computer-based models (*OpenDSS*).
- The main stages of this transformation process are:
  1. Creation of line segments
  2. Topology reconnection
  3. OpenDSS representation
Network Creation: Line segments creation

- The GIS files use the concept of polyline to store the data.
- The polyline is a continuous line comprised by one or more line segments, which is treated as a single object within the GIS.
- Process required: Translation from polyline to line segments.
Network Creation: Topology Reconnection

- There are many connections that seem connected but in reality they are separated by very small distance.
- The easy way to identify the connectivity issues is through the determination of the connected components.

<table>
<thead>
<tr>
<th>Feeder (Way_NO)</th>
<th>Number of connected components</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>19</td>
<td>36%</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>89%</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>98%</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>90%</td>
</tr>
</tbody>
</table>

Dunton Green

CI (connectivity index) is the proportion between the longest connected component and the total feeder length.
Network Creation: Topology Reconnection

- Reconnection process: this stage joints every single connected component to the main one in order to have a totally connected feeder.

Feeder 2 after the reconnection process

- Determination of the main connected component
- Determination of the line equations for the main connected component
- Distance Calculation among the vertices and the segments
- Selection of the closest vertex and segment line
- Restructuration of the network structure
Network Creation: OpenDSS Representation

- OpenDSS is a software package to solve multi-phase power flow simulations in electrical distribution systems.
- Using the information received, it is possible to create all of the files required to represent the data in OpenDSS format.
- The files automatically created are:
  - Lines
  - Loads
  - Load shapes
  - Lines code
  - Transformers
  - Monitors

3 phase model with single phase connection is implemented
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Impact Assessment: LV Stochastic Behavior

Different behaviour and sizes of loads and LCT along the day

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Photovoltaic Panels (PV)

Electric Heat Pumps (EHP)

Micro combine heat & power (uCHP)

Residential Loads
Impact Assessment: Methodology

This process is repeated 100 times for each feeder and penetration level (% of houses with PV panels).

- **Random allocation for each customer node.**
- **Random allocation of sites and sizes.**
- **Time Series Simulation.**
- **3 Phase four wire power flow**

### Loads
- Random allocation for each customer node.

### LCT
- Random allocation of sites and sizes.
- Time Series Simulation.
- 3 Phase four wire power flow

### Power Flow
- Number of people per house:
  - 4 (20%)
  - 3 (16%)
  - 2 (35%)
  - 1 (29%)

### Residential Capacity

- Frequency
- Cumulative

<table>
<thead>
<tr>
<th>Capacity [kW]</th>
<th>0%</th>
<th>1%</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
<th>5%</th>
<th>6%</th>
<th>7%</th>
<th>8%</th>
<th>9%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Houses</td>
<td>0%</td>
<td>1%</td>
<td>2%</td>
<td>3%</td>
<td>4%</td>
<td>5%</td>
<td>6%</td>
<td>7%</td>
<td>8%</td>
<td>9%</td>
<td>10%</td>
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</table>
Impact Assessment: Metrics

- Impacts metrics:
  - Customers with voltage problems: defined according to the Standard BS EN 50160.
  - Utilization level of the head of the feeder: hourly maximum current divided by the ampacity.
  - Daily energy losses in the feeder.
Impact Assessment: Example

- As an example, the main results are presented for the feeder shown in the figure.
- The voltage, thermal problems and energy losses are calculated for PV, EV, EHP and uCHP.
- $V_{sec} = 241 \ \text{Vfn} \ (1.05 \times V_{nom})$
Impact Assessment: Voltage Problems

% of Customers with Voltage Problems – BS EN 50160
Impact Assessment: Thermal Problems

Utilization Level of the Head of the Feeder

- hourly max current/ampacity

PV

EHP

µCHP

EV
Impact Assessment: Daily Energy Losses

PV Penetration [%] vs Losses [kWh]

EHP Penetration [%] vs Losses [kWh]

μCHP Penetration [%] vs Losses [kWh]

EV Penetration [%] vs Losses [kWh]
Impact Assessment: Probability Distributions

- Since many scenarios were simulated, it is possible to build the cumulative distribution for each penetration level.

Probability to have less than X% of customers with problems

![Graph showing cumulative distribution for PV and EHP penetration levels.](image-url)
Impact Assessment: Probability Distributions

- Since many scenarios were simulated, it is possible to build the cumulative distribution for each penetration level.

Probability to have more than X% of customers with problems
Impact Assessment: Case Studies

- **Case I**: Balanced versus unbalanced analysis.
- **Case II**: Impact of the granularity data.
- **Case III**: Different feeders – Different Impacts

<table>
<thead>
<tr>
<th>Feeder</th>
<th>Length (m)</th>
<th>No. of Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2514</td>
<td>77</td>
</tr>
<tr>
<td>2</td>
<td>2867</td>
<td>107</td>
</tr>
<tr>
<td>3</td>
<td>3981</td>
<td>169</td>
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<td>4</td>
<td>4101</td>
<td>138</td>
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<tr>
<td>5</td>
<td>1538</td>
<td>23</td>
</tr>
<tr>
<td>6</td>
<td>1651</td>
<td>68</td>
</tr>
<tr>
<td>7</td>
<td>1300</td>
<td>54</td>
</tr>
</tbody>
</table>

2.2 km (including services cables) and 70 loads
Impact Assessment: Case I

- **Balanced/Unbalanced Feeder**: The impacts are determined by assuming a normal case and a perfectly balanced case (1/3 of the load and LCT per phase)

![Graphs showing % of Customers with Voltage Problems and Feeder Energy Losses](image)

**PV Analysis**
Impact Assessment: Case II

- **Granularity**: The impacts are determined by using 1, 5, 10, 15, 30 and 60 min resolution.
Impact Assessment: Case III

- Different feeders Different Impacts:

% of Customers with Voltage Problems

Utilization Level at the head of the feeder
Outline

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- Multi-Feeder Analysis
- Conclusions
Multi-Feeder Analysis

- To have a better understanding about the LCT impacts, 128 feeders are modelled and the impact assessment methodology is applied to all of them.
- PV, EV, EHP and µCHP are implemented.
Multi-Feeder Analysis: General Overview

- The feeders with less than 25 customers do not present any technical problem for any of the technologies analysed.
- The summary of the results for the feeders with some technical problem for some penetration level are presented in:
Multi-Feeder Analysis: Correlation Studies

- The main characteristics of each feeder are recorded in order to find some relationship among these parameters and the apparition of the problems.

- The parameters explored are:
  - Feeder Length.
  - Customer Number.
  - Initial Utilization Level.
  - Customer per km.
  - Main Path.
  - Main Path Impedance.
  - Supplied Area.
  - Supplied Perimeter.
  - Total Impedance Aggregation.
  - Total Path Impedance
Multi-Feeder Analysis: Correlation Studies

- Example: Problems versus **Customers Number** (PV case):
  - One dot – one feeder.
  - Horizontal axis: number of customers in each feeder.
  - Vertical axis: average penetration level when the problems start in each feeder.
    - at least 1% of the customers with voltage problems, or
    - The average utilization level in the head of the feeder is at least 100%.

![Graph showing data and fitted curve with R²=0.57](image)
Multi-Feeder Correlation: PV Case

- Customer Number
  - $R^2: 0.57$

- Initial Utilization Level
  - $R^2: 0.65$

- Supplied Area
  - $R^2: 0.55$

- Total Equivalent Impedance
  - $R^2: 0.76$
Multi-Feeder Correlation: EHP Case

Customer Number

R²: 0.65

Initial Utilization Level

R²: 0.70

Feeder length

R²: 0.59

Total Equivalent Impedance

R²: 0.78
Multi-Feeder Correlation: EV Case

- **Customer Number**
  - $R^2: 0.51$

- **Initial Utilization Level**
  - $R^2: 0.53$

- **Feeder length**
  - $R^2: 0.47$

- **Total Equivalent Impedance**
  - $R^2: 0.70$
Multi-Feeder Analysis: Correlation Studies

- The metrics with the highest coefficient of determination for PV, EHP and EV are Initial Utilization Level and the Total Impedance Path.

<table>
<thead>
<tr>
<th></th>
<th>R2</th>
<th>Initial Utilization Level</th>
<th>Total Path Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>0.65</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>EHP</td>
<td>0.70</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>0.53</td>
<td>0.70</td>
<td></td>
</tr>
</tbody>
</table>

- So, what about if we combined both metrics.
- New metric: Multiplication of the Initial utilization Level and the total Path Impedance.
Multi-Feeder Analysis: Correlation Studies

- Combined Metric:

![Graphs showing correlation studies for EHP, PV, and EV with R² values of 0.88, 0.78, and 0.79 respectively.]
Multi-Feeder Analysis: Correlation Alternative

- The utilization level could require the deployment of monitors and the total path impedance calculation could require the existence of network models.
- So, can we approach those metrics?

The customer number correlates better with the initial utilization level.
The feeder length correlates better with the Total path impedance

<table>
<thead>
<tr>
<th>Technologies</th>
<th>R2</th>
<th>Customer Number</th>
<th>Feeder Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>0.57</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>EHP</td>
<td>0.65</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>0.51</td>
<td>0.47</td>
<td></td>
</tr>
</tbody>
</table>
Multi-Feeder Analysis: Correlation Alternative

- Combined Metric: Customers and Length

- PV: $R^2:0.61$

- EHP: $R^2:0.70$

- EV: $R^2:0.59$
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Conclusions

- The proposed probabilistic impact assessment approach allows:
  - Taking into account uncertainties of LCT in LV networks
  - Considering high resolution LCT profiles (PV, EV, EHP, µCHP)
  - Quantifying different impacts and their likelihood

- The utilization of small resolution data (e.g., 15 min, 30min and 60 min) for loads and generation profiles underestimates the impacts of LCT.

- The utilization of single-phase equivalent representation (balanced case) for networks and loads underestimates the impacts of LCT.
Conclusions - Impacts

- The approach was applied to 128 real LV feeders
  - Best metric to relate the occurrence of problems: total path impedance and the initial utilization level.
  - Second best and practical metric: customer number and feeder length.
  - Feeders with less than 25 customers do not present any technical problem for any of the technologies under analysis.
  - The percentage of feeders with the occurrence of voltage problems is higher in the PV case (about 62% of the feeders) and the percentage of feeders with thermal problems is higher in the EHP case (around 57% of the feeders).
  - The technology with lower proportion of feeders with problems is the µCHP.
  - In the PV case, the first occurrence of problems is driven by voltage issues in all the feeders examined. For the EHP and EV case, the first occurrence of problems is driven by voltage and thermal issues.
Dissemination: Publication List


Collaborations related with LCTs:


Dissemination: Work in Progress

Publications Submitted:


Work in progress:


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alejandro.navarroespinosa@manchester.ac.uk

Supervised by Dr Luis(Nando) Ochoa

3rd October 2014

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