EV Charging Impacts on Residential LV Networks

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Overview

• My Electric Avenue Project – Motivation
  • CARWINGS Analysis

• Residential Low Voltage Feeders
  • MEA Feeders
  • LV Network Solutions (LVNS) Feeders

• Impact Studies (Business As Usual)
  • Methodology
  • Deterministic Analysis

• Esprit Philosophy
MEA Project – Motivation (1/2)

DECC EV Uptake Scenarios

- EV Uptake Scenarios Scenario 1
- EV Uptake Scenarios Scenario 2 & 3
- EV Uptake Scenarios Scenario 4

DRIVING TOGETHER FOR A CLEANER FUTURE
MEA Project – Motivation (2/2)

• Funded via the UK Ofgem’s Low Carbon Networks Fund (£9M+)

• Aims
  • To investigate the impacts of EVs on 9 LV feeders
  • To trial a cost-effective and practical solution to control EVs (Esprit technology)
CARWINGS Analysis (1/5)

112 Social trials
109 Technical trials
221 in total

Google Maps®

DRIVING TOGETHER FOR A CLEANER FUTURE
CARWINGS Analysis (2/5)

# of Connections (charging) per day

<table>
<thead>
<tr>
<th>Number of Connections</th>
<th>Probability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
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</tbody>
</table>

Weekday

Weekend

DRIVING TOGETHER FOR A CLEANER FUTURE
CARWINGS Analysis (3/5)

Start Charging Time

- **Weekday**: Connection Time - 15 min resolution
- **Weekend**: Connection Time - 15 min resolution

- **Probability (%)**
  - 2h
  - 4h
  - 6h
  - 8h
  - 10h
  - 12h
  - 14h
  - 16h
  - 18h
  - 20h
  - 22h
  - 24h
### CARWINGS Analysis (4/5)

**Initial Charging Level**

<table>
<thead>
<tr>
<th>Number of Units (1-12)</th>
<th>Probability (%)</th>
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<tr>
<td>0</td>
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<td>1</td>
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<td>2</td>
<td>4</td>
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<td>3</td>
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<td>10</td>
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<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

- **Weekday**
- **Weekend**

![Bar chart showing probability distribution of initial charging levels for weekdays and weekends.](chart.png)
CARWINGS Analysis (5/5)

Final Charging Level

Statistical Analysis ➔ Realistic EV Models
Residential LV Feeders

Transformer
11/0.4 kV

Cable
Sensor

Charging point

Nissan LEAF
• 24kWh
• Mode 1 (IEC 61851-1)
• Demand 3.3kW

DRIVING TOGETHER FOR A CLEANER FUTURE
Residential LV Feeders – MEA (1/2)

• **Northern Powergrid**
  • Four residential LV feeders
  • One commercial LV feeder

• **SSEPD**
  • Five residential LV feeders

<table>
<thead>
<tr>
<th>LV Feeder Name</th>
<th>Main Path Length (m)</th>
<th>Total Cable Length (m)</th>
<th>First Segment Cable Type</th>
<th>Rating (A)</th>
<th>No. of Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PC1</td>
</tr>
<tr>
<td>Cleadon Manor</td>
<td>418</td>
<td>1099</td>
<td>Waveform 300mm²</td>
<td>420</td>
<td>51</td>
</tr>
<tr>
<td>Gosforth Audley</td>
<td>670</td>
<td>1449</td>
<td>AL 0.3in²</td>
<td>350</td>
<td>56</td>
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<tr>
<td>Valley Lane East</td>
<td>556</td>
<td>1371</td>
<td>Cu 0.3in²</td>
<td>445</td>
<td>61</td>
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<tr>
<td>Wylam Dene</td>
<td>813</td>
<td>1988</td>
<td>Waveform 300mm²</td>
<td>420</td>
<td>71</td>
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<tr>
<td>Clydesdale Road</td>
<td>717</td>
<td>1732</td>
<td>Consac 185mm²</td>
<td>357</td>
<td>61</td>
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<tr>
<td>Corney Road</td>
<td>1152</td>
<td>2330</td>
<td>Waveform 185mm²</td>
<td>374</td>
<td>149</td>
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<tr>
<td>Cufaude Village</td>
<td>993</td>
<td>3120</td>
<td>Consac 185mm²</td>
<td>357</td>
<td>106</td>
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<tr>
<td>Forest Edge</td>
<td>621</td>
<td>1362</td>
<td>ABC 95mm²</td>
<td>242</td>
<td>20</td>
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<tr>
<td>Ryans Mount</td>
<td>546</td>
<td>1449</td>
<td>AL 0.3in²</td>
<td>392</td>
<td>56</td>
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<tr>
<td>Your Homes</td>
<td>-</td>
<td>-</td>
<td>Waveform 185mm²</td>
<td>320</td>
<td>-</td>
</tr>
</tbody>
</table>
Residential LV Feeders – LVNS

- Developed as part of a Tier 1 Low Carbon Networks Fund project (Low Voltage Network Solutions – LVNS – Project)

- They represent a population of 141 LV networks (232 feeders) in the North West of England

<table>
<thead>
<tr>
<th>LV Feeder Name</th>
<th>Main Path Length (m)</th>
<th>Total Cable Length (m)</th>
<th>First Segment Cable Type</th>
<th>Rating (A)</th>
<th>No. of Customers</th>
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</thead>
<tbody>
<tr>
<td>Feeder 1</td>
<td>270</td>
<td>1207</td>
<td>Consac 185mm²</td>
<td>235</td>
<td>34 2 Other</td>
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<tr>
<td>Feeder 2</td>
<td>374</td>
<td>1676</td>
<td>Cu 0.25in²</td>
<td>355</td>
<td>96 6 6 (PC 3 - 4)</td>
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<tr>
<td>Feeder 3</td>
<td>370</td>
<td>1871</td>
<td>Cu 0.15in²</td>
<td>260</td>
<td>30 1 6 (PC 3 - 4); 1 (PC 5 - 8)</td>
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<tr>
<td>Feeder 4</td>
<td>517</td>
<td>2963</td>
<td>Cu 0.30in²</td>
<td>400</td>
<td>91 10 5 (PC 3 - 4); 2 (PC 5 - 8)</td>
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<tr>
<td>Feeder 5</td>
<td>253</td>
<td>962</td>
<td>Consac 240mm²</td>
<td>320</td>
<td>9 0 14 (PC 3 - 4)</td>
</tr>
<tr>
<td>Feeder 6</td>
<td>360</td>
<td>1828</td>
<td>Cu 0.20in²</td>
<td>310</td>
<td>73 3 0</td>
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<tr>
<td>Feeder 7</td>
<td>522</td>
<td>3673</td>
<td>Cu 0.50in²</td>
<td>525</td>
<td>161 6 2 (PC 3 - 4)</td>
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<tr>
<td>Feeder 8</td>
<td>264</td>
<td>797</td>
<td>Consac 360mm²</td>
<td>360</td>
<td>19 12 0</td>
</tr>
</tbody>
</table>


**DRIVING TOGETHER FOR A CLEANER FUTURE**
LV Network Impact Studies (1/7)

Methodology

Transformer
11/0.4 kV
Charging point
Cable
Sensor

Time of Day
Load Demand (kVA)

Load 1
Load 2
Load 3

Ev Demand (kVA)

0h 2h 4h 6h 8h 10h 12h 14h 16h 18h 20h 22h 24h
0 1 2 3 4

Time-series, three-phase power flow results


DRIVING TOGETHER FOR A CLEANER FUTURE
LV Network Impact Studies (2/7)
Example – Single Feeder (149 houses)

Base case

100% Penetration

Thermal – Winter Weekday
LV Network Impact Studies (3/7)
Example – Single Feeder (149 houses)

All Penetrations

Thermal – Winter Weekday
LV Network Impact Studies (4/7)
Example – Single Feeder (149 houses)

Base case

100% Penetration

Voltages – Winter Weekday
LV Network Impact Studies (5/7)
9 Validated MEA Feeders

Winter - Weekday

Summer - Weekday
LV Network Impact Studies (6/7)
8 LVNS Feeders

Winter - Weekday

Summer - Weekday
LV Network Impact Studies (7/7)
8 LVNS Feeders

<table>
<thead>
<tr>
<th>LV Feeder Name</th>
<th>Winter</th>
<th>Spring/Autumn</th>
<th>Summer</th>
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<tbody>
<tr>
<td></td>
<td>Weekday</td>
<td>Weekend</td>
<td>Weekday</td>
</tr>
<tr>
<td>Feeder 1</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Feeder 2</td>
<td>50</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td>Feeder 3</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Feeder 4</td>
<td>40</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Feeder 5</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Feeder 6</td>
<td>30</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Feeder 7</td>
<td>80</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>Feeder 8</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Esprit Philosophy

Transformer 11/0.4 kV
Charging point
PLC
Data and control flow
Sensor

DRIVING TOGETHER FOR A CLEANER FUTURE
Esprit-Like Control (1/8)

Conceptual approach

- Curtail the demand from EVs when technical problems are detected
- Reconnect and continue the charging of EVs when no problems are detected (considering security margins)
Esprit-Like Control (2/8)

Challenges

• Must follow a hierarchical approach
  – Crucial as problems can occur at the feeder level first
  – Hierarchical **Corrective** Disconnection

  Feeder Level (per phase per feeder) \(\rightarrow\) Transformer Level

  – Hierarchical **Preventive** Reconnection

  Transformer Level \(\rightarrow\) Feeder Level (per phase per feeder)

• The number and which EVs will be disconnected/reconnected
• Effects on customers – charging delays

Esprit-Like Control (3/8)
Methodology

Real UK LV Network
- North West of England
- Operated by UK DNO, ENWL
- 500 kVA Transformer
- 11kV/433V, 3-phase
- Unbalanced
- 370 Customers

Probabilistic Assessment:
- **Monte Carlo** analysis (100 simulations)
- **Time-Series** Analysis
- Different EV penetration (% house with EV) levels (i.e., 0-100%)
- **Metrics**: utilization factor and non-compliant customers (EN 50160)
- **Customer Metrics**: Charging Delays
Esprit-Like Control (4/8)

Network Performance

![Graph showing network performance with and without control.](image-url)
Esprit-Like Control (5/8)

EV Demand

Expected time: 160 min (2:40h)
Actual time: 389min (6:29h)
Charging Delay: 143.13%
Esprit-Like Control (6/8)

EV Demand

Impact Level 100% EV penetration

<table>
<thead>
<tr>
<th>Probability (%)</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>
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<tbody>
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<td>Impact Level</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Customer Impact Level

<table>
<thead>
<tr>
<th>Additional Charging Time (%)</th>
<th>0</th>
<th>1-25</th>
<th>26-50</th>
<th>51-75</th>
<th>76-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Impact Level</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional Charging Time (%)</th>
<th>101-125</th>
<th>126-150</th>
<th>151-175</th>
<th>176-200</th>
<th>&gt; 200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Impact Level</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

Driving together for a cleaner future
Esprit-Like Control (7/8)
Probabilistic Assessment and Control Cycles

Thermal Limit

Transformer
Esprit-Like Control (8/8)
Customer Impact Level

Impact Analysis for 1 min Control Cycle

Impact Level
Probability (%)
0 1 2 3 4 5 6 7 8 9
20
40
60
80
100

40% Penetration Level
60% Penetration Level
80% Penetration Level
100% Penetration Level

Control Cycle

<table>
<thead>
<tr>
<th>EV Penetration Level (%)</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 min</td>
<td>99</td>
<td>87</td>
<td>72</td>
<td>59</td>
<td>50</td>
<td>44</td>
<td>40</td>
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<tr>
<td>5 min</td>
<td>99</td>
<td>89</td>
<td>77</td>
<td>67</td>
<td>60</td>
<td>56</td>
<td>51</td>
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<tr>
<td>10 min</td>
<td>100</td>
<td>91</td>
<td>80</td>
<td>71</td>
<td>63</td>
<td>59</td>
<td>54</td>
</tr>
<tr>
<td>30 min</td>
<td>100</td>
<td>95</td>
<td>85</td>
<td>76</td>
<td>70</td>
<td>64</td>
<td>59</td>
</tr>
</tbody>
</table>

DRIVING TOGETHER FOR A CLEANER FUTURE
Key Remarks

• The ESPRIT technology is an **intelligent, cost-effective solution** to control EVs
  • Use of limited information / infrastructure
  • Attractive to network operators

• The MEA trial captures the **actual EV behaviour**
  • 200+ domestic EVs

• **Understanding the impacts** of control strategies on customers is crucial
Thanks for your attention!

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jairo.quirostortos@manchester.ac.uk