IEEE PES Student Chapter @ UoM

Intelligent Control of EVs:
Lessons Learned from the Largest UK EV Trial

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The University of Manchester, Manchester, UK

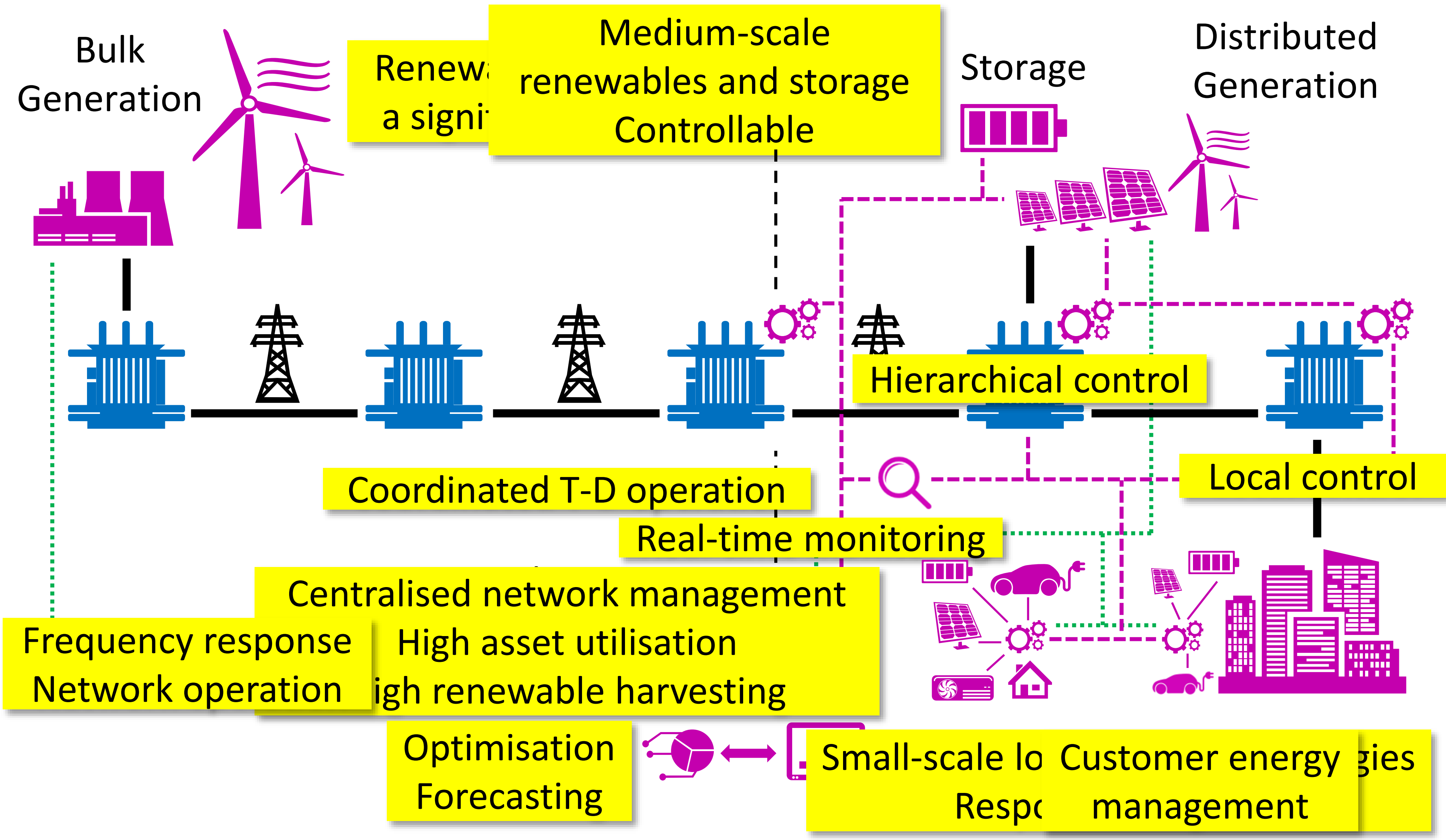
Outline

- Towards Smart and Low-Carbon Electricity Networks

- My Electric Avenue (MEA) Project
  - EV Charging Behaviour
  - EV Impact Studies (Business As Usual)
  - EV Management (ESPRIT-Based Control)
    - Field example
    - Economic and carbon assessment

- Conclusions

Smart & Low Carbon



UK Innovation Incentives

- Regulatory Period **2010-2015: DPCR 5**
  - Low Carbon Networks Fund (LCNF)
  - **US$750m+** for DNOs to **try out new technology, operating and commercial arrangements**
  - Tier 1: direct allocation for small projects
  - Tier 2: competitive for large projects

- Regulatory Period **2015-2023: RIIO-ED1**
  - Network Innovation Allowance
  - Tier 2 → Network Innovation Competition
  - … similar level of funding

R=I+I+O

Reducing the investment risk of moving towards Smart Grids

My Electric Avenue (MEA) 2013-2015

Total Cost
US$15m

MY ELECTRIC AVENUE

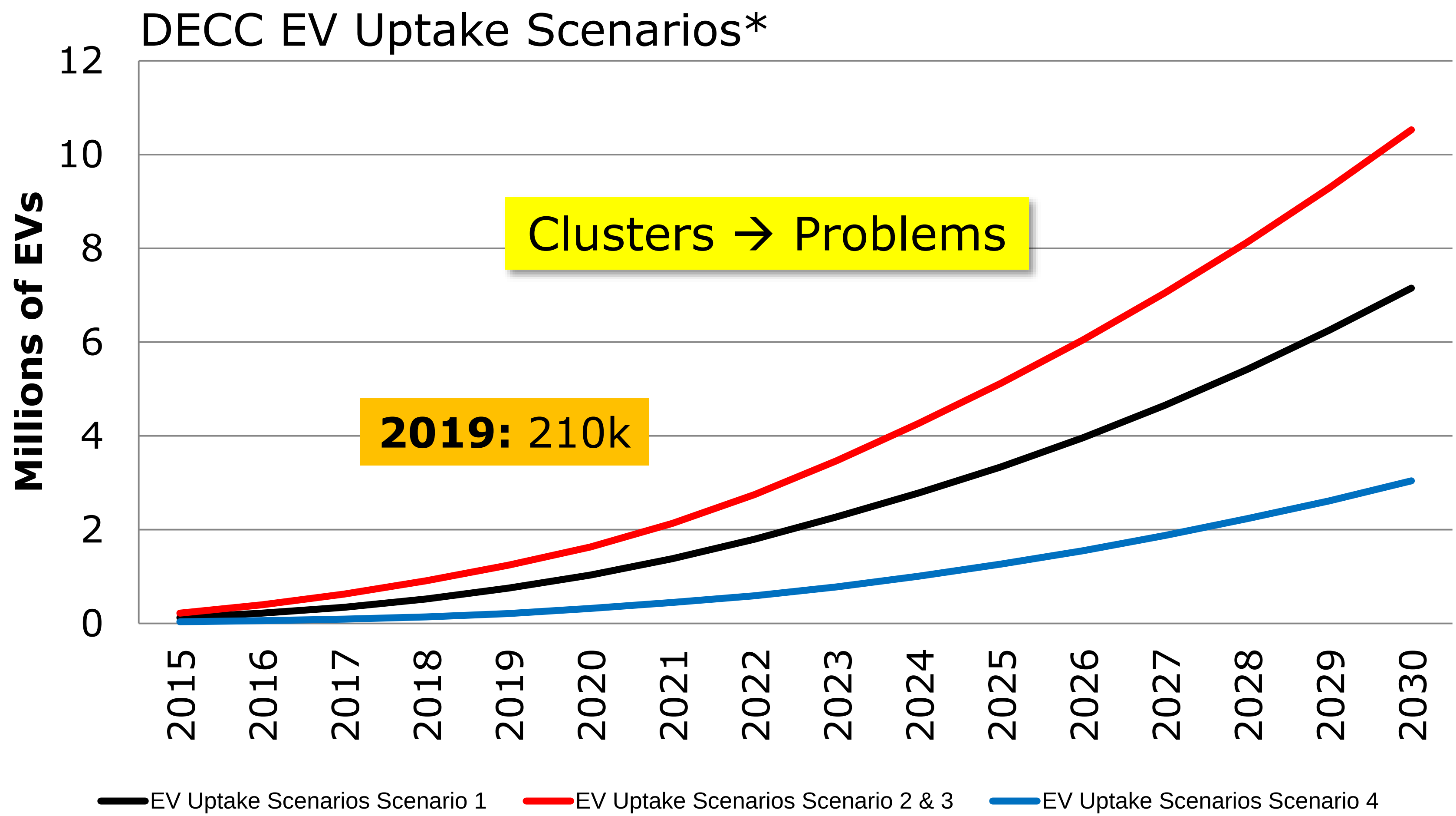
Project run by
EA Technology
Funding DNO
SSE PD

ea technology
Scottish and Southern Energy Power Distribution

myelectricavenue.info

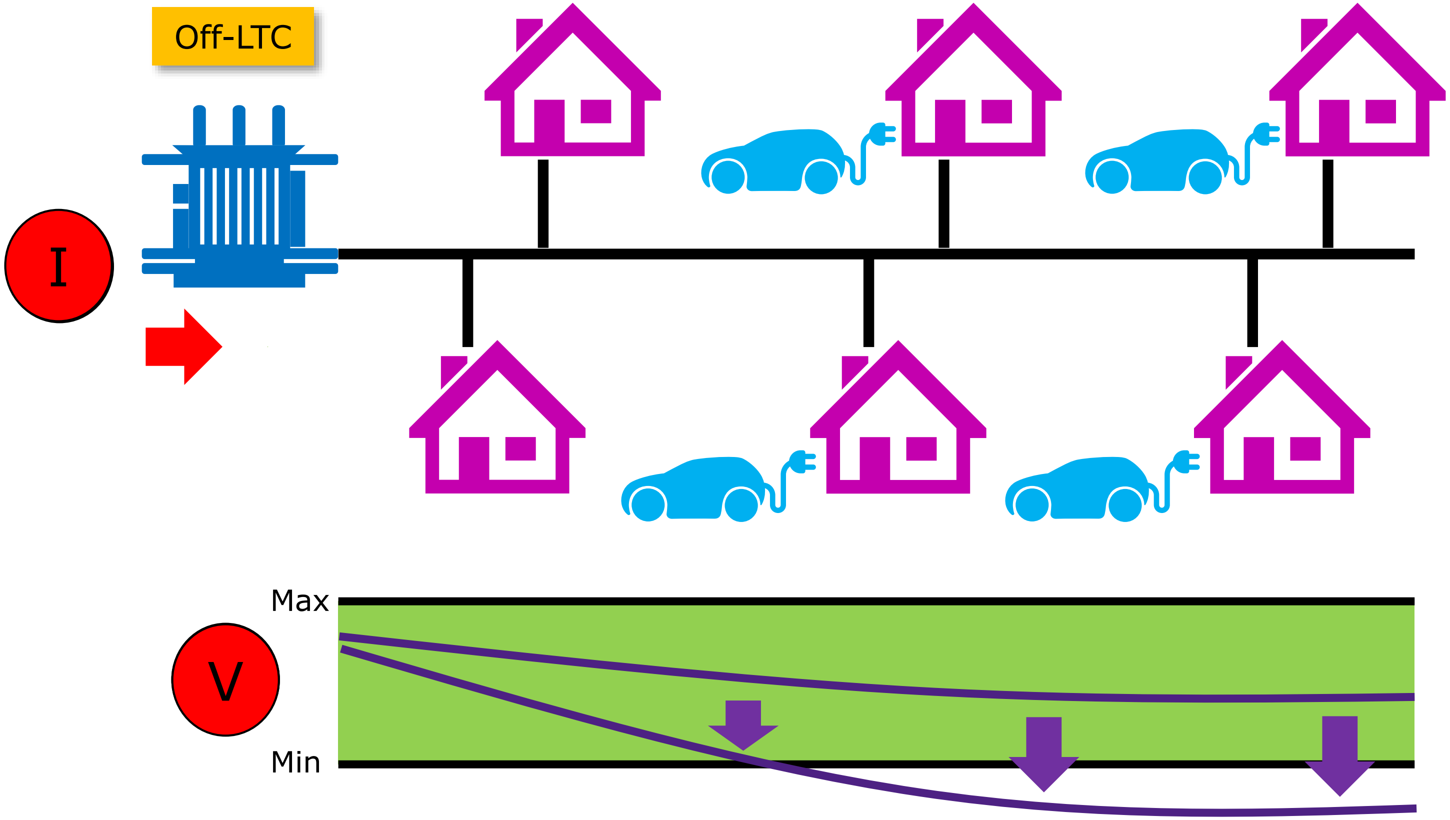
Electric Vehicles (EVs) in the UK

Old Estimates



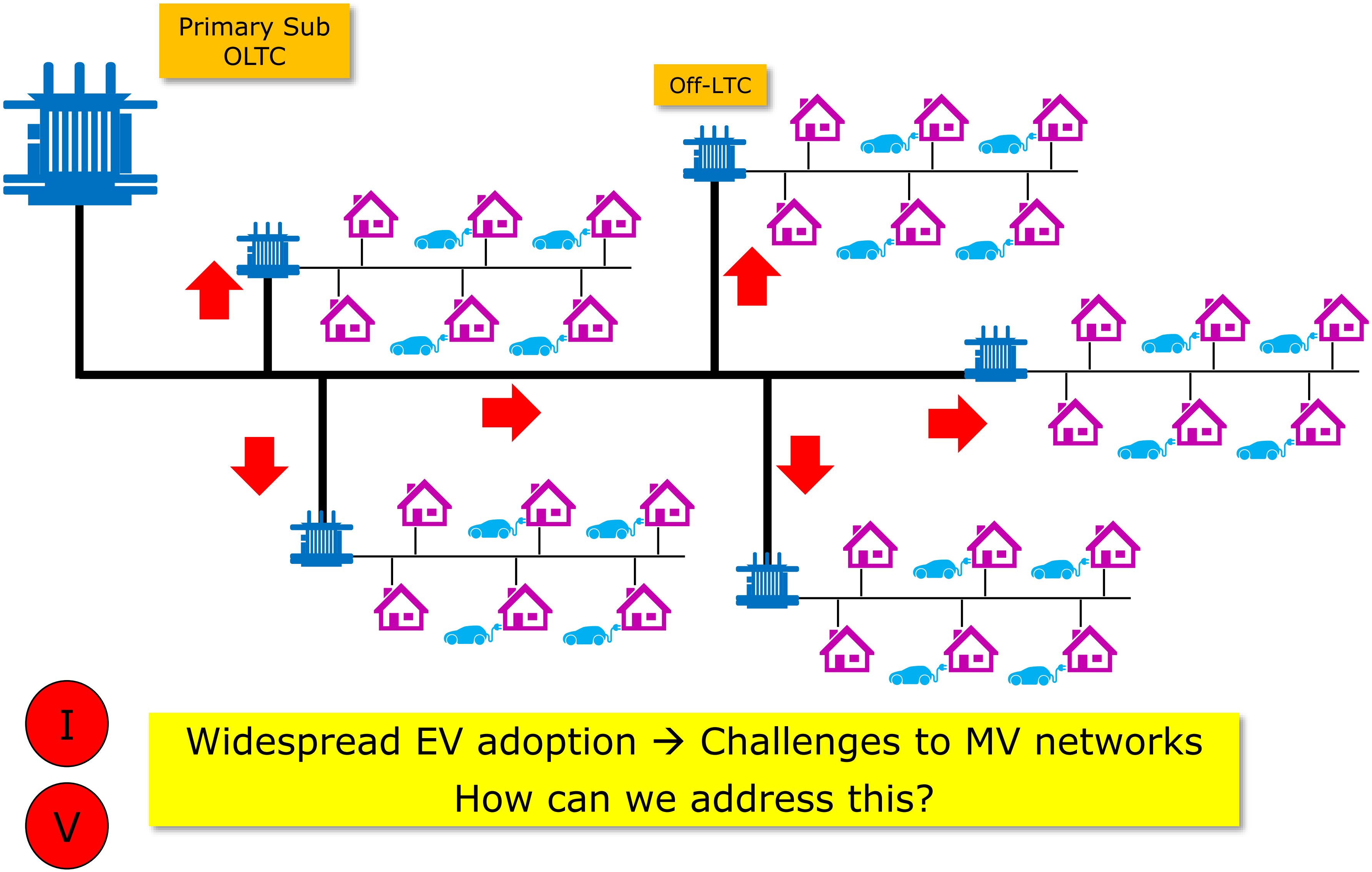
* Department of Energy and Climate Change (DECC) – https://www.ofgem.gov.uk/ofgem-publications/56824/ws3-ph2-report.pdf

Clusters → Prolems?



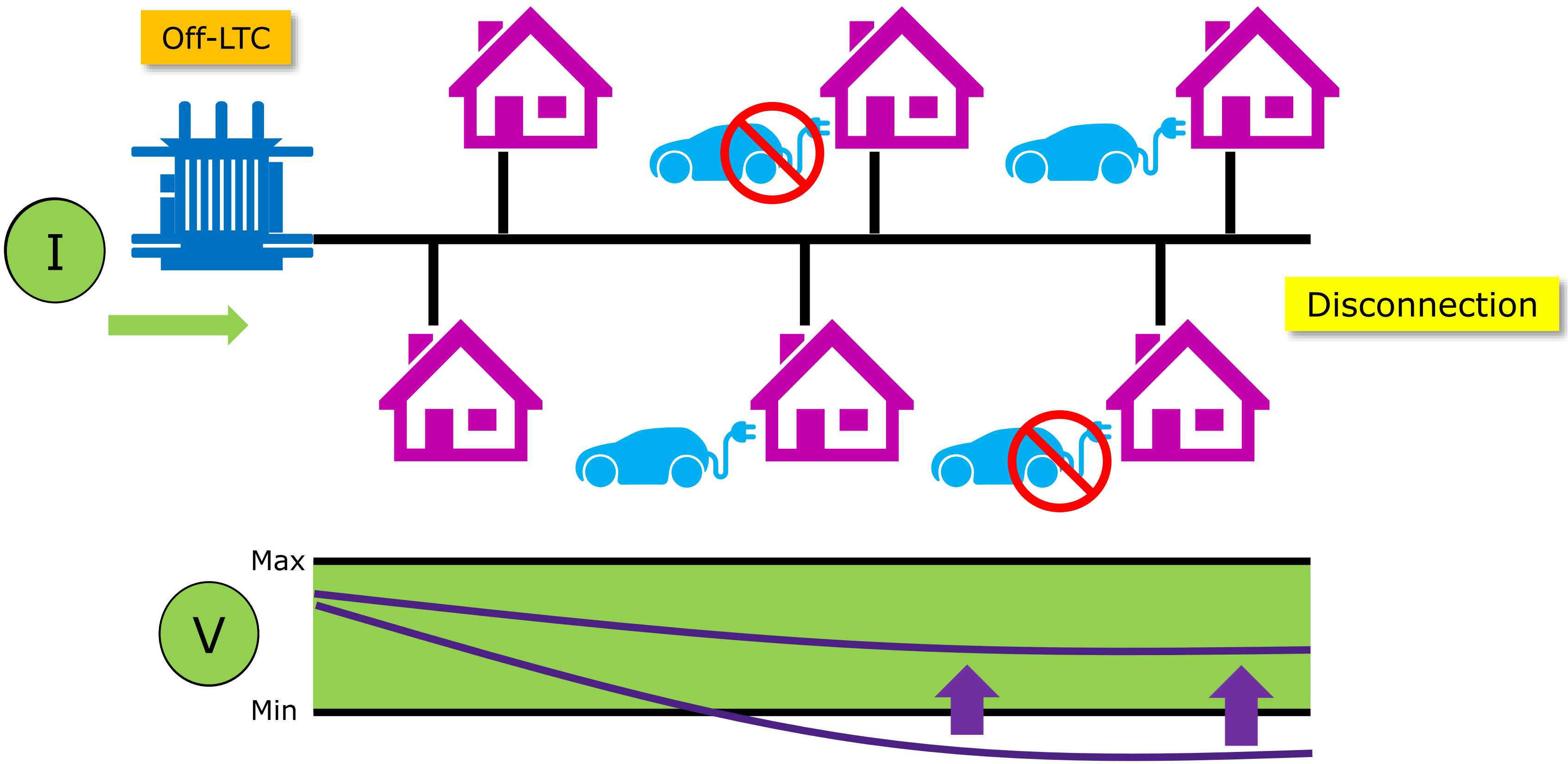
EV demand happens during peak hours, when people return home → Problems

Electric Vehicles & MV Networks



Widespread EV adoption → Challenges to MV networks
How can we address this?

Management of EV Charging Points



EV impacts ***could*** be avoided disconnecting charging points when needed

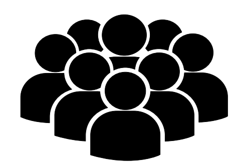
EV Challenges

- EV Clusters
  - Can affect the infrastructure close to customers (LV networks)
  - Thermal overloads, voltage drops

MY ELECTRIC AVENUE

Control of EV Charging Points

- EV Management
  - Cost-effective infrastructure
  - Fair criteria to control EVs
  - Customer acceptance

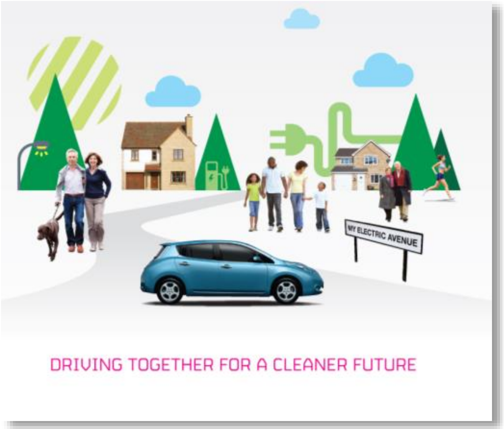


My Electric Avenue (MEA)

Aims:

- To understand charging behaviour of (200+) EV users
- To investigate the impacts of EVs on 9 real LV networks
- To trial a cost-effective and practical solution to control EV charging points (Esprit Technology*)

MY ELECTRIC AVENUE



Geographical Extent of the Trial

112 Social Trials

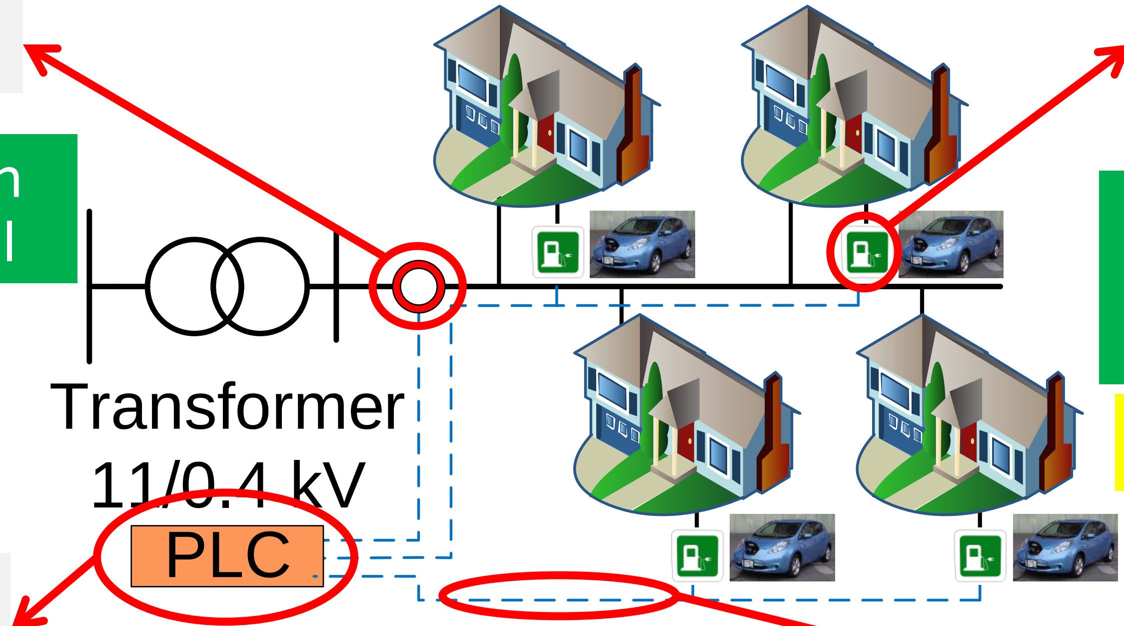
109 Technical Trials

221 in total

Infrastructure Overview

Sensors (V, I) head of feeders

Violations in the thermal



Sensors and actuators at EV charging points

Significant voltage drops

State of Charge: Unknown

PLC-like device at substations

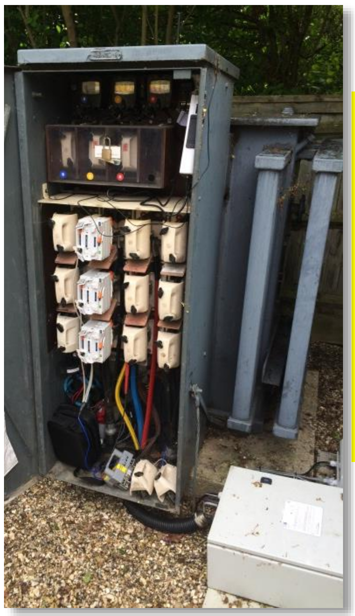
(control hub)

Power Line Carrier-based communications

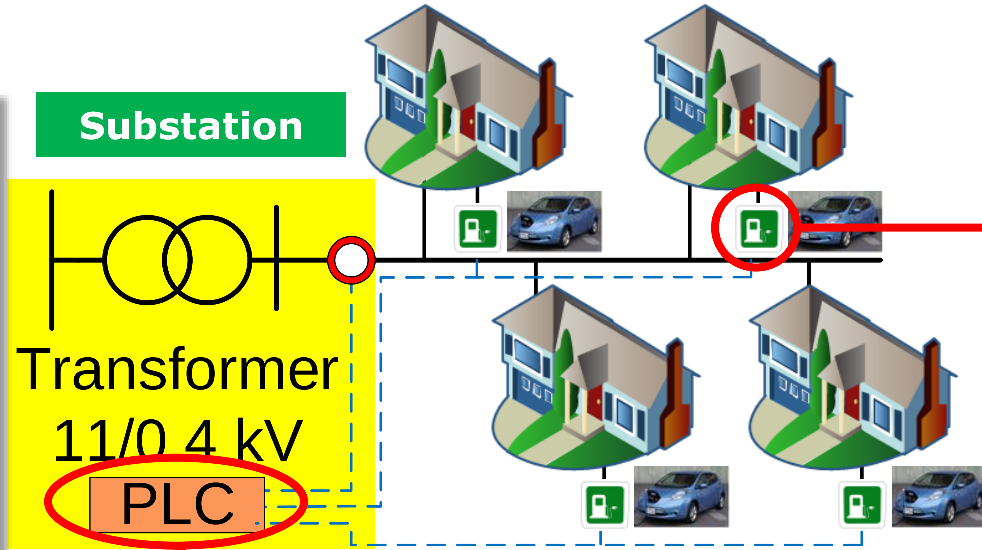
(**bi-directional**)

MEA makes the most of available infrastructure

Infrastructure Overview



Real 500 kVA Transformer



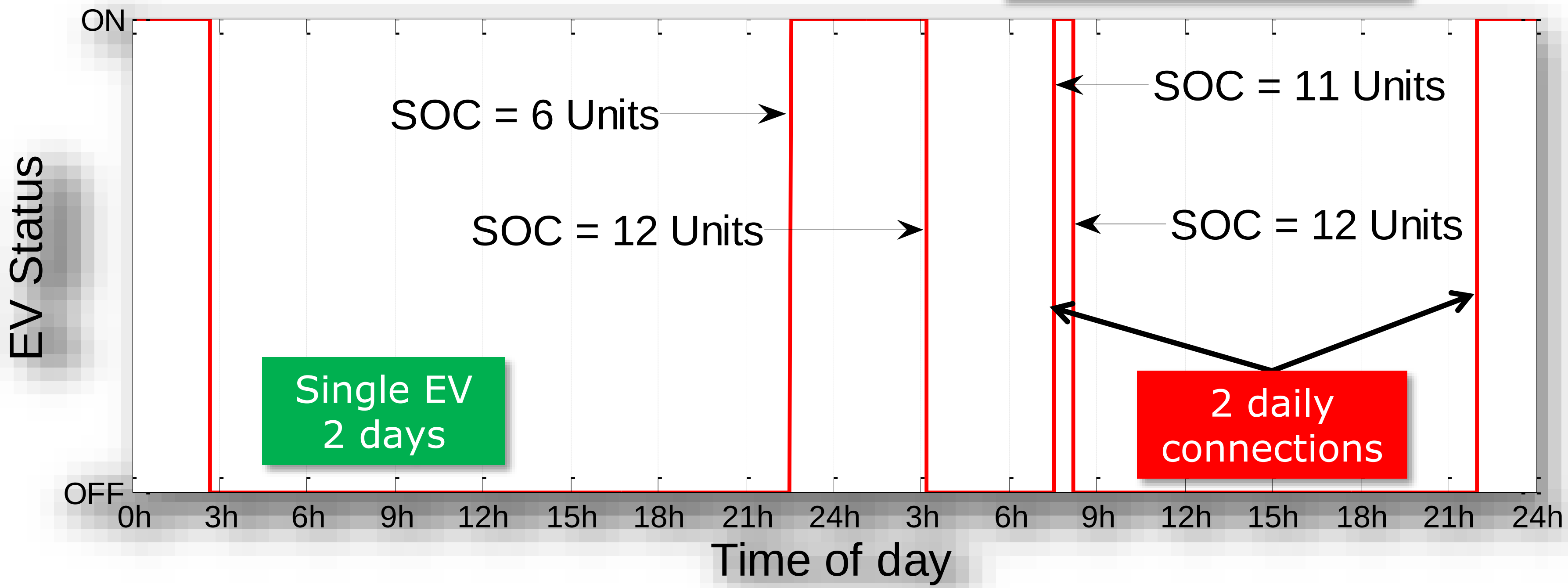
ROLEC*
charging point
+
EA Technology
Intelligent Control Box

* http://www.rolecserv.com/

EV Charging Behaviour

More than 75,000 charging samples

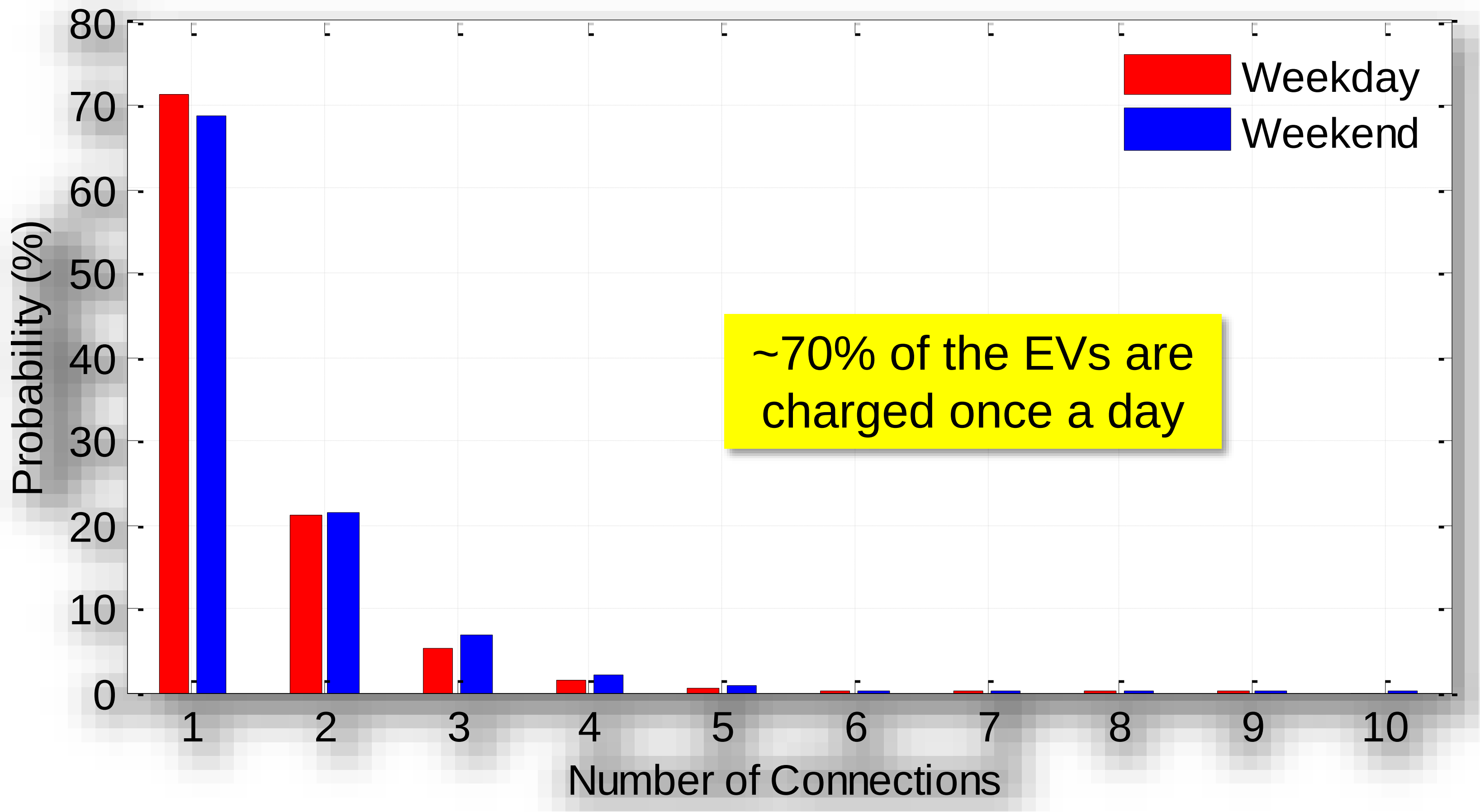
(without control)



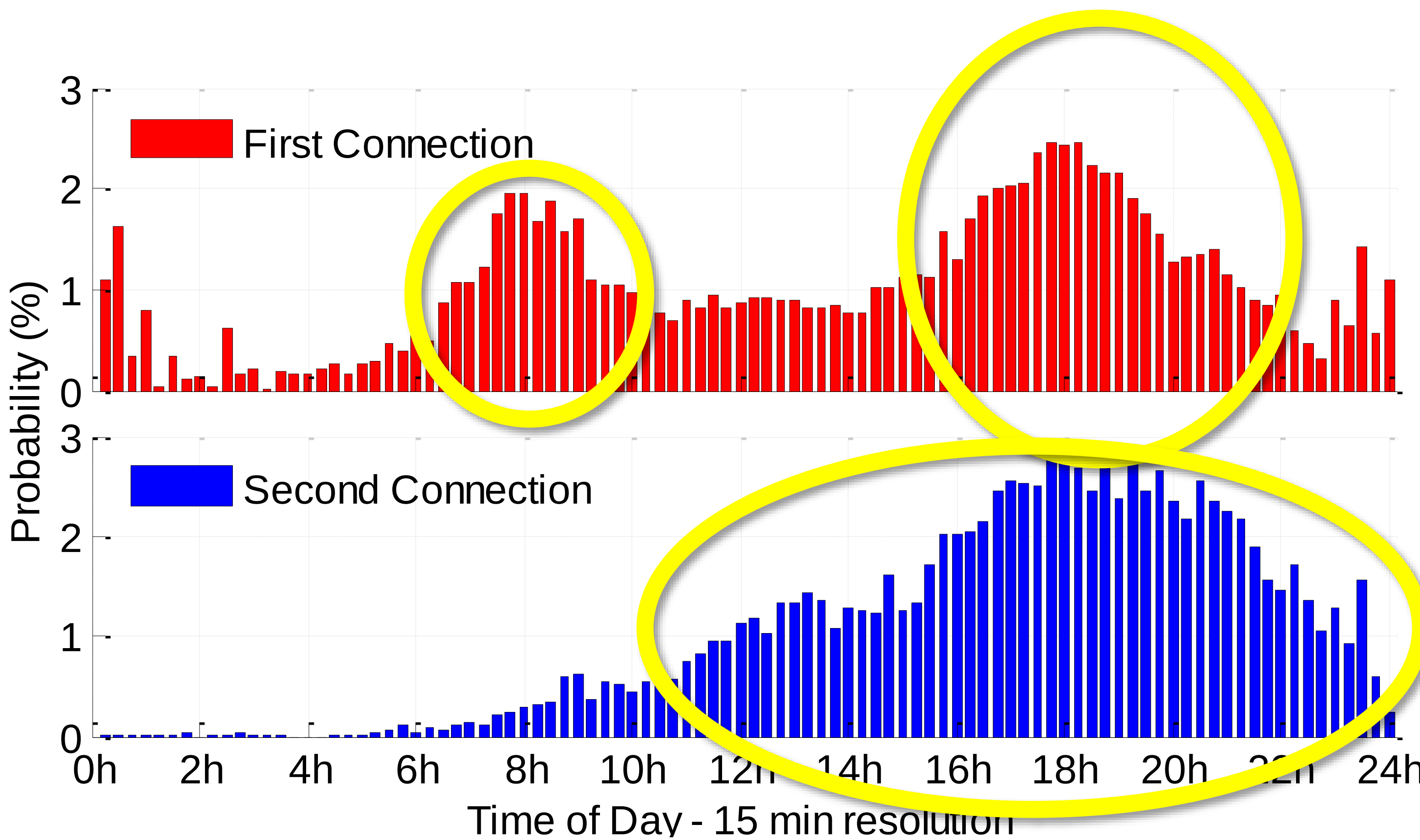
Crucial to understand EV users charging behaviour

*https://www.youtube.com/watch?v=Ox2bQ4vpLNg

Number of Charging Events per Day

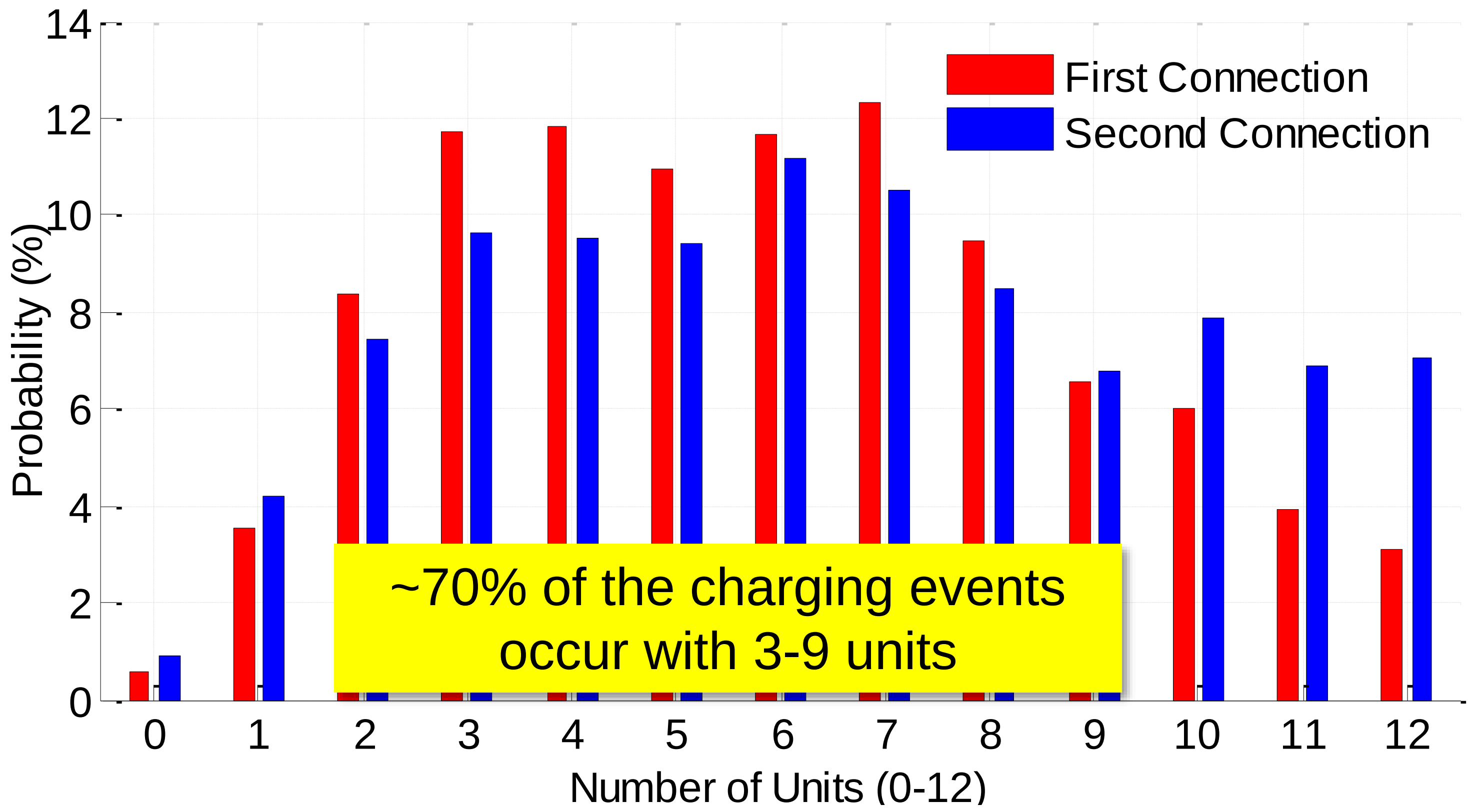


Start Charging Time



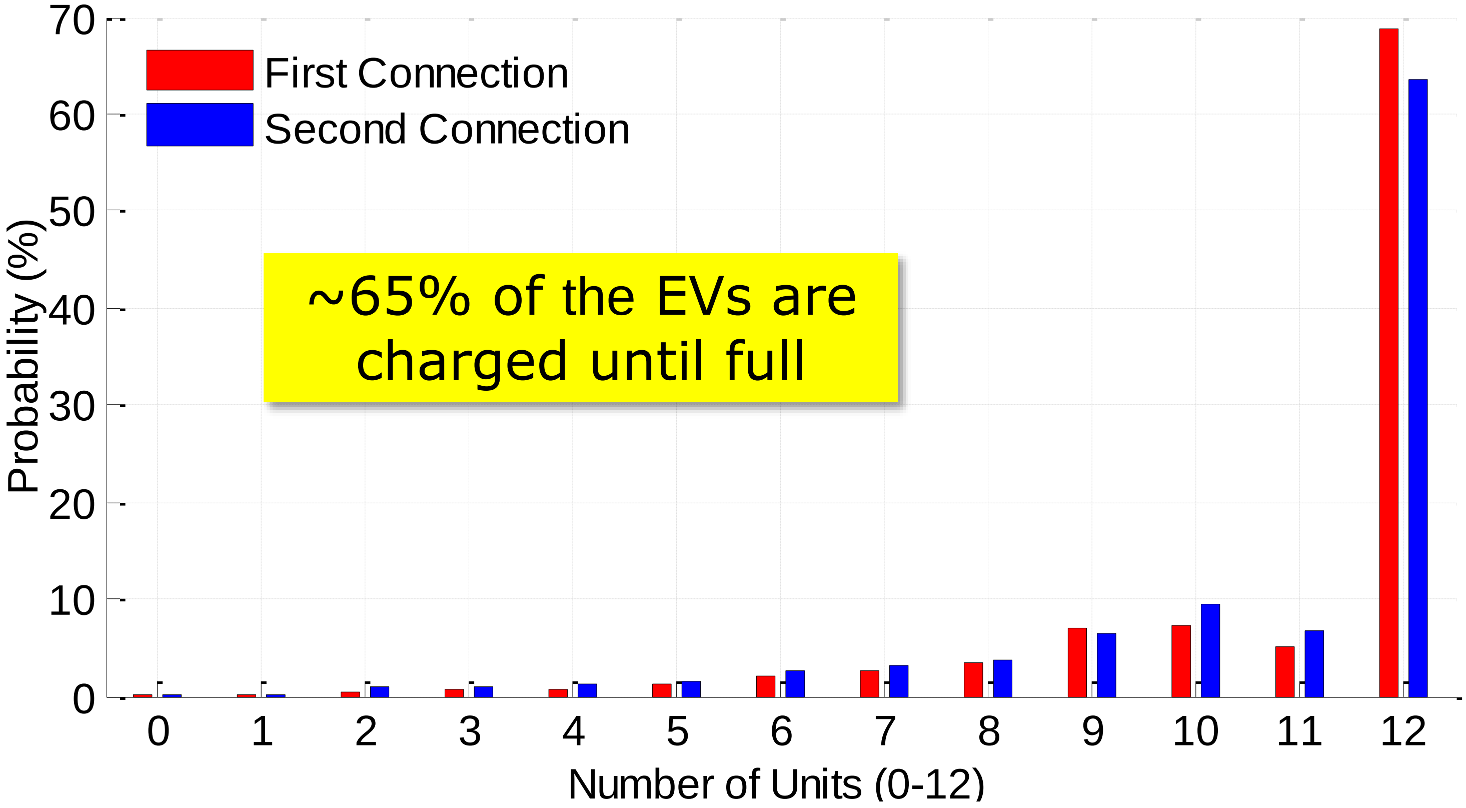
Weekdays

Initial Charging Level



Weekdays

Final Charging Level

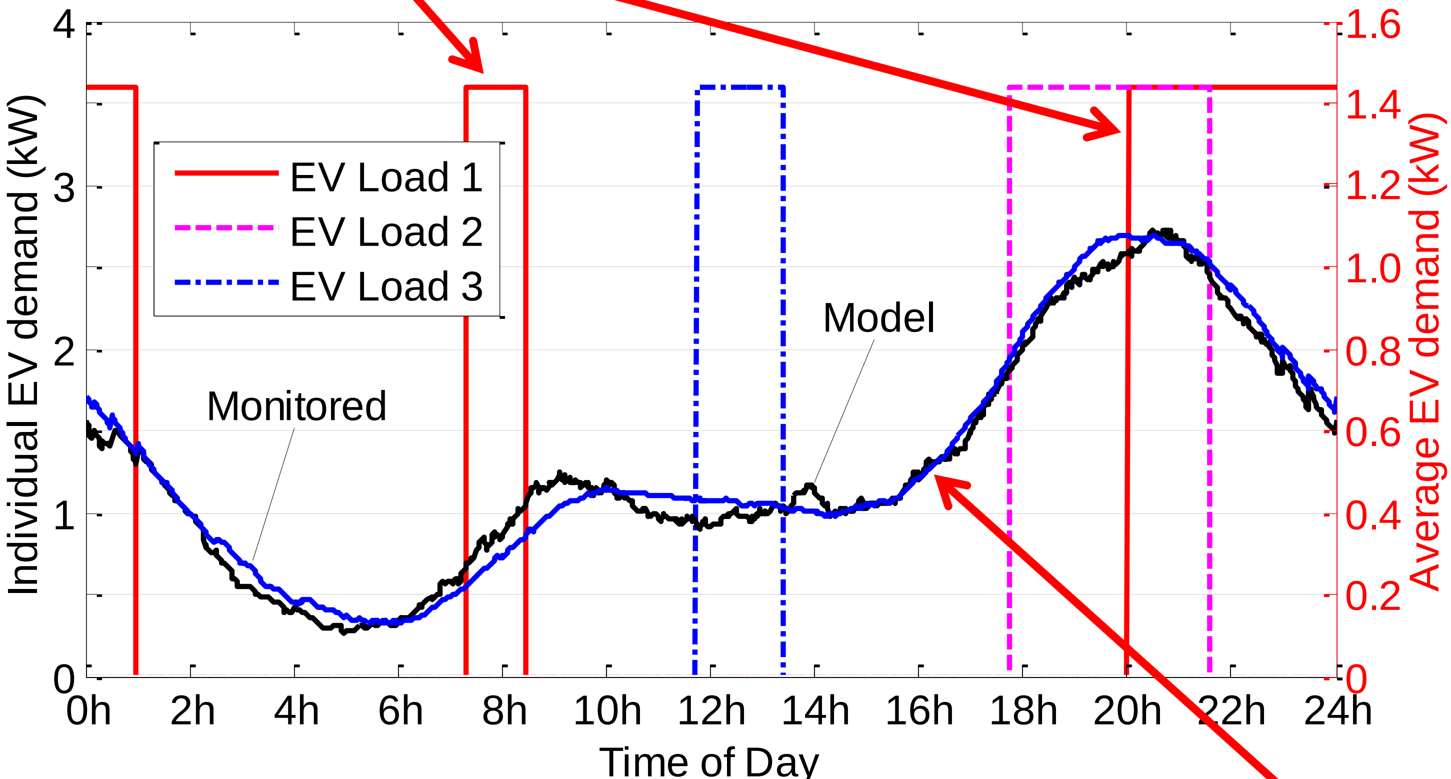


Weekdays

EV Charging Behaviour

Two charging events

EVs can be connected any time



Created models match monitored behaviour

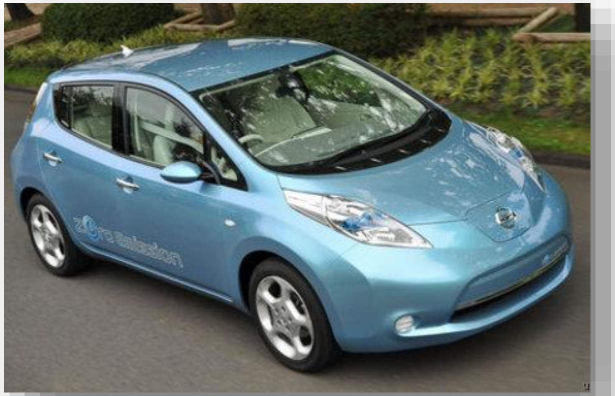
Weekdays

Stochastic Impact Analysis of EVs

- To understand the behaviour and needs of future LV networks with high penetrations of EVs

- Stochastic Analysis (Monte Carlo) to cater for uncertainties
  - EV charging behaviour, load profile, etc.

- Metrics
  - Thermal overloads
  - Voltage issues (BS EN 50160)



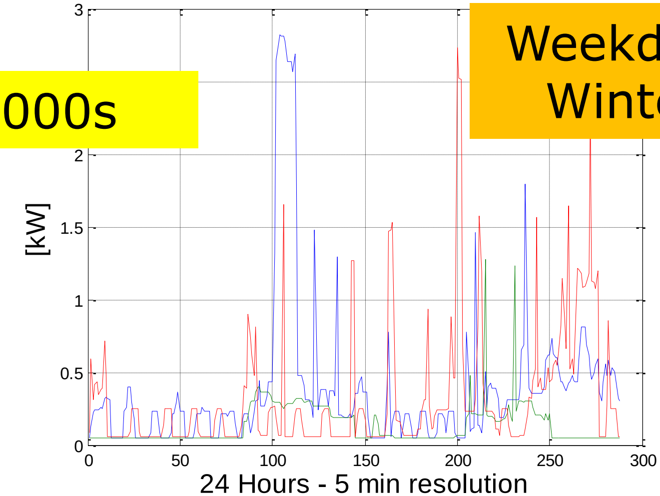
*https://www.youtube.com/watch?v=Ox2bQ4vpLNg

Impact Analysis: Input Data

- Real LV **networks**
- Realistic **domestic** load **profiles***

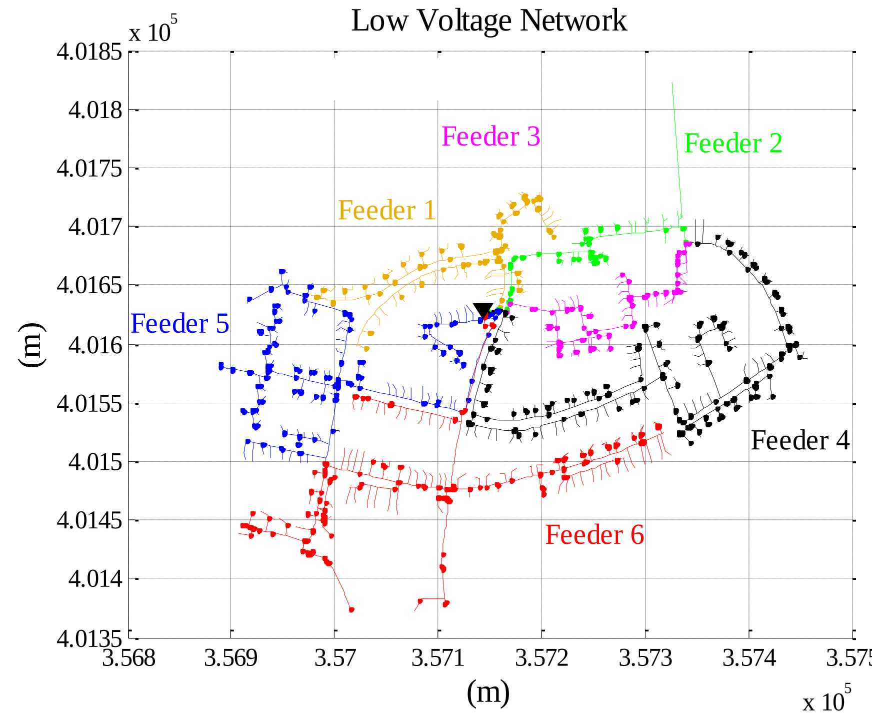
1000s

Weekday/ Winter



- Realistic **EV** load **profiles***

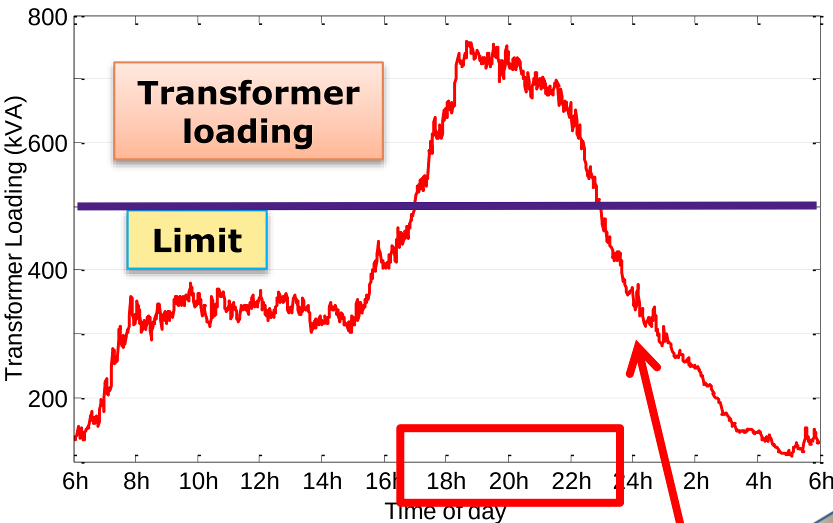
MEA Project

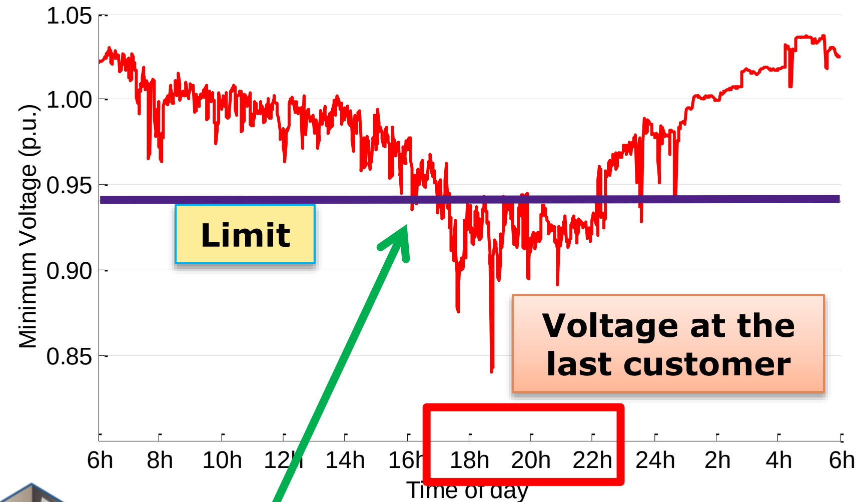


9 Real UK LV Networks

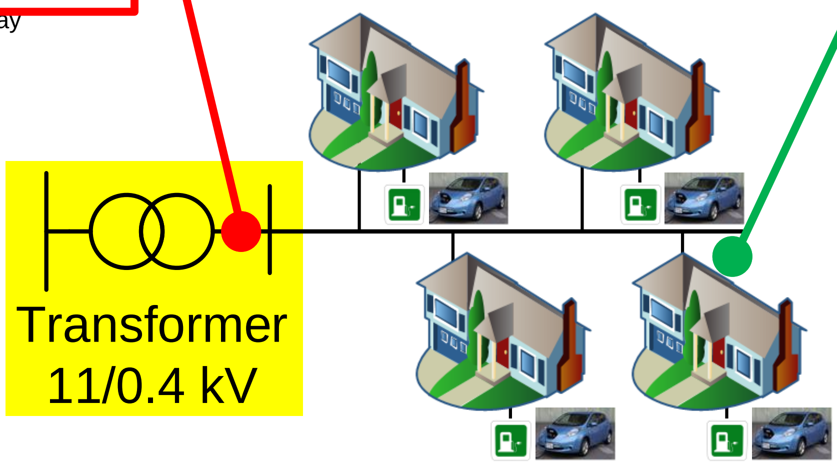
- 11kV/433V, three-phase
- Single-phase customers
- 31 LV feeders
- Main cable: 220–750m
- 2,000+ customers

Example LV Network





500 kVA transformer
370 customers
6 LV feeders
Length: 250 – 650 m

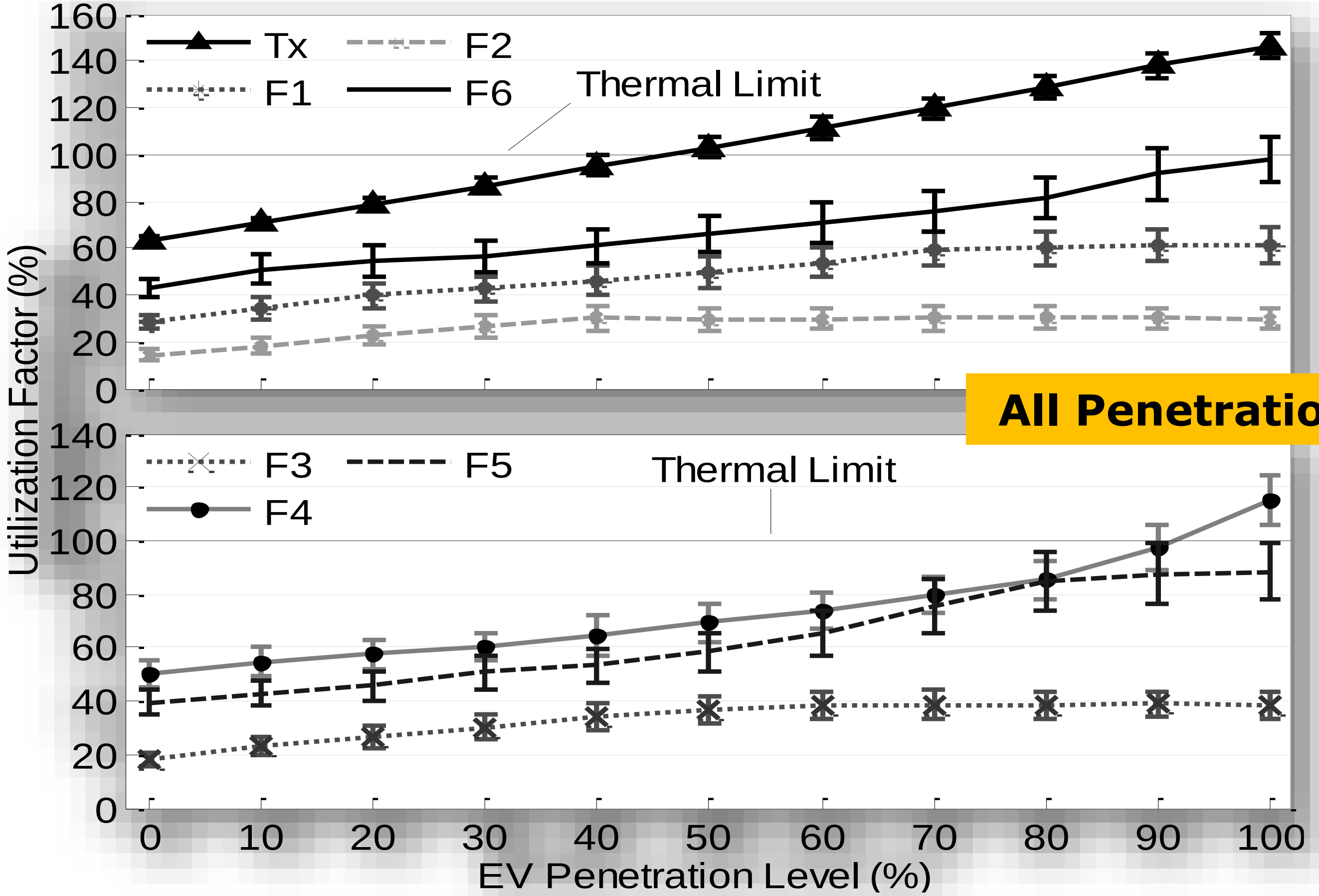


100% PV Penetration

What happens with other penetrations?
Which problem occurs first?
When problems start?

Multi-penetration and multi-network assessment

Example LV Network

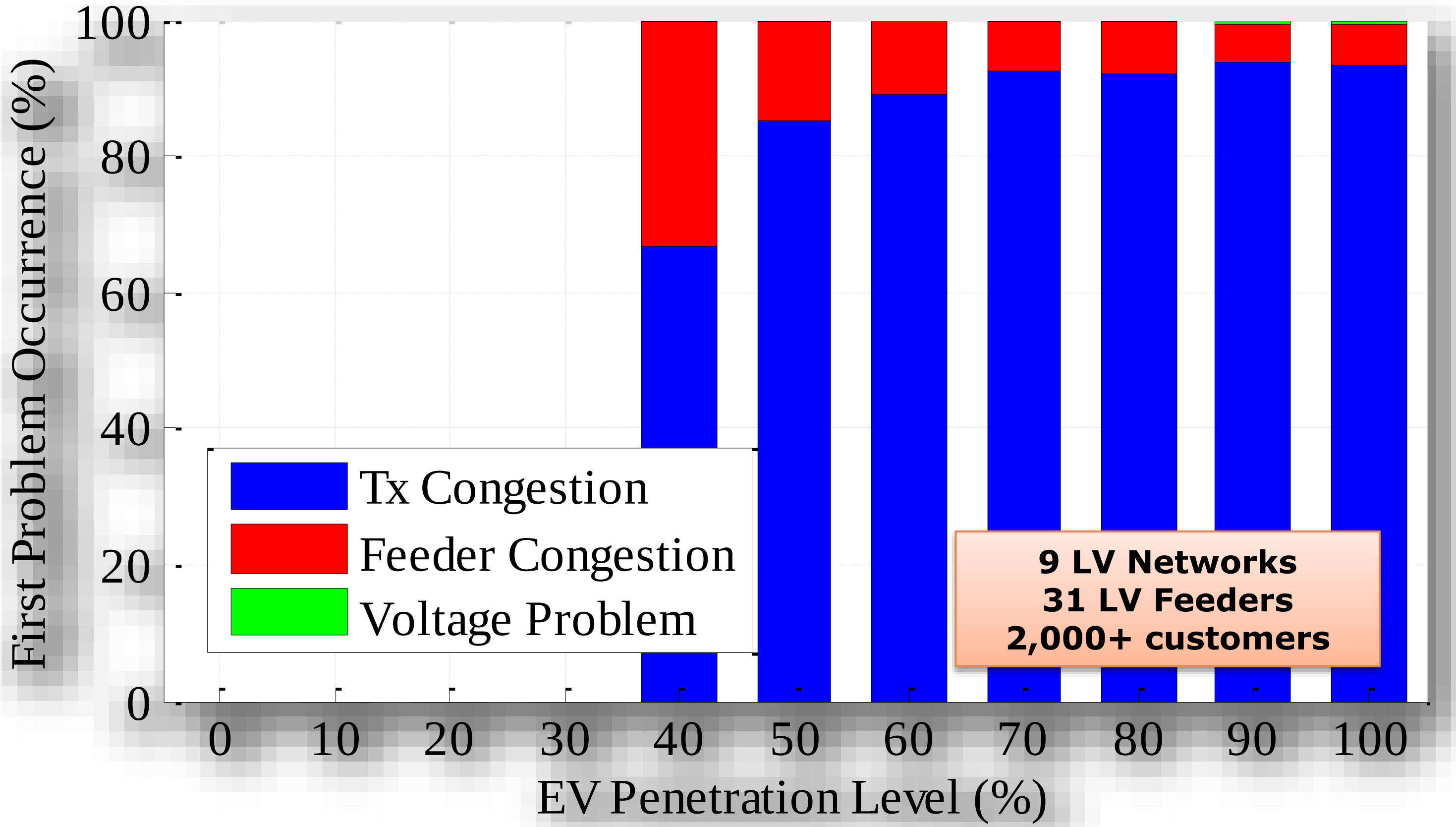


All Penetration Levels

Transformer (500 kVA) congestion appears first

Then feeders are affected (highly loaded ones)

Impact Analysis: Key Remarks



Congestion main constraint from **40% of EV penetration**

Different LV networks experience different problems

ESPRIT-Based Control

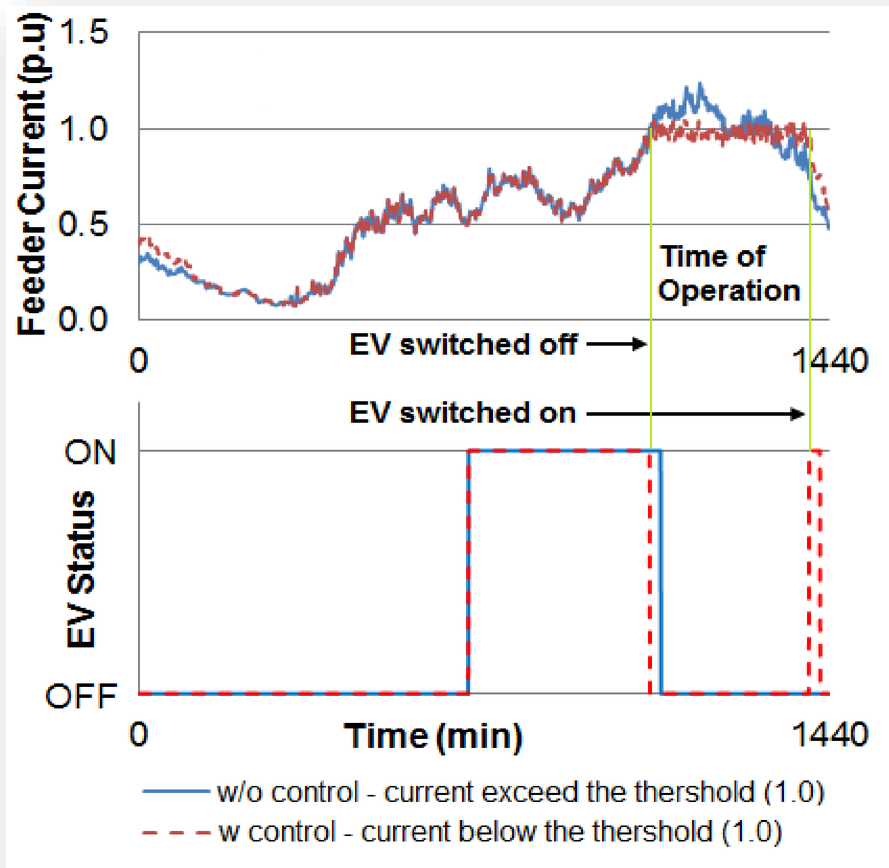
- To understand the extent to which a cost-effective and practical solution can manage EV charging points
- Stochastic Analysis (Monte Carlo) to cater for uncertainties
  - EV charging behaviour, load profile, etc.
- Metrics
  - Thermal overloads
  - Voltage issues (BS EN 50160)
  - Customer Impact Level

*https://www.youtube.com/watch?v=Ox2bQ4vpLNg

Conceptual Approach

1. Disconnect EVCPs when problems are detected
   - Following a hierarchical (corrective) approach
2. Reconnect EVCPs when no problems are detected
   - Following a hierarchical (preventive) approach
3. Suitable selection of the EVs will be managed

Simplest Control Algorithm → Advanced Control Algorithms

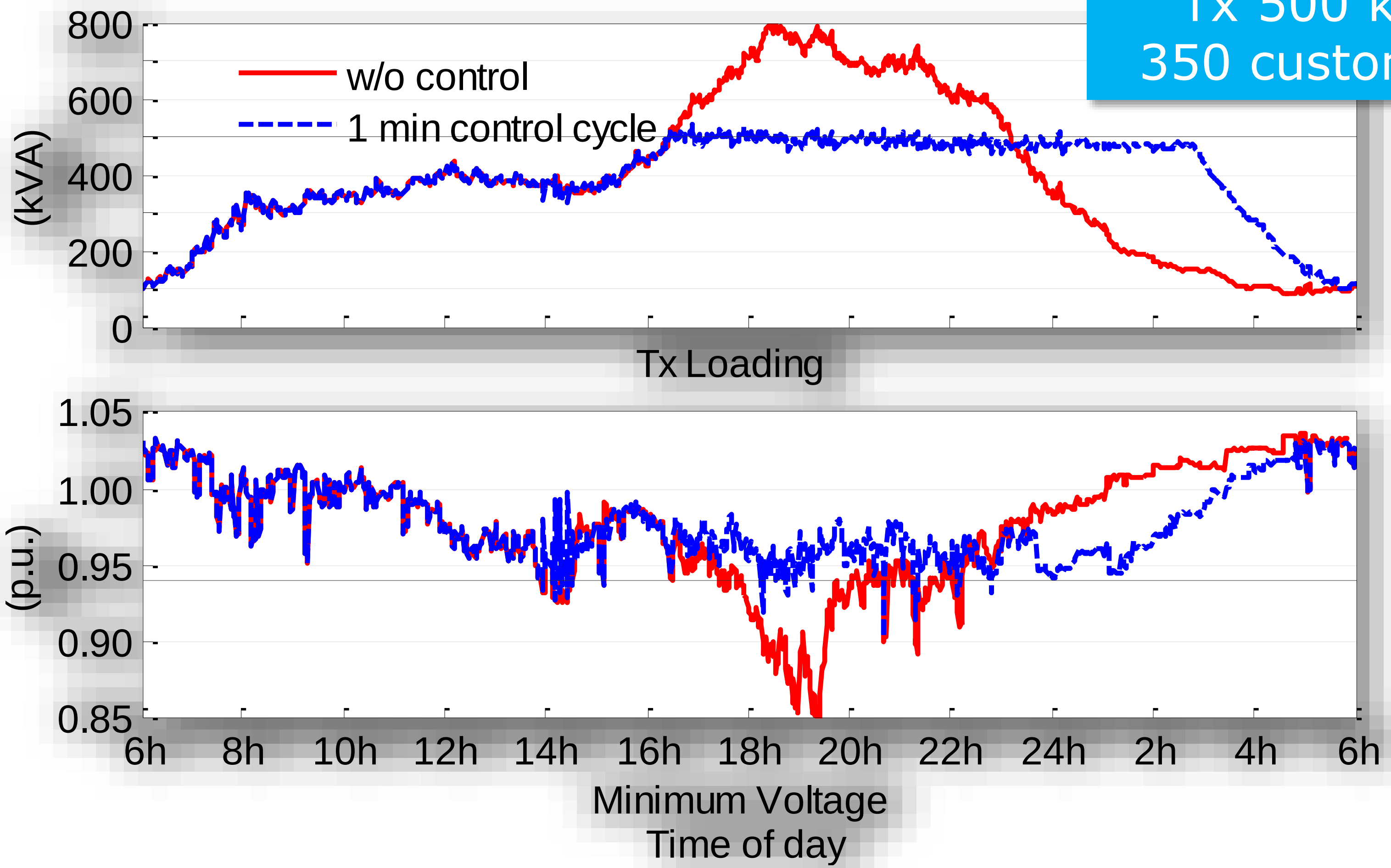


MEA progressively trialled the control algorithm

*J. Quirós-Tortós, et al, "Control of EV charging points for thermal and voltage management of LV networks," IEEE Transactions on Power Systems, 2016

Network Performance (100% EVs)

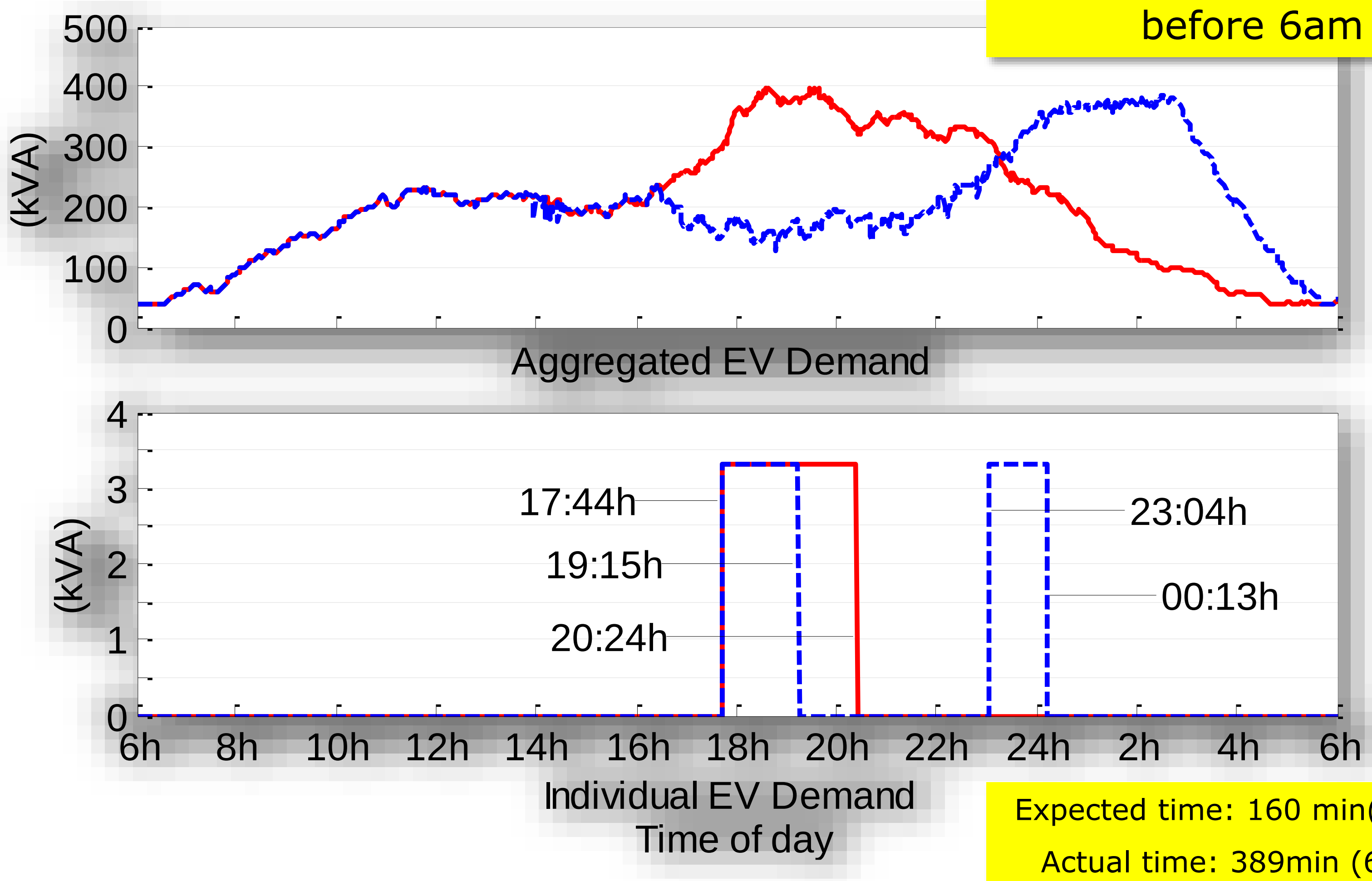
Tx 500 kVA
350 customers



1-min control cycle → Problems solved! (in theory)

Effects on EV Demand

Most EVs are charged before 6am

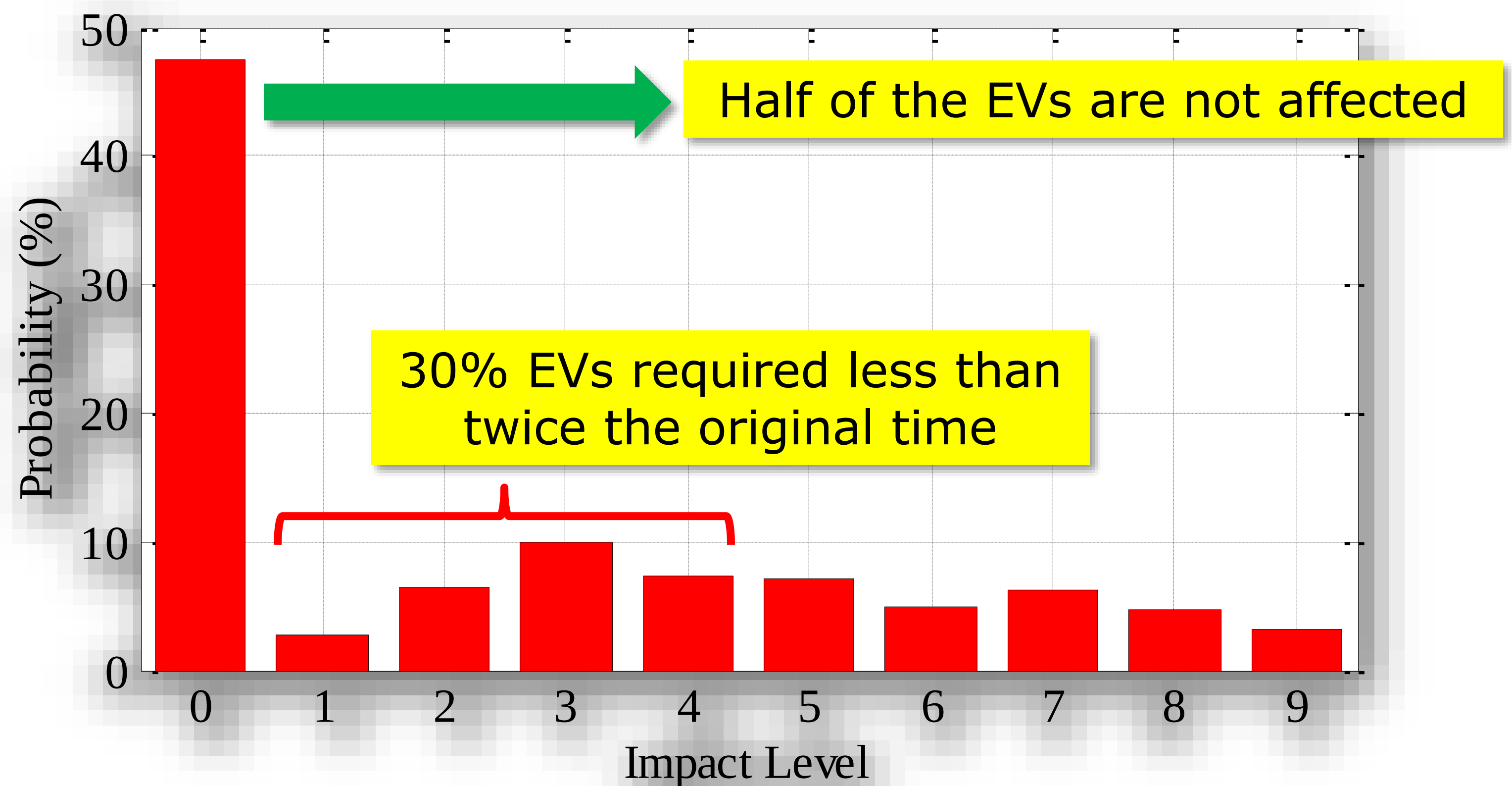


Expected time: 160 min(2:40h)

Actual time: 389min (6:29h)

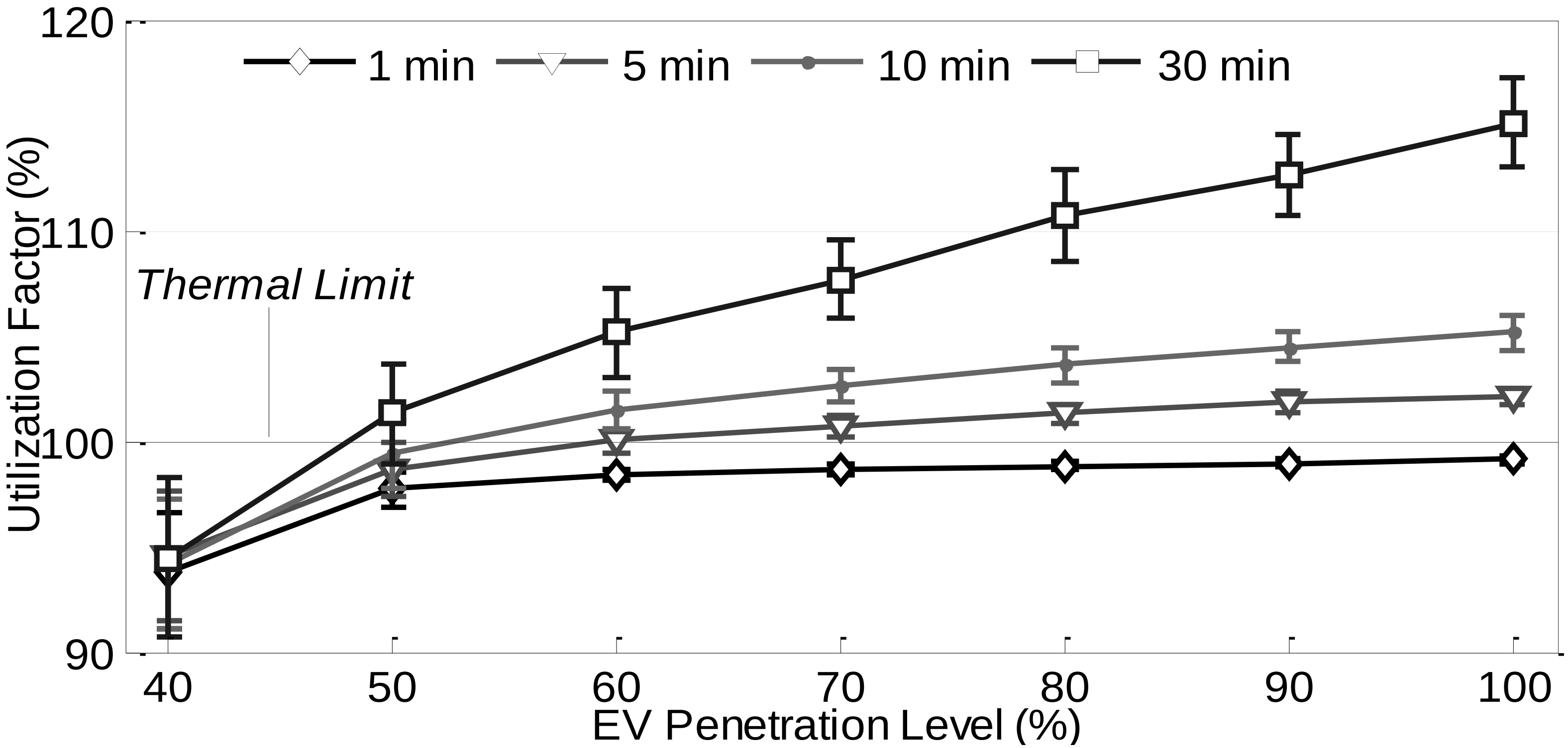
Charging Delay: 143.13%

Customer Impact Level (CIL)



Customer Impact Level	0	1	2	3	4
Additional Charging Time (%)	0	1-25	26-50	51-75	76-100
Customer Impact Level	**5**	**6**	**7**	**8**	**9**
Additional Charging Time (%)	101-125	126-150	151-175	176-200	> 200

Transformer Loading



10-min control cycle can be as effective

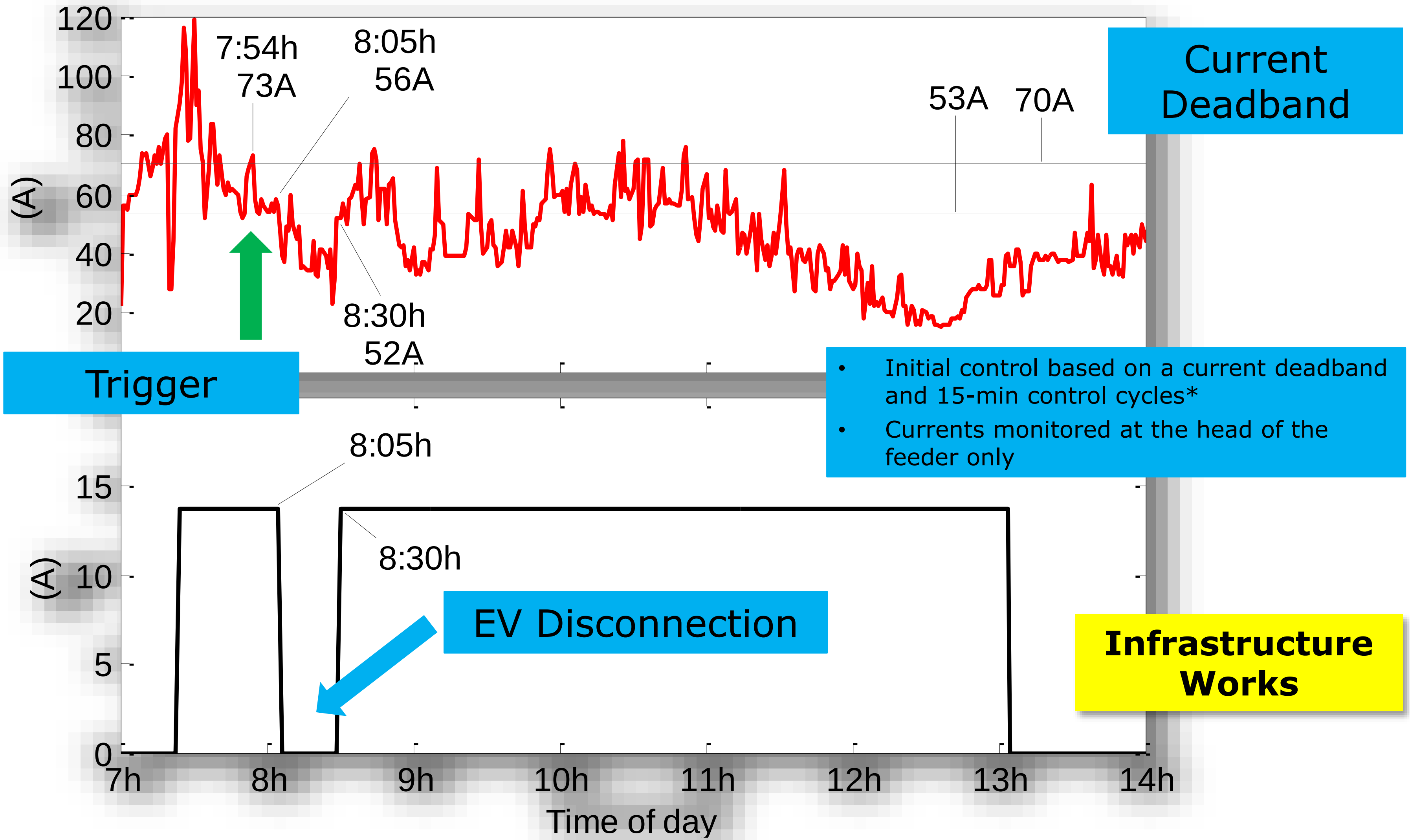
Probabilistic Assessment: CIL

Percentage of EV users
w/o delay
CIL = 0

Control Cycle	EV Penetration Level (%)						
	40%	50%	60%	70%	80%	90%	100%
1 min	99	87	72	59	50	44	**40**
5 min	99	89	77	67	60	56	**51**
10 min	100	91	80	71	63	59	**54**
30 min	100	95	85	76	70	64	59

and it improves customer acceptance

ESPRIT Control: Field Example

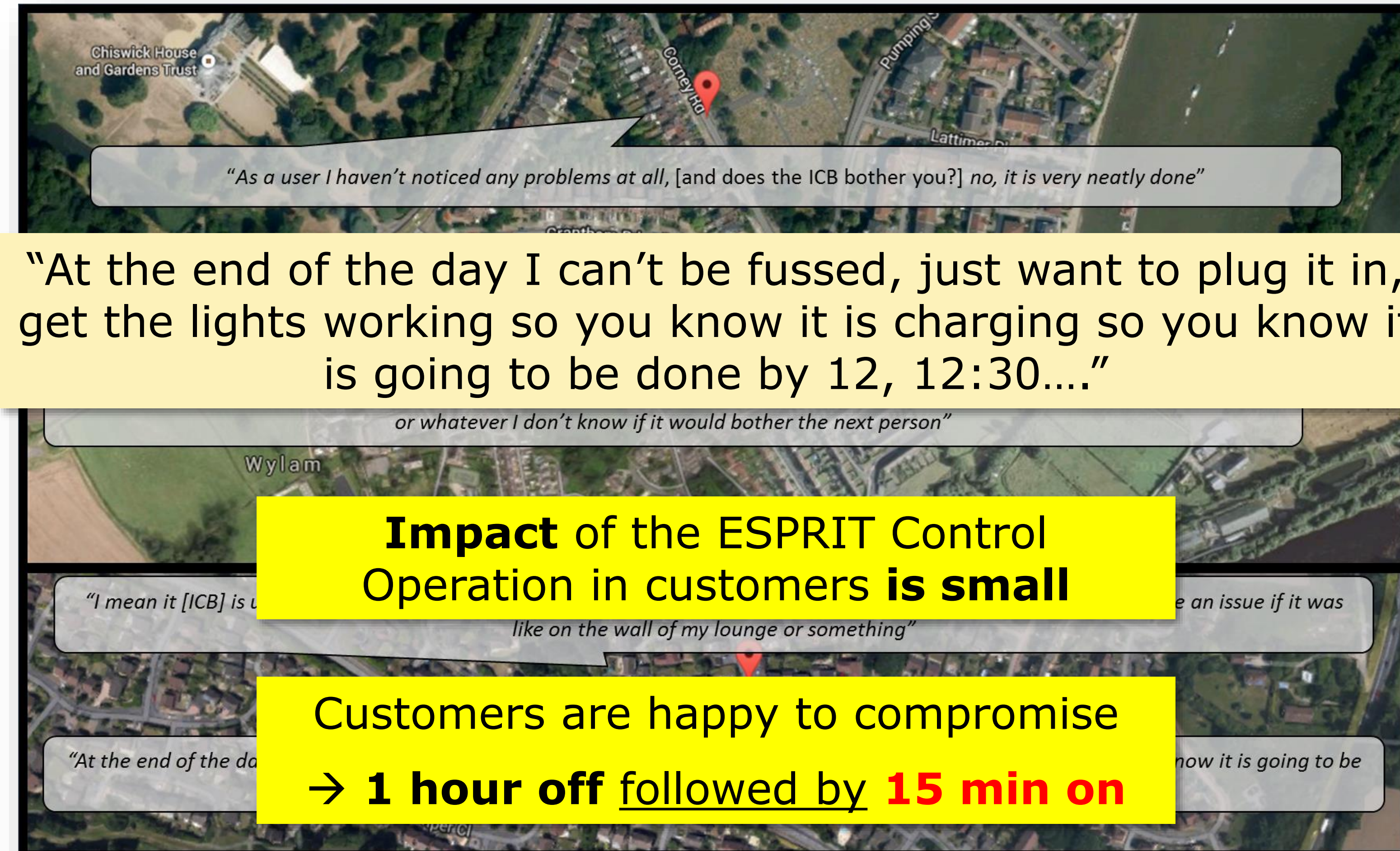


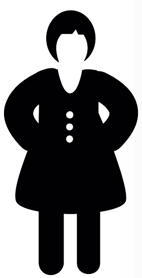
- Initial control based on a current deadband and 15-min control cycles*
- Currents monitored at the head of the feeder only

* http://myelectricavenue.info/sites/default/files/86002_8_R_SDRC%209.7%20Issue%202.pdf

Control May 2015

ESPRIT Control: Social Acceptance





"At the end of the day I can't be fussed, just want to plug it in, get the lights working so you know it is charging so you know it is going to be done by 12, 12:30…."

Impact of the ESPRIT Control Operation in customers **is small**

Customers are happy to compromise

→ **1 hour off** followed by **15 min on**

* http://myelectricavenue.info/sites/default/files/86002_8_R_SDRC%209.7%20Issue%202.pdf

Financial & Environmental Benefits

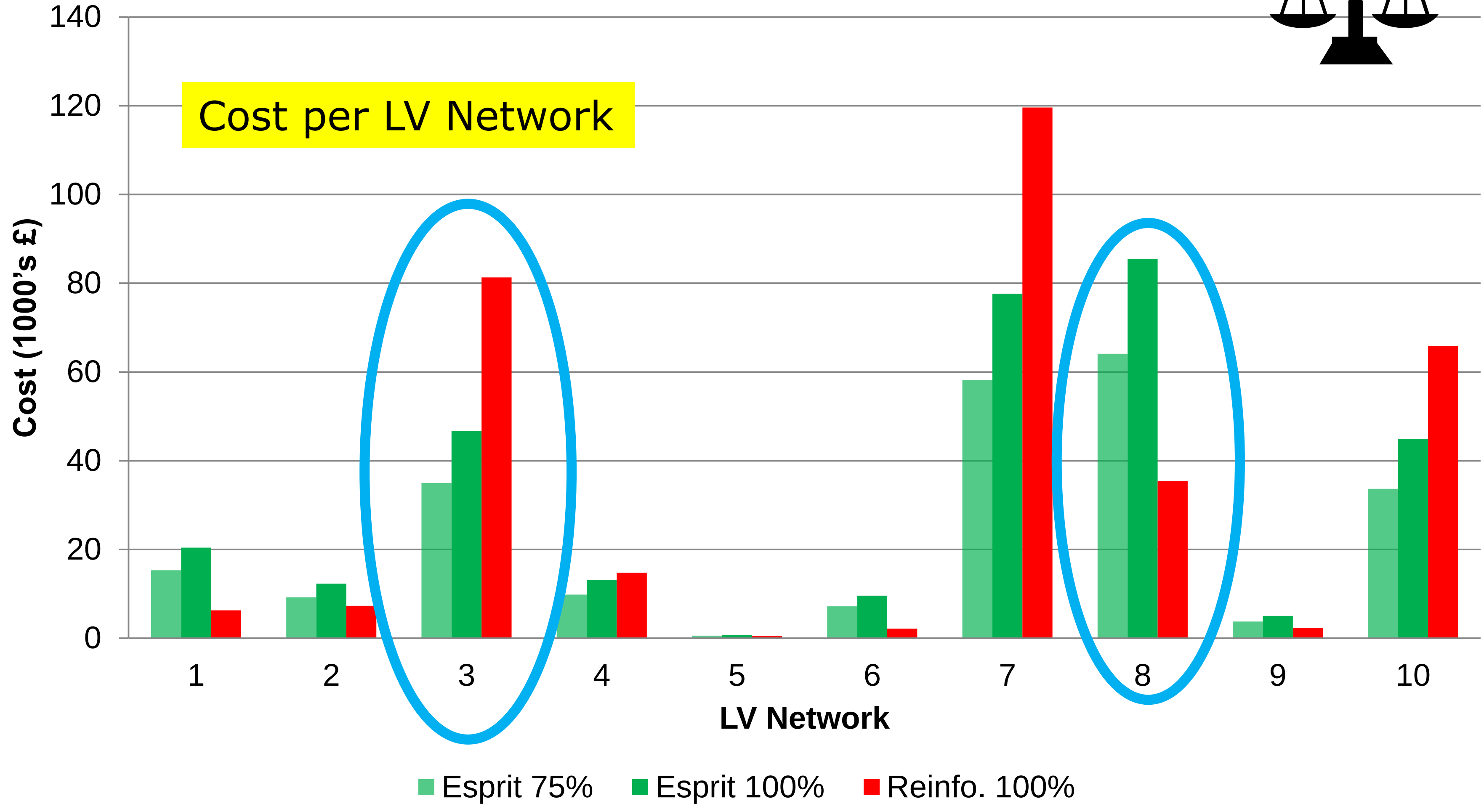
- To understand the economical savings and environmental benefits of the cost-effective and practical EV management

- Realistic and stochastic assessment
  - Actual costs, emission factors, etc.
  - On 10 LV networks (10.51% of 15030 ENWL LV Networks)
  - Compared against traditional reinforcement

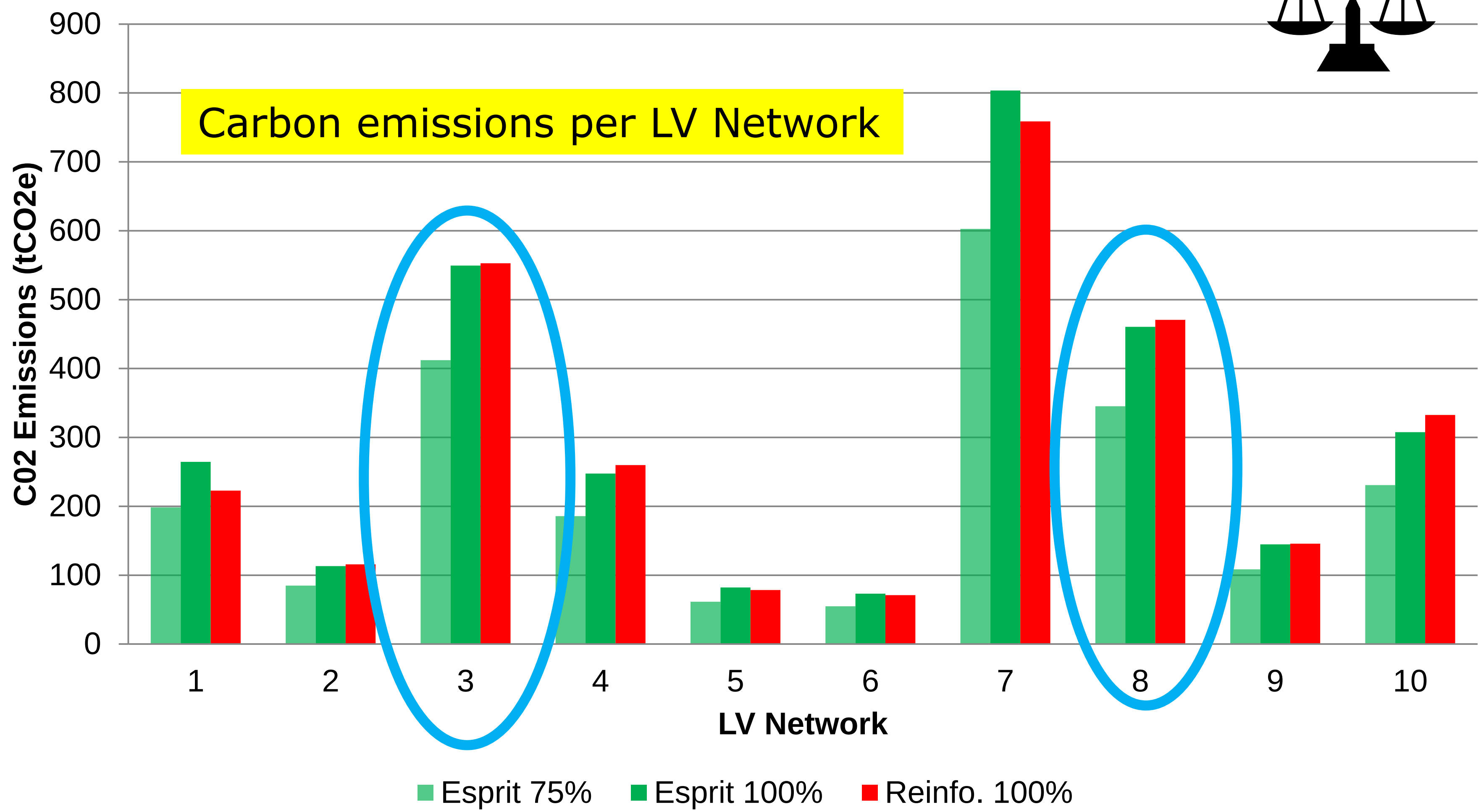
- Metrics
  - Thermal overloads
  - Voltage issues (BS EN 50160)
  - Cost (Net Present Value)
  - Carbon emissions

*https://www.youtube.com/watch?v=Ox2bQ4vpLNg

ESPRIT Control vs Reinforcement

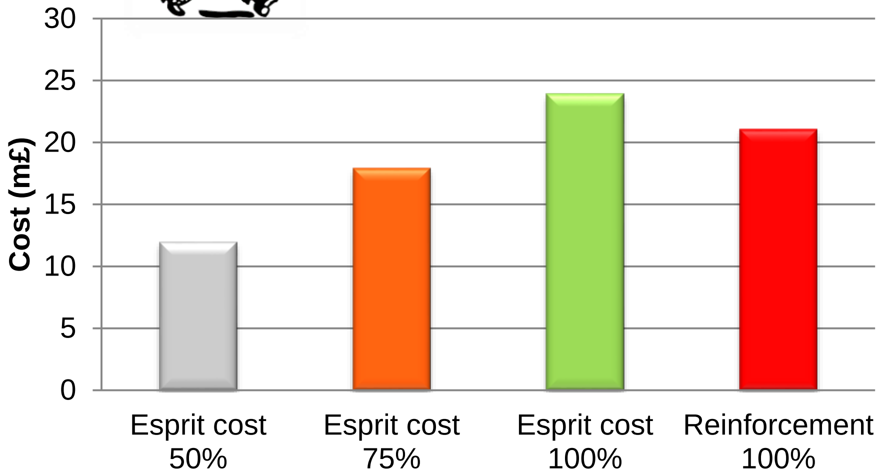


ESPRIT Control vs Reinforcement

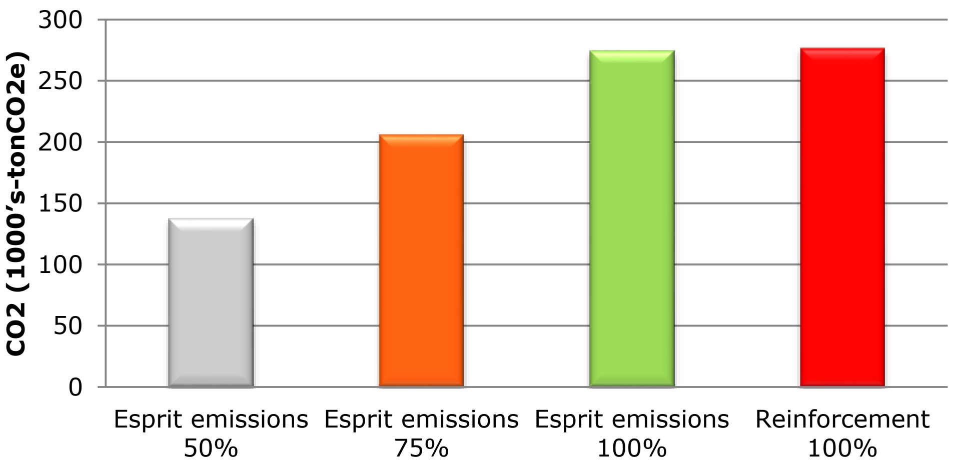


ESPRIT Control vs Reinforcement

ENWL Region



ESPRIT cost → 75% (~3m*)



ESPRIT is greener (~70,000 ton)

*For the 10.51% of studied 15030 ENWL LV Networks

Conclusions

- **Trials** are crucial to **capture** the actual EV behaviour and customer acceptance
  - Significant changes from weekday to weekend but no seasonality
  - 30% of EV users charge more than once a day
- EV **impacts** will start at ~40% of penetration (~2030)
  - Different networks will present different problems
- **ESPRIT-Based EV Management**
  - Actual trial proves the required infrastructure works
  - Practical solutions are needed in industry
  - The solution is **cheaper** and **greener** than traditional reinforcement

Further Reading 1/2

How Electric Vehicles and the Grid Work Together

Lessons Learned from One of the Largest Electric Vehicle Trials in the World

By Jairo Quirós-Tortós, Luis (Nando) Ochoa, and Timothy Butler

IN THE COMING YEARS, HUNDREDS OF THOUSANDS of new electric vehicles (EVs), from plug-in hybrids to fully electric, will hit the roads around the world, adding to the current EV fleet of more than 2 million, according to the Global EV Outlook 2017. The electrification of transportation can bring environmental, health, and economic benefits when coupled with a low-carbon electricity generation portfolio; however, ensuring that this transition goes smoothly requires addressing several grid-integration challenges.

To understand the challenges and opportunities that come with the widespread adoption of EVs, particularly passenger light-duty vehicles, many distribution network operators (DNOs) and stakeholders in various countries have carried out EV trials. One of the largest EV trials in the world was My Electric Avenue (MEA) (www.myelectricavenue.info) in the United Kingdom. Led by EA Technology, the trial ran from January 2013 to December 2015 and was subsidized by the Low Carbon Networks Fund along with partners from industry, DNOs, and academia. The MEA project deployed more than 200 Nissan LEAFs to customers in the United Kingdom to study the driving and charging habits of a geographically and socioeconomically diverse population. This industrial project also investigated the technical effects of EVs on European-style low-voltage networks and trialed the direct control of EV charging points to increase hosting capacity.

In this article, we provide details about the MEA trials, including the main infrastructure adopted. Based on the data analysis and network studies carried out, we present key findings in terms of 1) the charging habits of EV users, 2) the impact of EVs on low-voltage networks, and 3) the effectiveness of the proposed strategy to increase hosting capacity. Using what was learned from this large-scale project, we then show the additional results that aid in understanding the extent to which EVs could provide services to the electric grid. Finally, we summarize the key lessons learned from MEA.

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The My Electric Avenue Project

The MEA project deployed more than 200 Nissan LEAFs with a battery size of 24 kWh across the United Kingdom (Figure 1), making it one of the largest (if not the largest) EV trials in the world to date that examines the challenges and benefits arising from the use of this technology at home (slow-charging mode at approximately 3.6 kW). The project's main objective was to trial a solution (known as Esprit) to mitigate the impacts that EVs may pose on European-style low-voltage networks (i.e., multiple low-voltage feeders connected to the same distribution transformer supplying dozens or hundreds of customers). To achieve this, the project performed EV data analysis, modeling, impacts, and management studies. MEA was the first project to focus on how to best manage the local electricity network when a large number of EVs charge on the same street at the same time.

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IEEE PES Magazine Nov/Dec 2018

Further Reading 2/2

- Project Website: myelectricavenue.info
- Technical Reports and Papers:

  https://sites.google.com/view/luisfochoa/publications

3028 IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 31, NO. 4, JULY 2016

Control of EV Charging Points for Thermal and Voltage Management of LV Networks

Jairo Quirós-Tortós, *Member, IEEE*, Luis F. Ochoa, *Senior Member, IEEE*, Sahban W. Alnaser, *Student Member, IEEE*, and Tim Butler, *Student Member, IEEE*

***Abstract*—High penetrations of domestic electric vehicles (EVs) in U.K. low voltage (LV) networks may result in significant technical problems. This paper proposes an implementable, centralized control algorithm, currently being trialed in 9 U.K. residential LV networks, that uses limited information to manage EV charging points to mitigate these technical problems. Two real U.K. LV networks are used to quantify the potential impacts of different EV penetration levels and to demonstrate the effectiveness of the control algorithm (using different control cycles)**
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are undertaken to

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TPWRS 2016

PSCC 2018

Statistical Representation of EV Charging: Real Data Analysis and Applications

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***Abstract*—The electrification of the transport sector is posed to create challenges but also opportunities for the electricity system. In this transition, it is crucial to understand the charging behavior of electric vehicles (EVs) so detailed studies can be carried out. However, to date, EV data is scarce. This paper proposes the use of probability density functions based on Gaussian Mixture Models (GMMs) to represent key charging metrics of EVs. These GMMs are then combined to produce realistic EV profiles needed in diverse studies. Real data from 221 EVs part of the largest trial**

scale trials [4]–[6]. While these models can represent more realistically the behavior of EV users, the size of the EV population used to create the models might limit their representativeness.

Although a number of recent large-scale trials have been carried out in Europe [7]–[9], the findings in terms of the charging behavior of EVs, particularly from a perspective useful for network studies, have not been reported. However, considering the expected adoption of EVs, it is critical to understand the stochas-

Thanks!

Questions?

Acknowledgements

- EA Technology
- **Dr. Jairo Quiros**
  Universidad de Costa Rica