Impact Assessment of LCTs on LV Networks

<u>Appendix I</u>

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The University of Manchester, Manchester

Outline

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

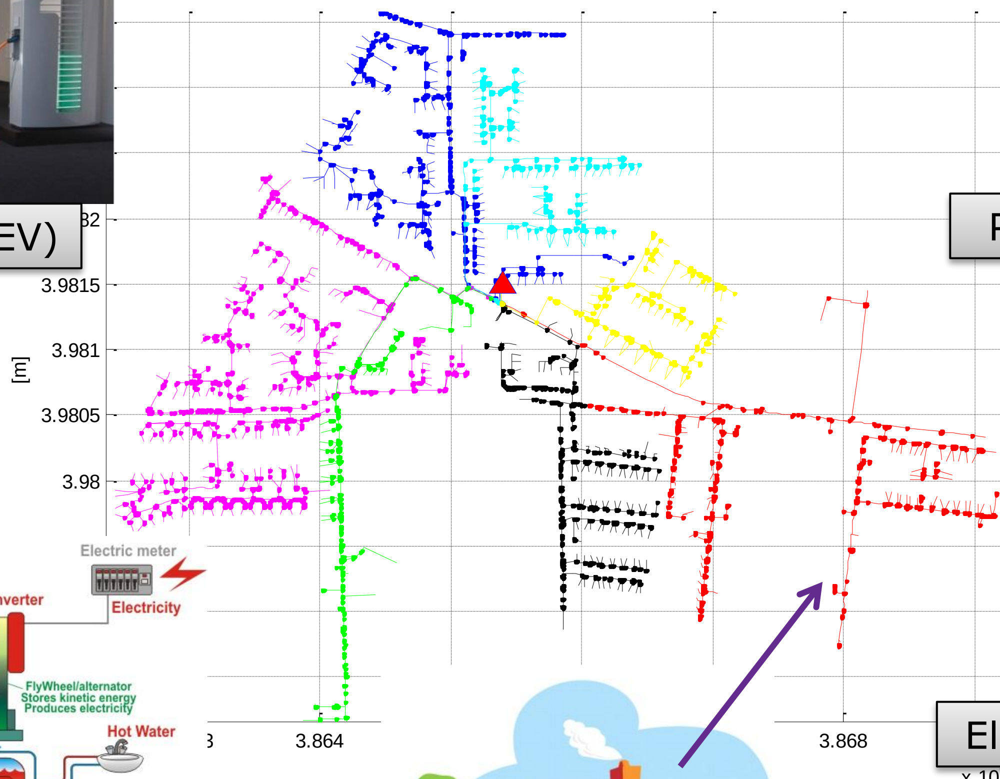
Objectives

- 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

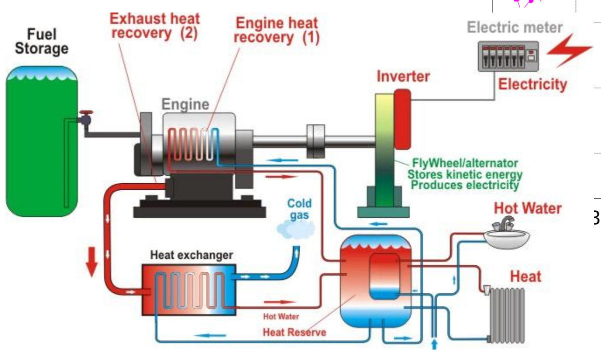
Different behaviour and sizes of loads and LCT along the day

Electric Vehicles (EV)



Photovoltaic Panels (PV)

Electric Heat Pumps (EHP)



Micro combine heat & power (uCHP)

Residential Loads

Problem Description

- Impacts Assessment of Low Carbon Technologies (LCT) penetration in real LV networks.
- 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).

Loads

- Random allocation for each customer node.

LCT

- Random allocation of sites and sizes.

Power Flow

- Time Series Simulation.
- 3 Phase four wire power flow

Therefore, for the random allocation process, we need to create thousands of individual residential profiles

Outline

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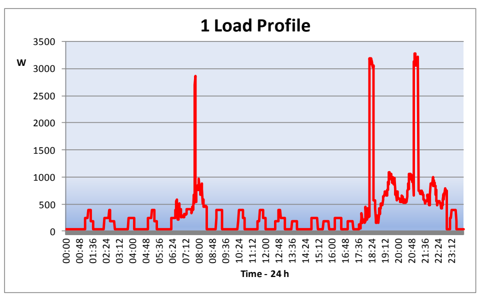
Profile Creation: Loads

- 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.



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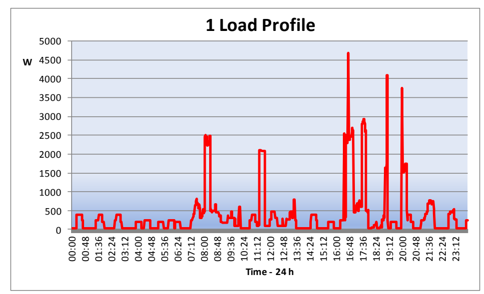

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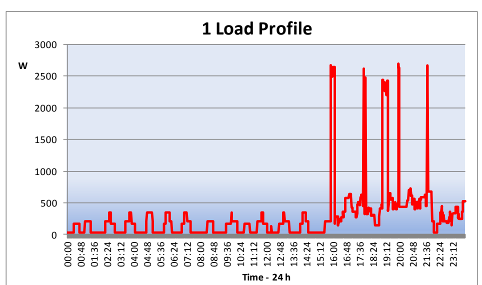

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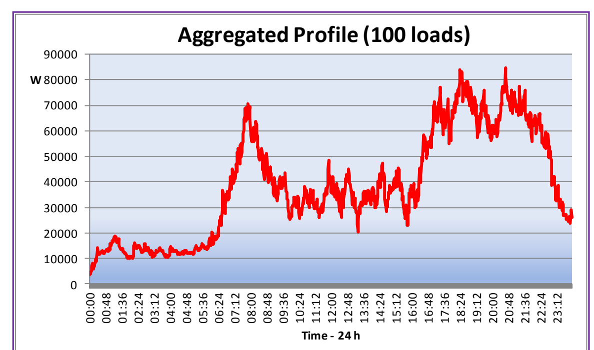
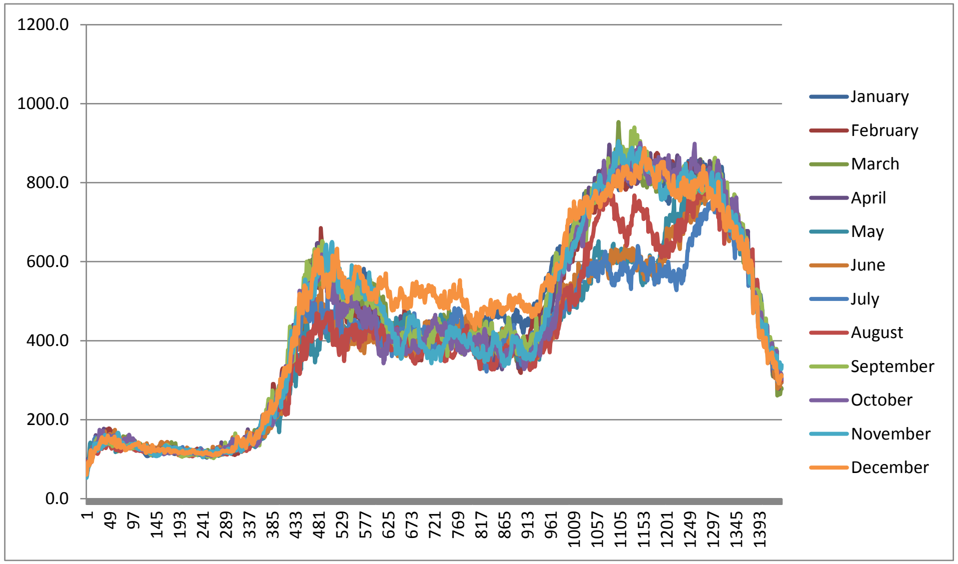
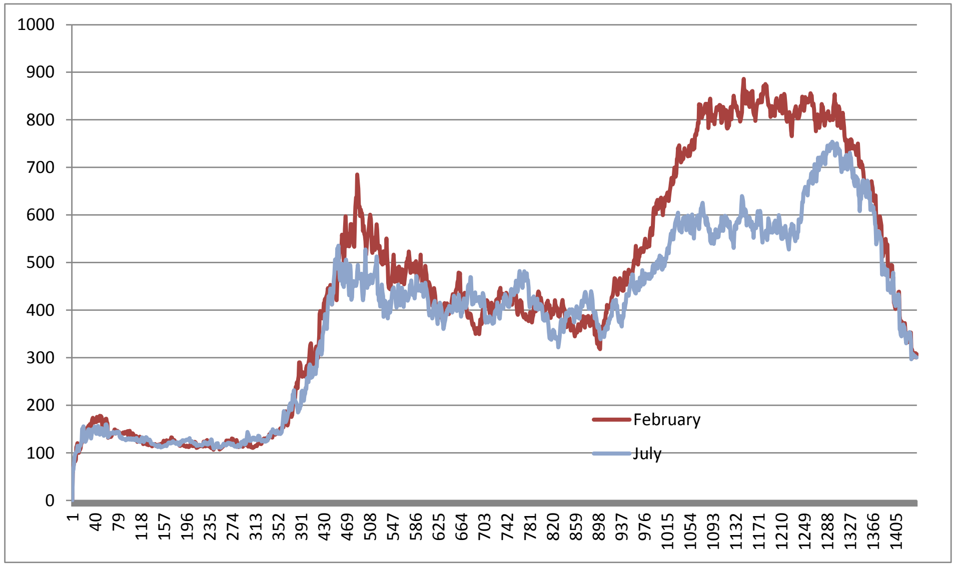


Profile Creation: Winter and Summer Loads

- A diversified profile is created from a pool of 1000 profiles for each month.

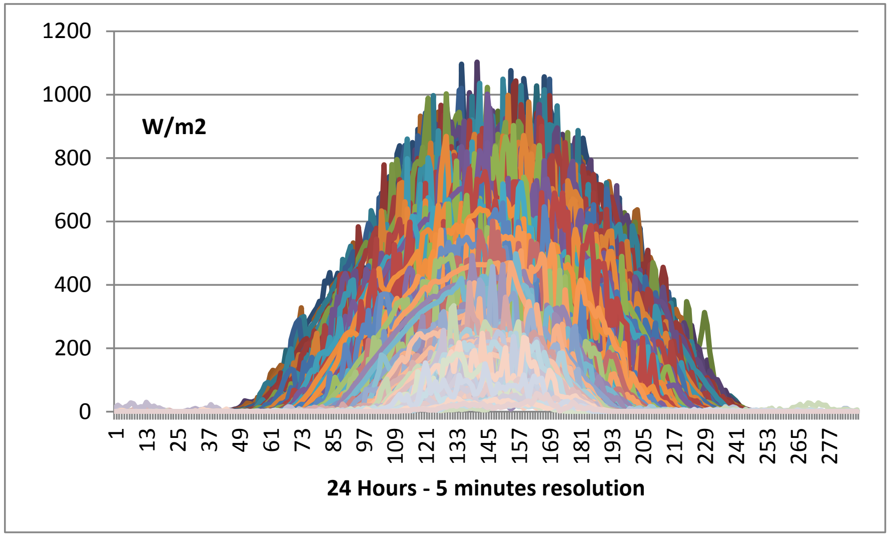


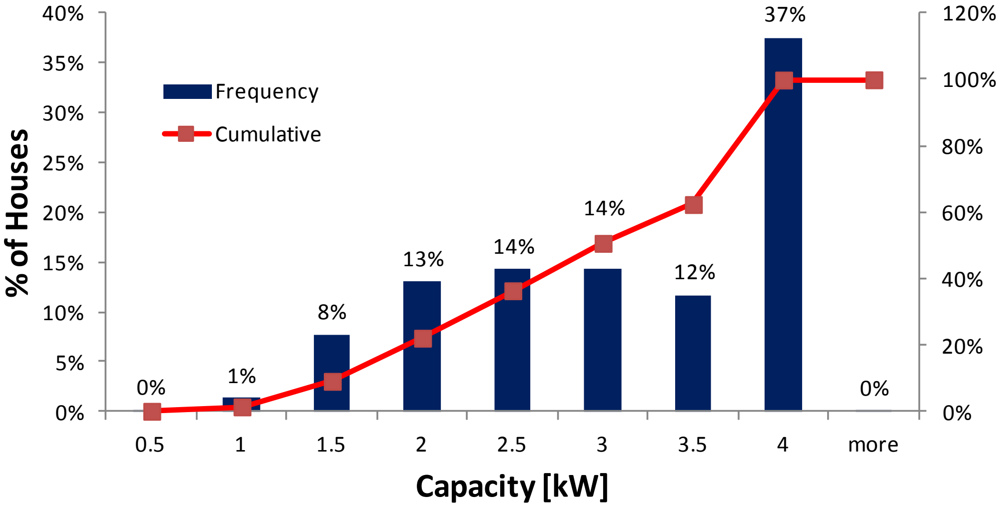


- Summer profile: July (PV analysis)
- Winter profile: February (EV, EHP, uCHP analysis)

Profile Creation: PV

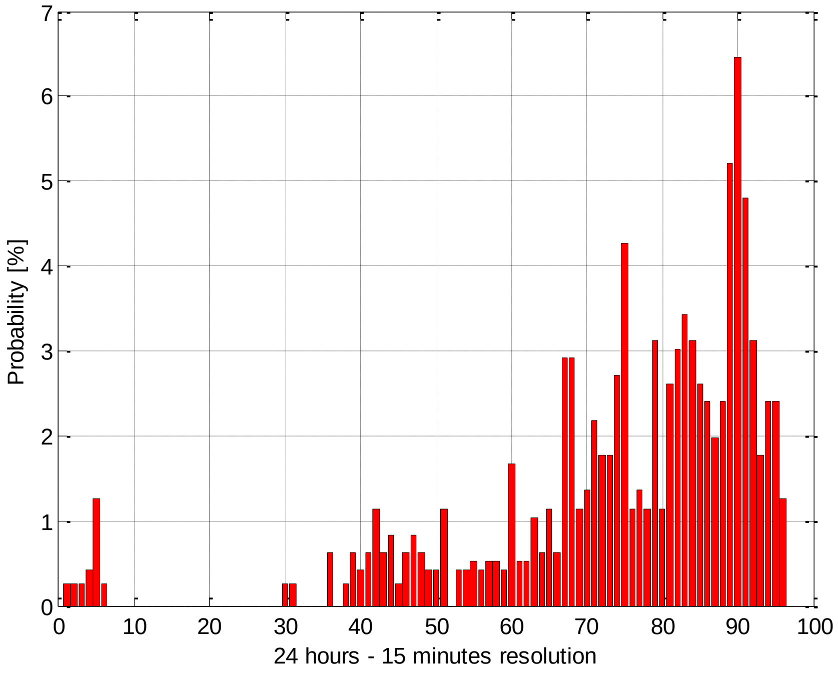
- Real daily profiles for 2012
- Measured by The University of Manchester (Sackville Building)
- The size of the PV panels is allocated according to UK statistics.
- Sunny scenarios: The 30 sunniest profiles are considered in the simulations.

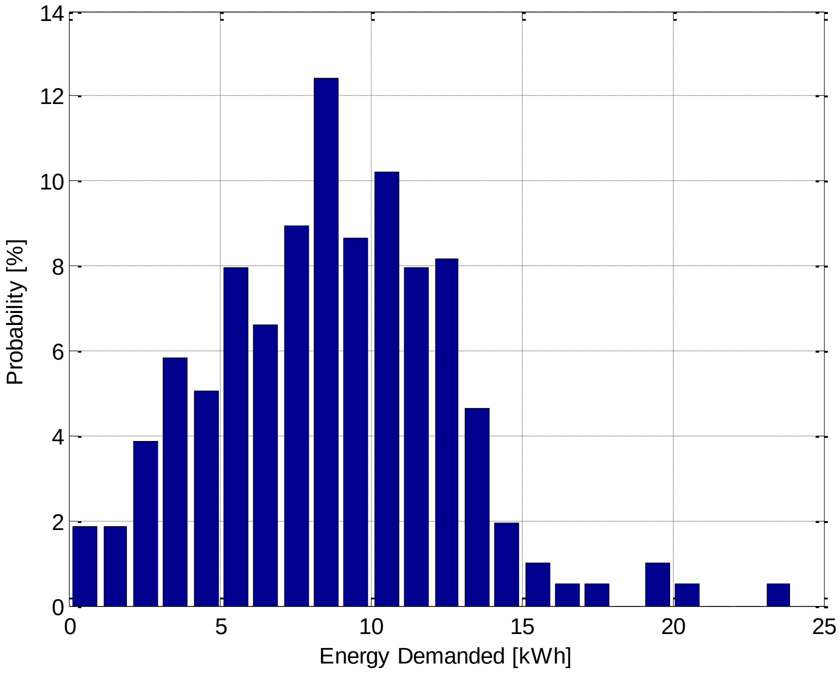




Profile Creation: EV

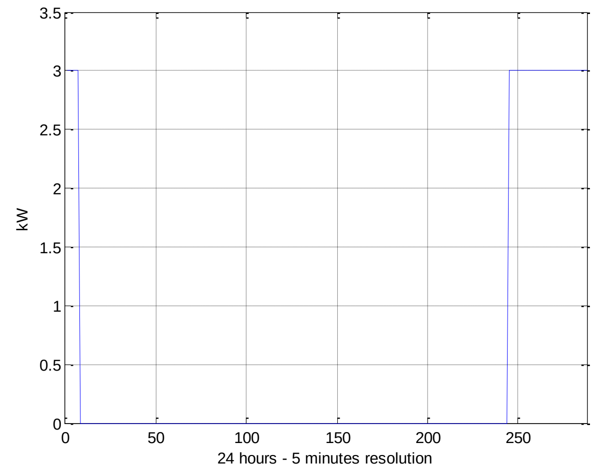
- Information Source: “Impact of Electric Vehicle Charging on Residential Distribution Networks : An Irish Demonstration Initiative” (CIRED, 2013).
- Input Data (from field trial):
  - Probability distribution function of EV connection times.
  - Probability distribution function for the daily EV energy requirement.

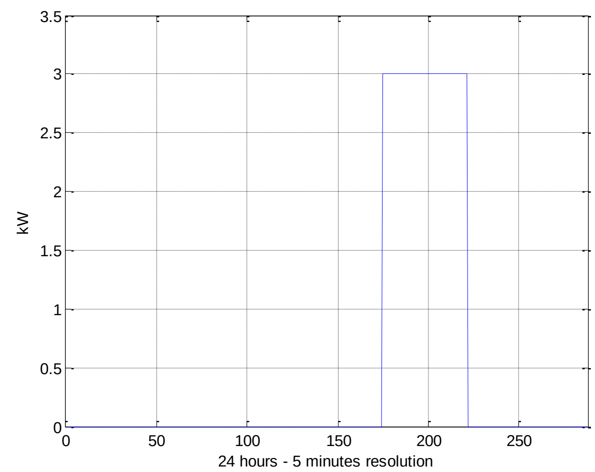




Profile Creation: EV

- 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)



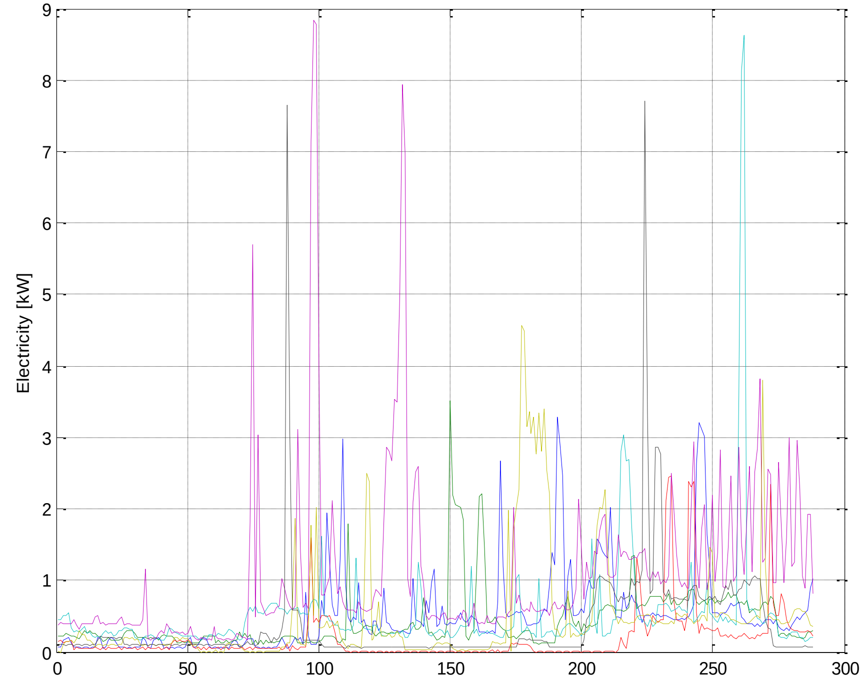


Examples – EV Profiles

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 o England (20/12/2006): cold day (min:-4C max:+3C).

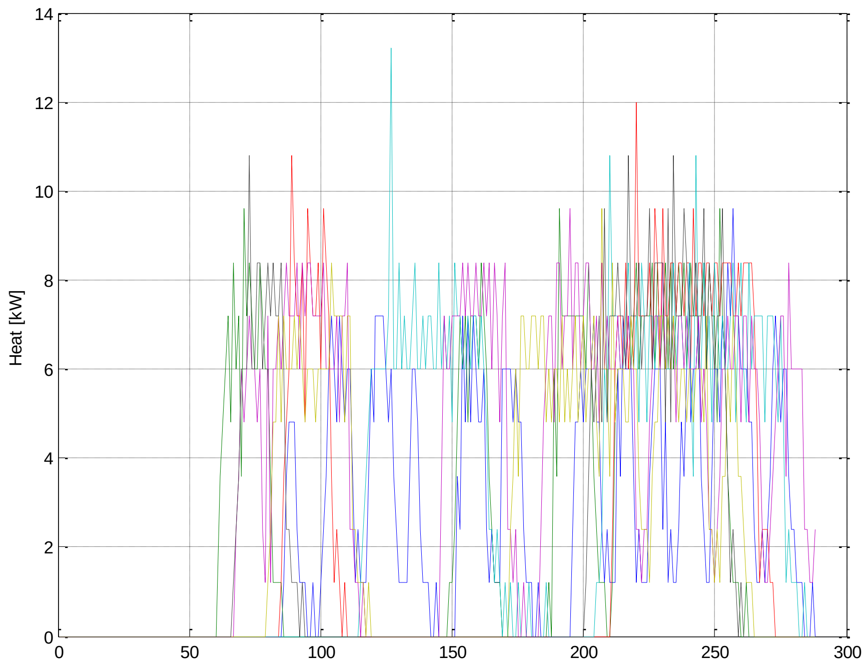
Electricity Production



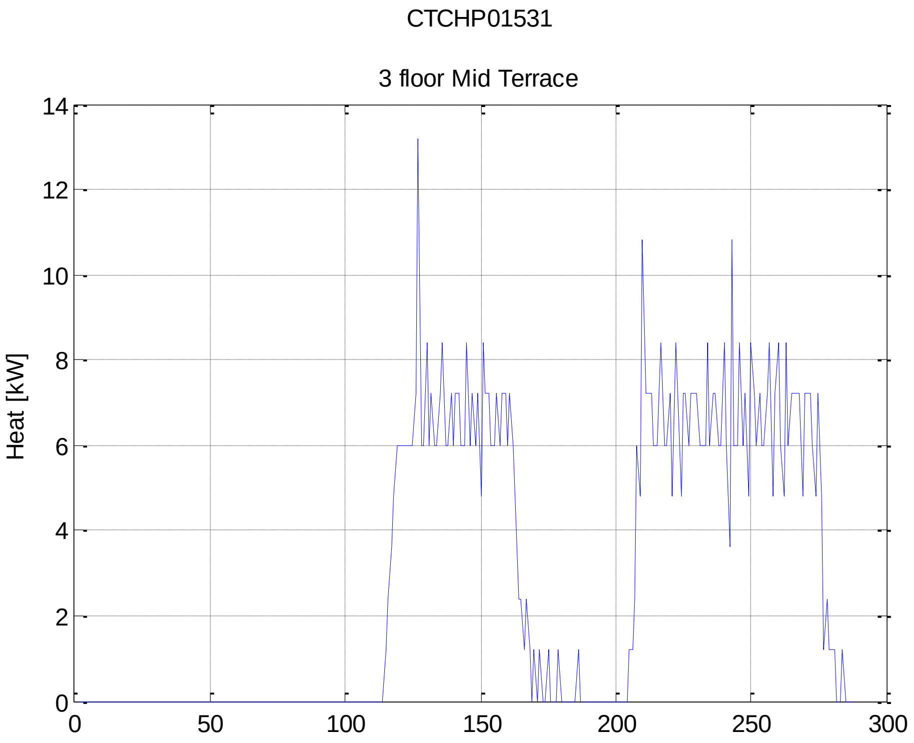
Electricity Consumption

Profile Creation: EHP

- From the same data base, it is also possible to obtain the heat requirement for each of the houses measured.
- This heat requirement information allow us to build the EHP profile for each home

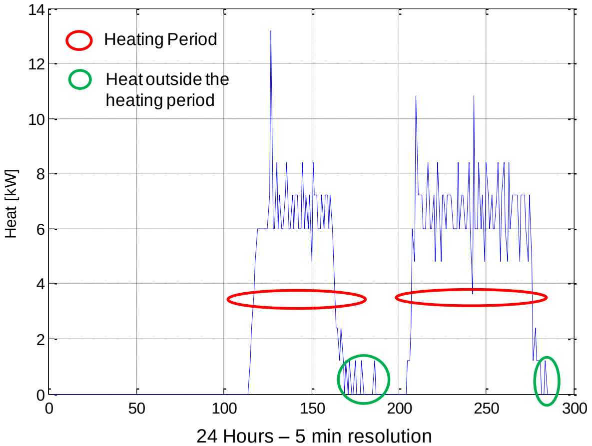


Heat Requirements

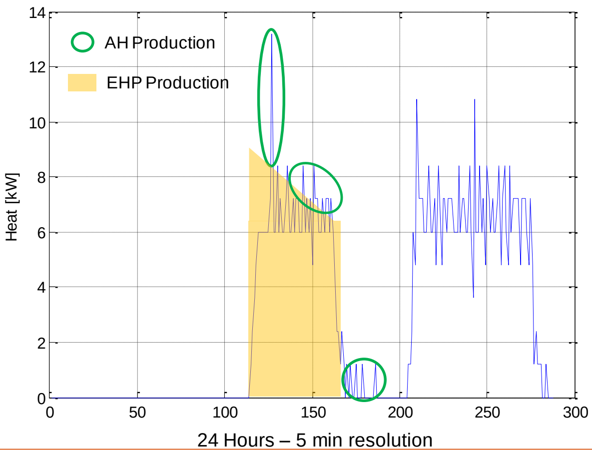


Individual Heat Consumption

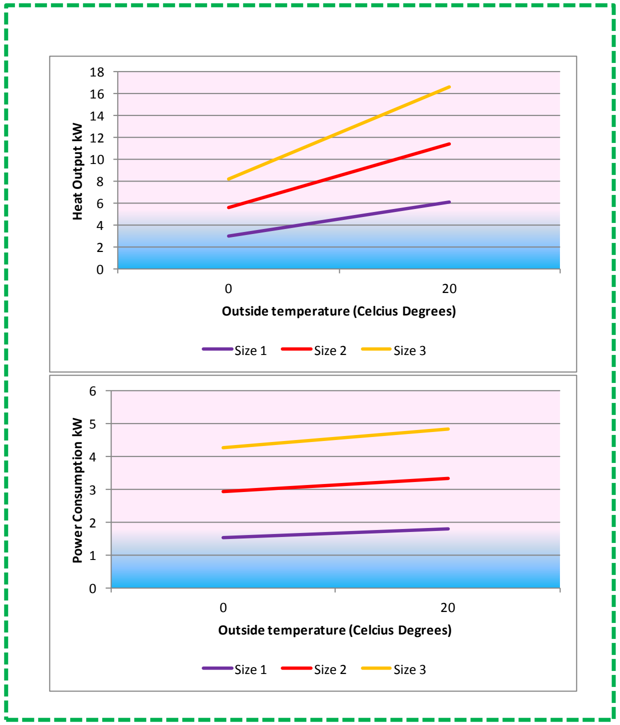
Profile Creation: EHP



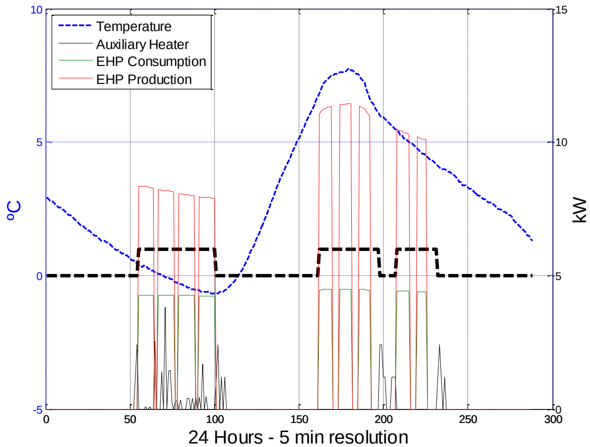
1. Heating period identification



2. Heat to be supplied by AH or EHP



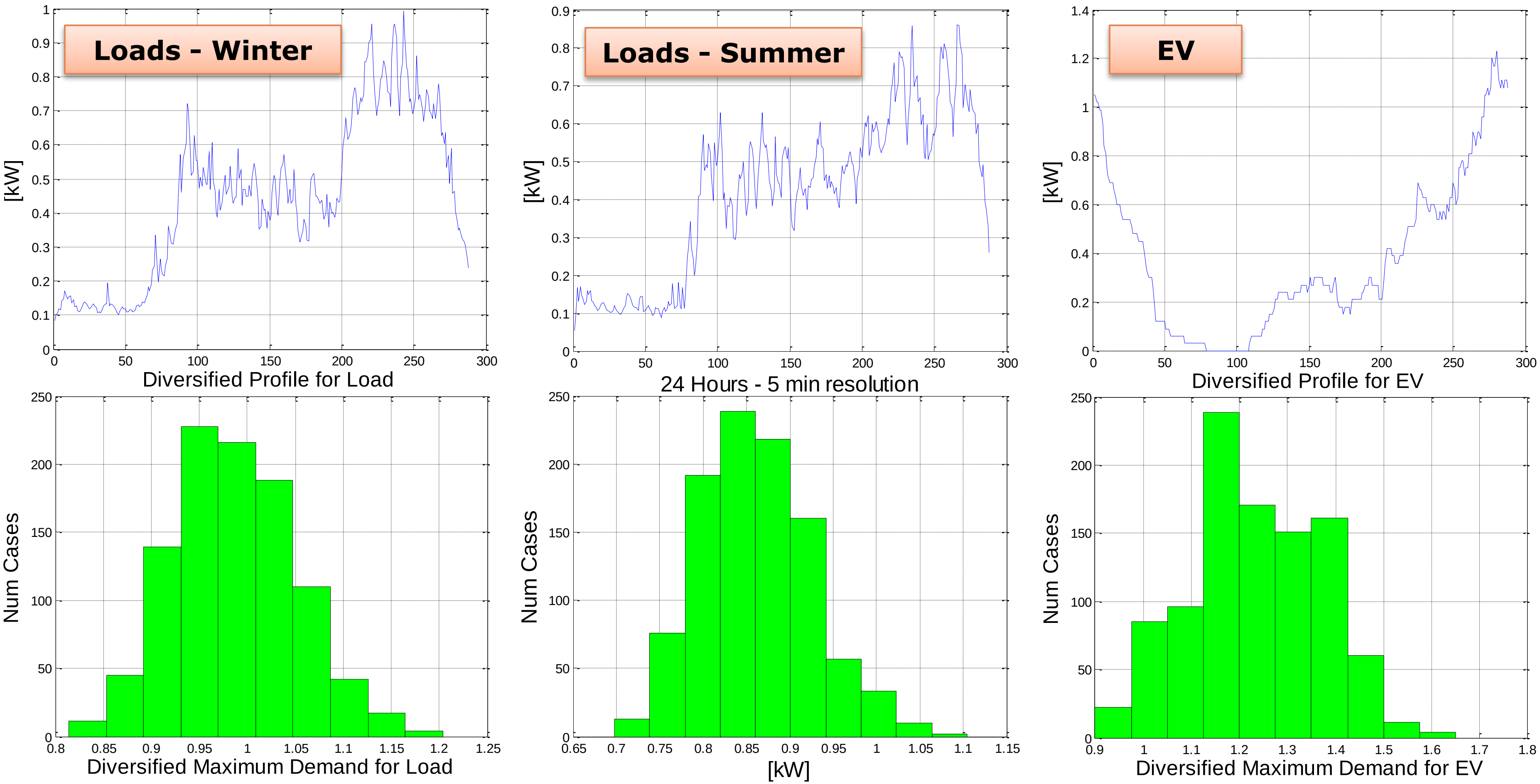
3. EHP Operation by using Manufacturer Data



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.



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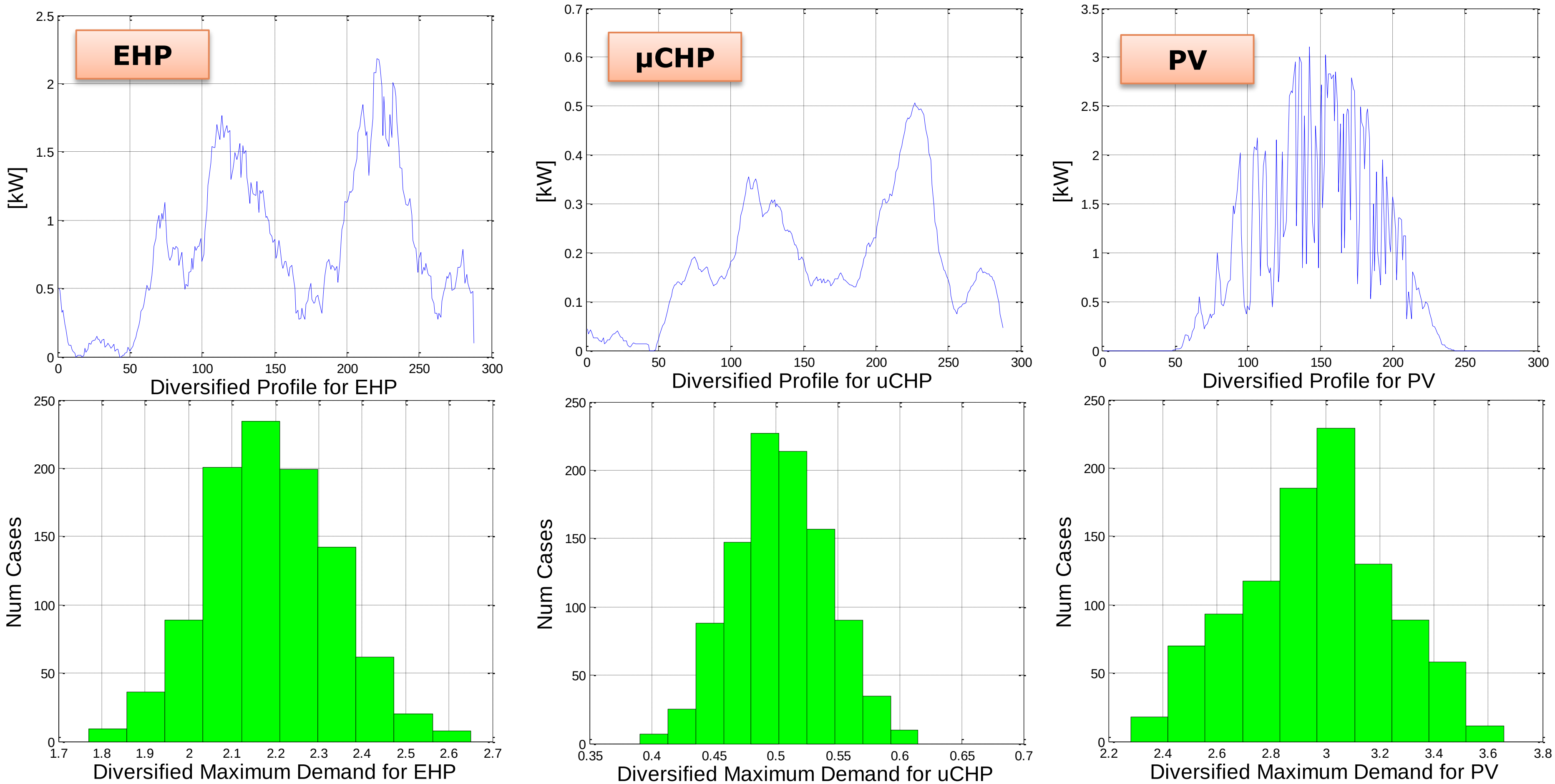
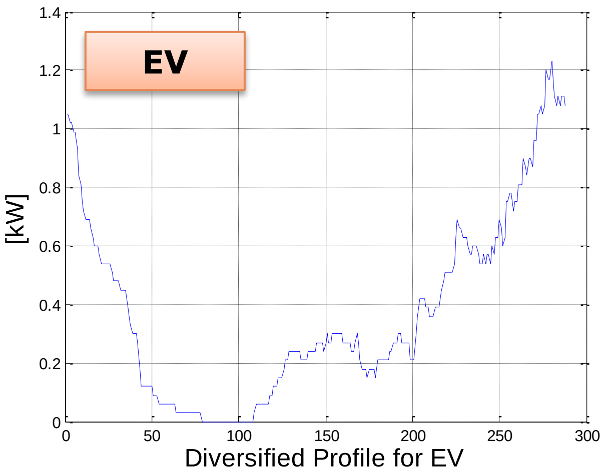
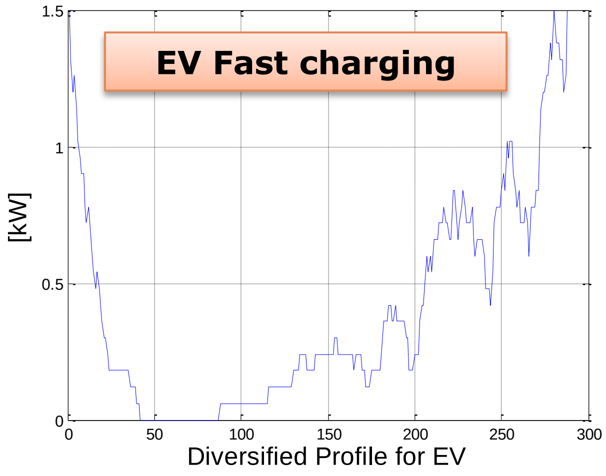
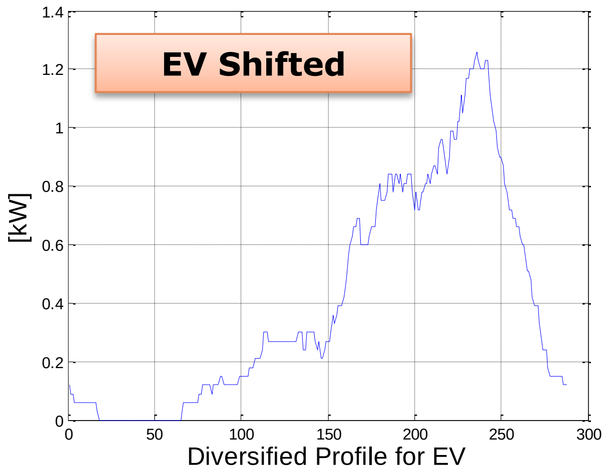


Profile Creation: Sensitivities

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



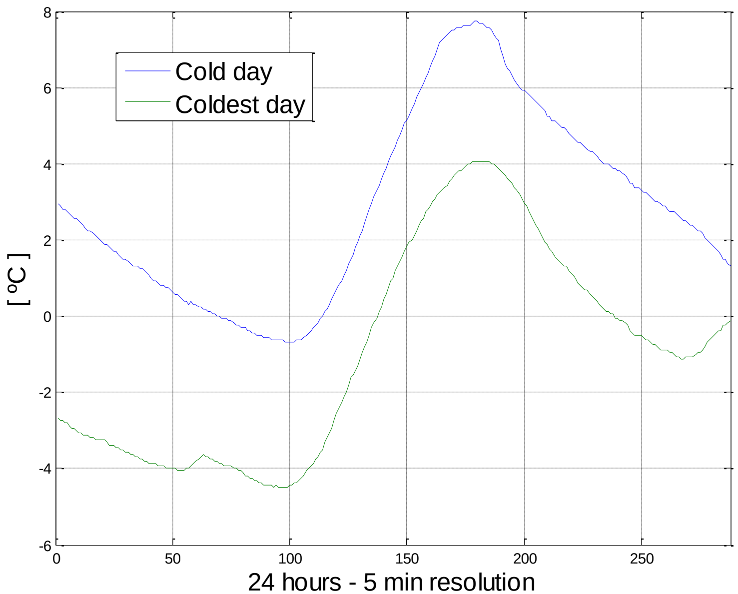




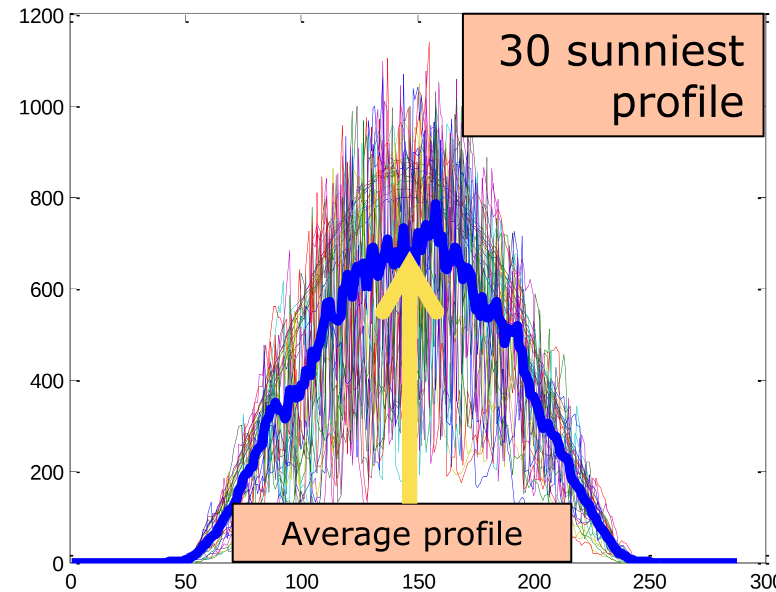
Median average profile for 100 loads from 1000 groups

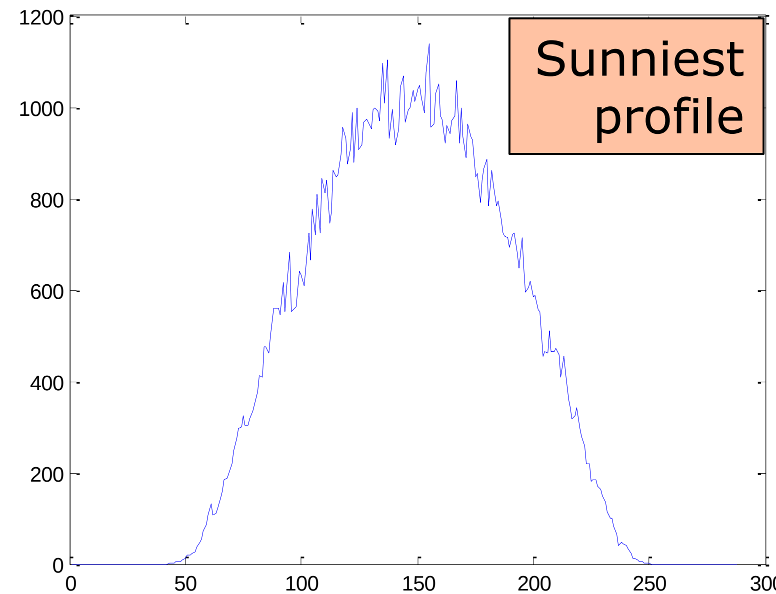
Profile Creation: Sensitivities

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



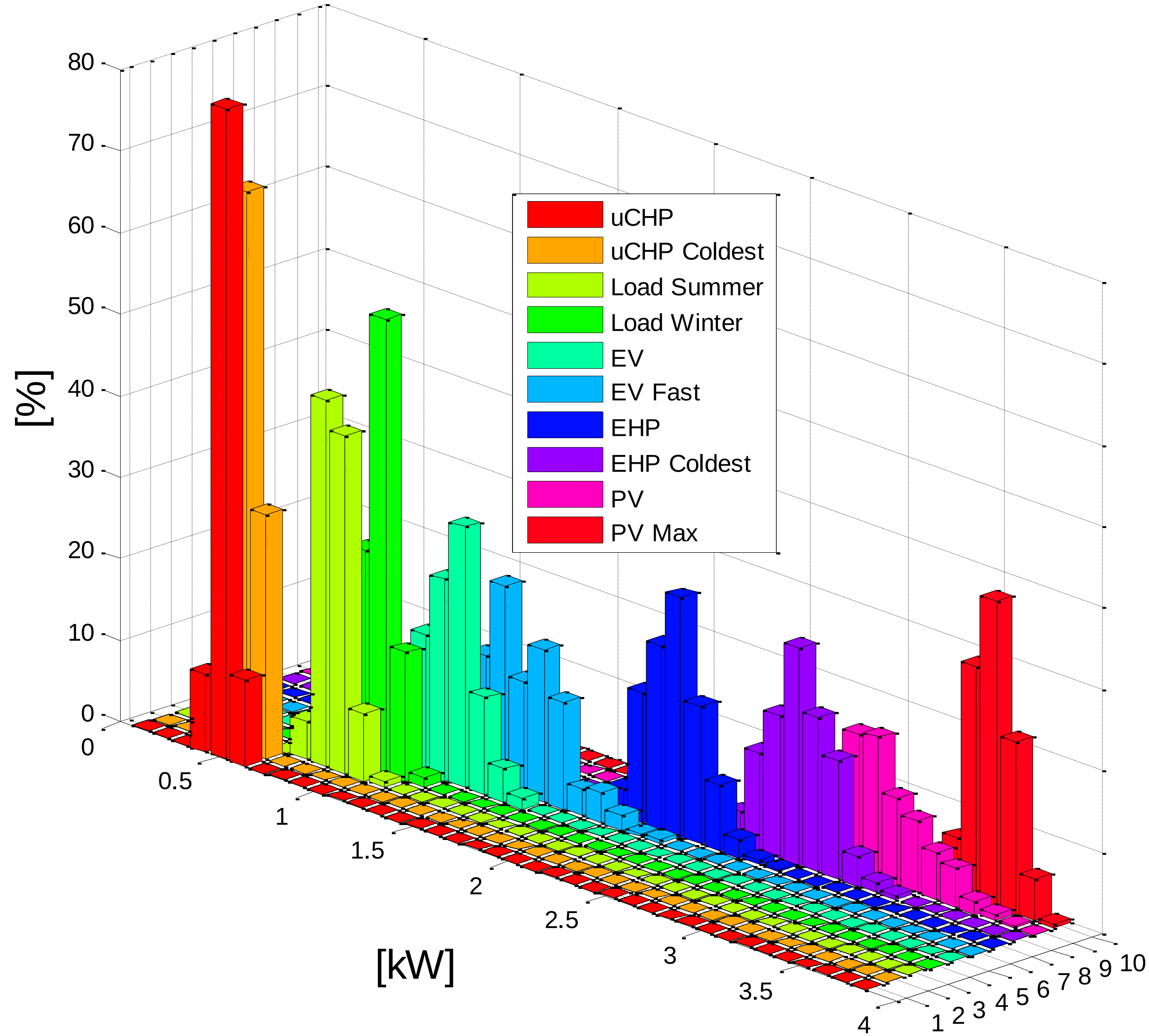
Daily Temperature





Profile Creation: Diversified Profiles

- Diversified Maximum Demand Histogram for 1000 groups of 100 profiles for each technology.



Outline

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- Network Creation
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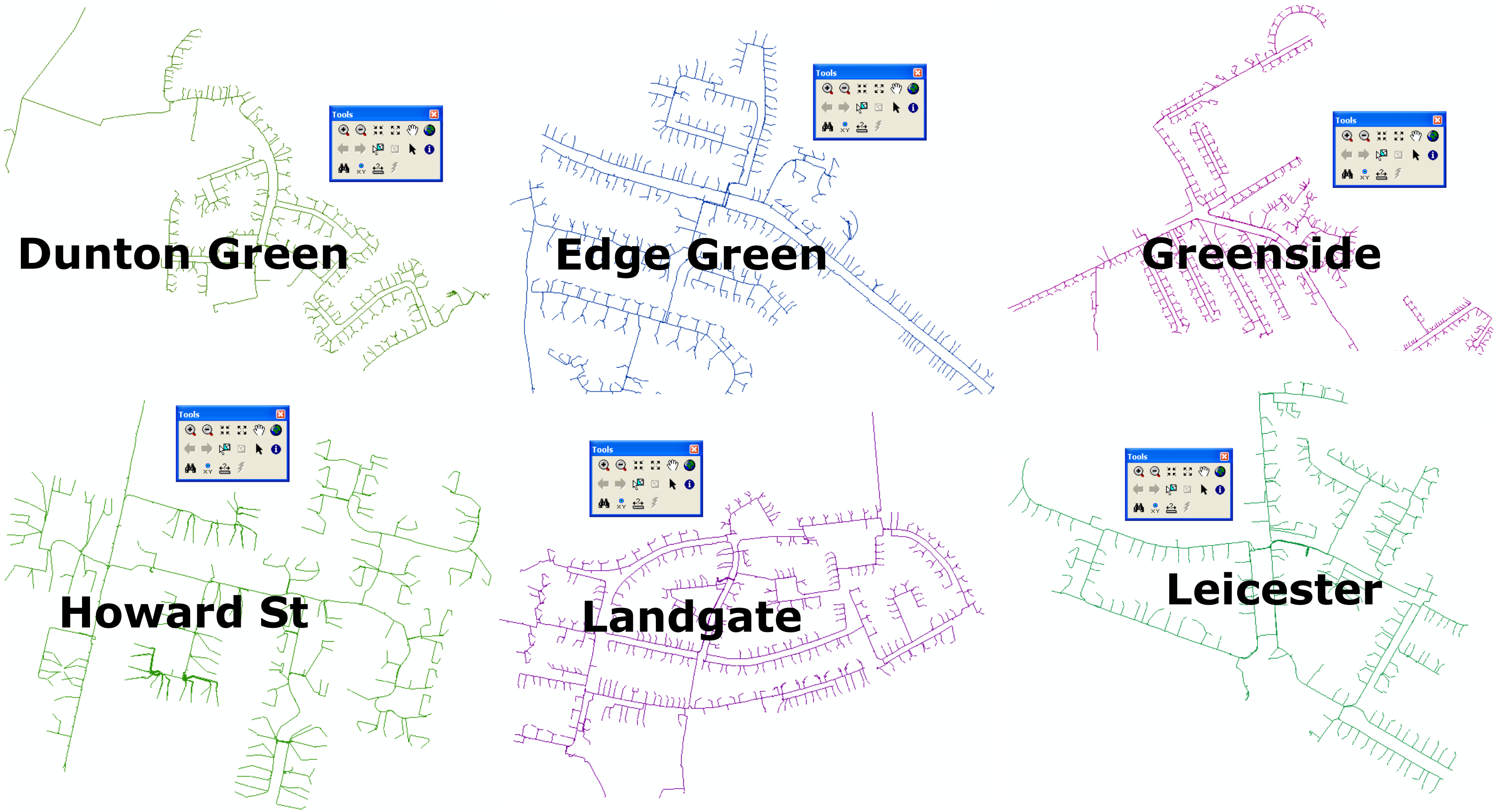
Network Creation: Information Received

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

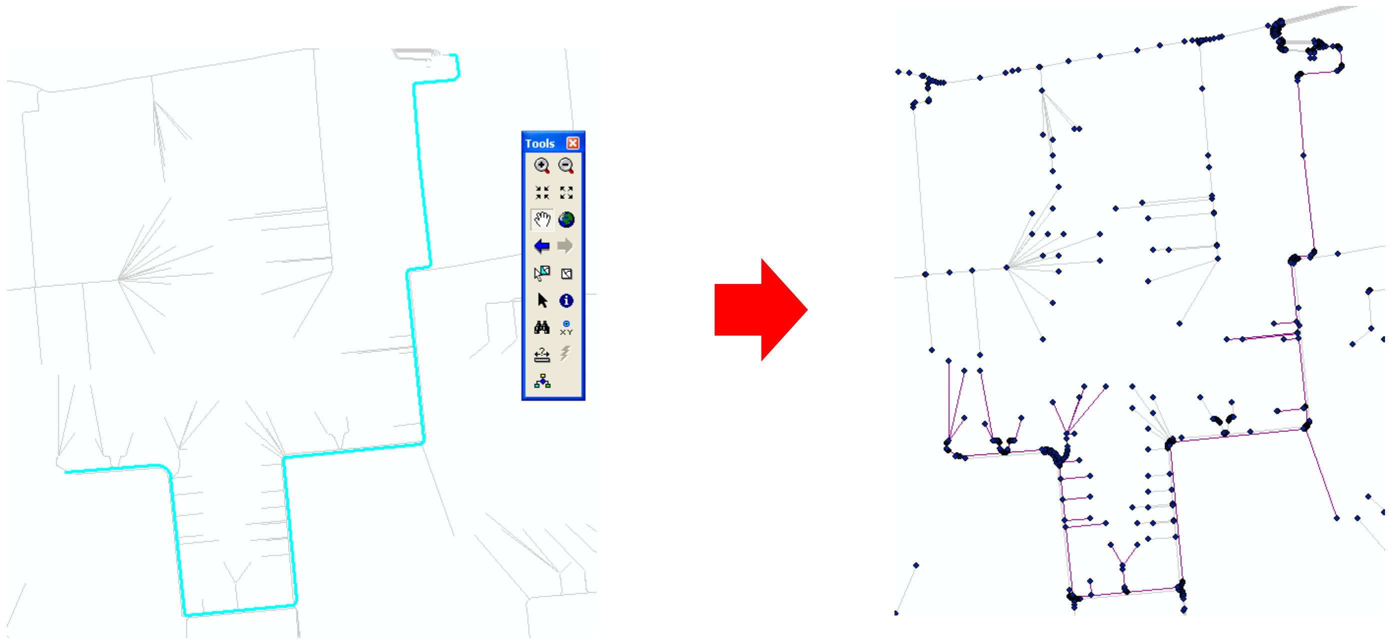


Network Creation: Stages

- To understand the LV network behaviour, The GIS data need to be transform 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.

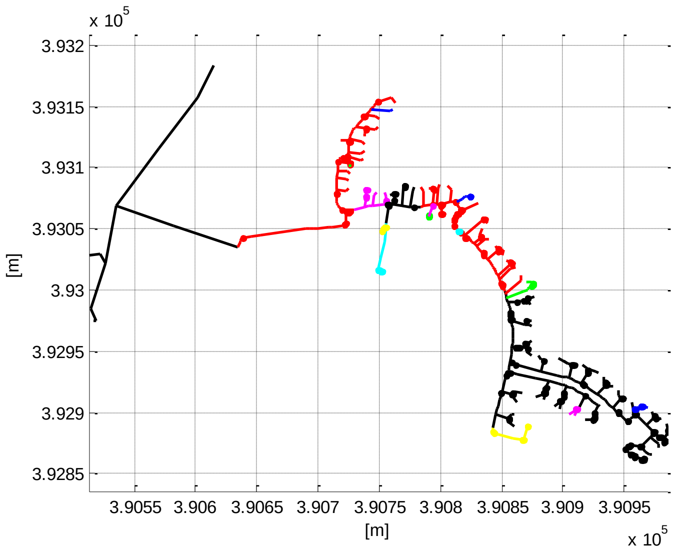


Network Creation: Topology Reconnection

- 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.

Feeder (Way_NO)	Number of connected components	CI
2	19	36%
3	8	89%
4	3	98%
5	9	90%

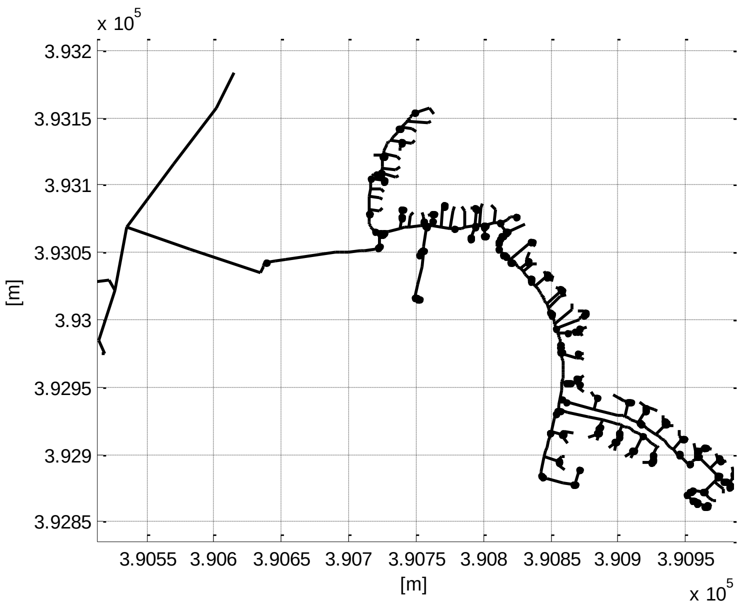
Dunton Green



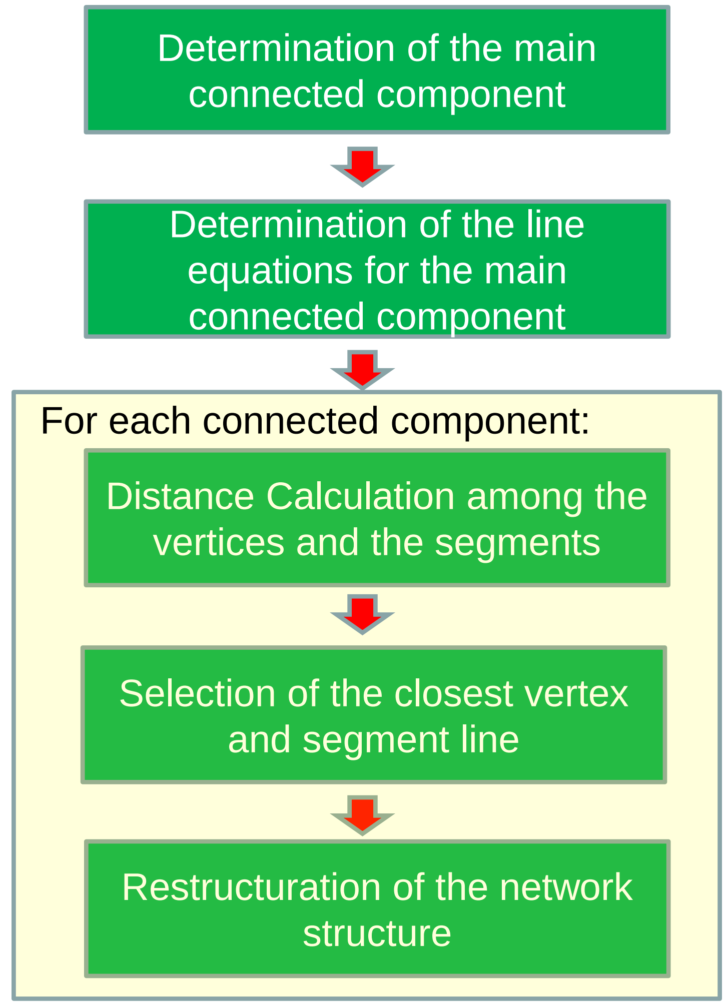
CI (connectivity index) is the proportion between the longest connected component and the total feeder length.

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.



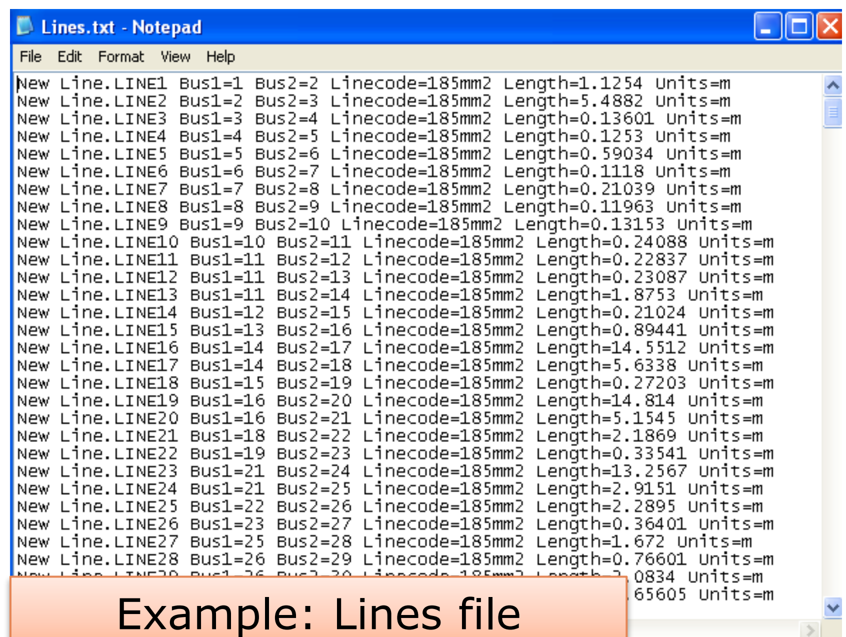
Feeder 2 after the reconnection process



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



Example: Lines file

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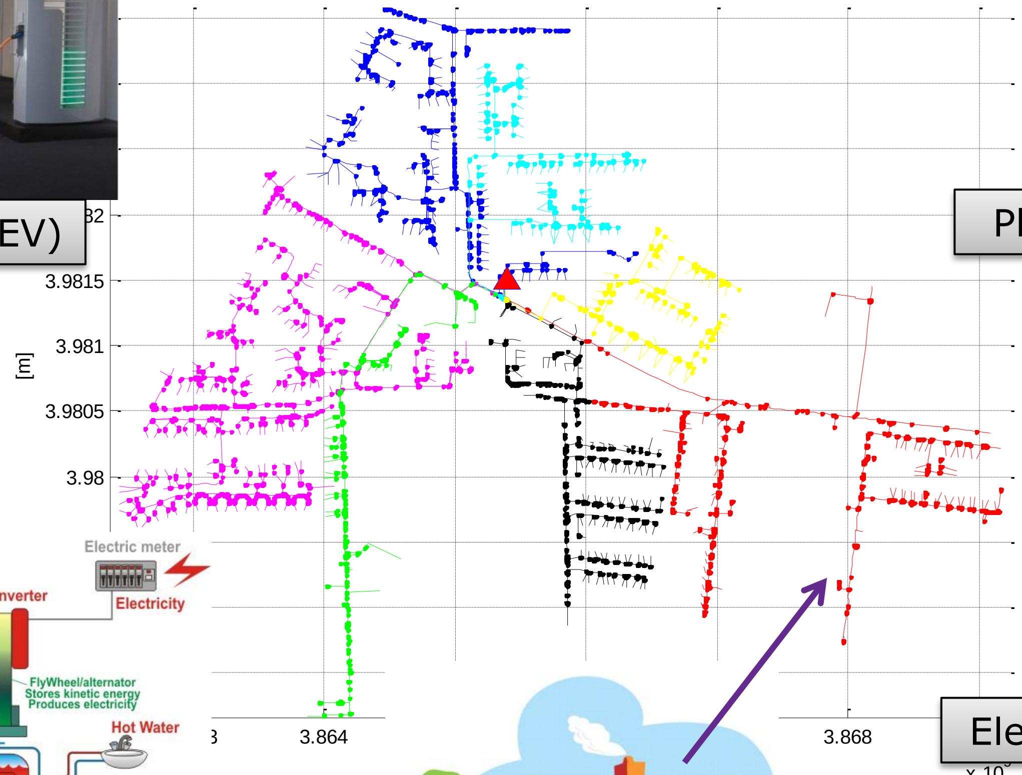
Impact Assessment: LV Stochastic Behavior

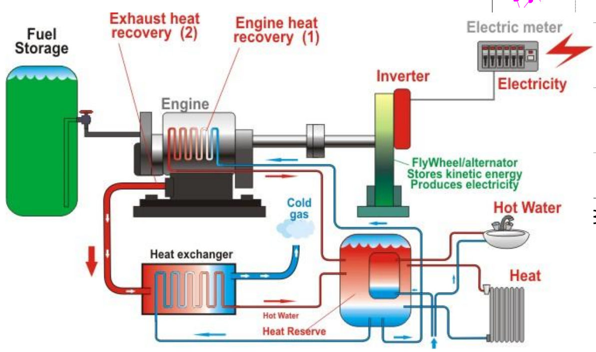
Different behaviour and sizes of loads and LCT along the day

Electric Vehicles (EV)

Photovoltaic Panels (PV)



Electric Heat Pumps (EHP)



Micro combine heat & power (uCHP)

Residential Loads

Impact Assessment: Methodology

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

Loads

- Random allocation for each customer node.

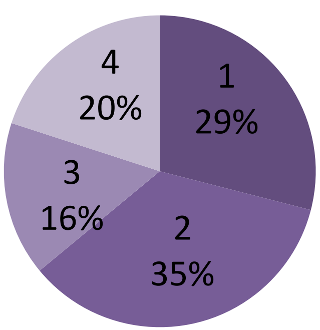
LCT

- Random allocation of sites and sizes.

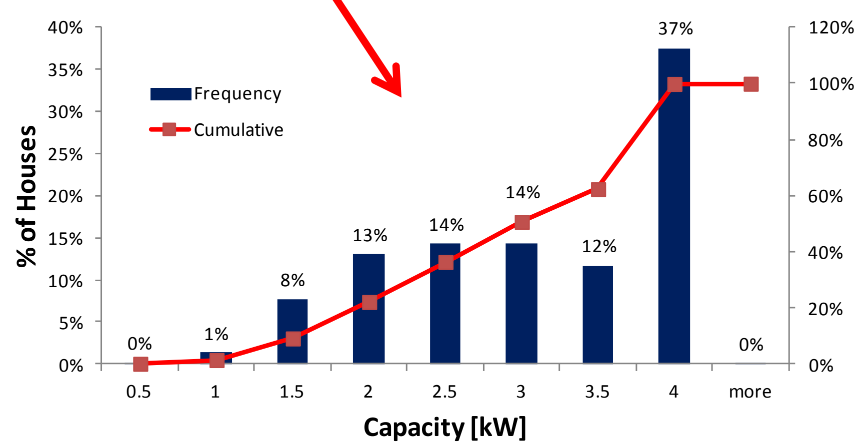
Power Flow

- Time Series Simulation.
- 3 Phase four wire power flow

Number of people per house



Residential Capacity

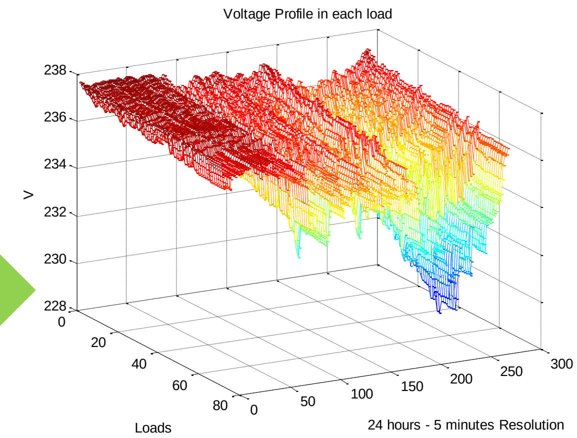


Impact Assessment: Metrics

Loads
- Random allocation for each customer node.

LCT
- Random allocation of sites and sizes.

Power Flow
- Time Series Simulation.
- 3 Phase four wire power flow



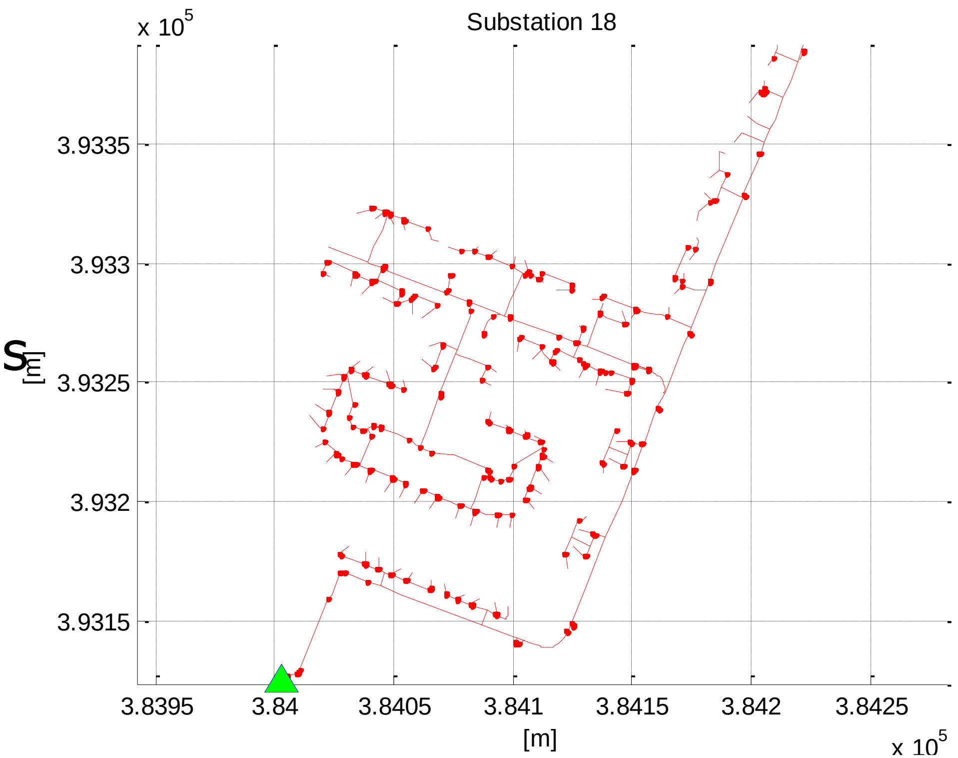
Results Storage

Impact Assessment

- 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.

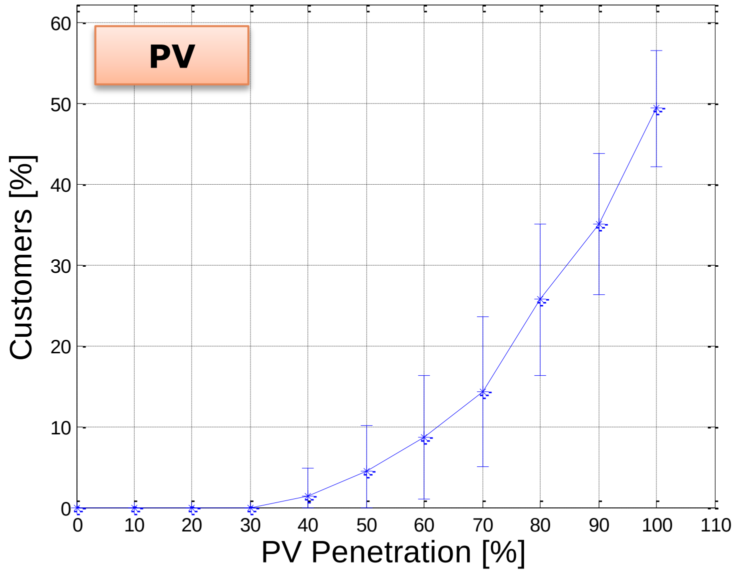
Impact Assessment: Example

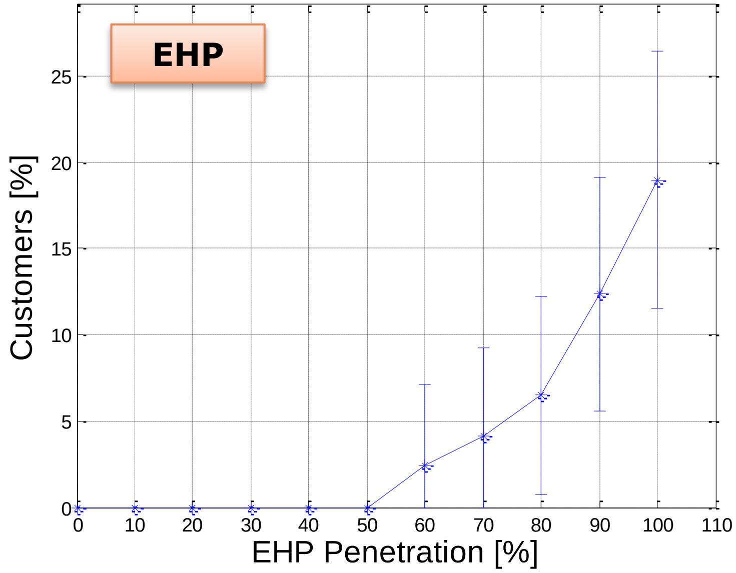
- As an example, the main results are presented for the feeder shown in the figure.
- The voltage, thermal problems and energy losses are calculated for PV, EV, EHP and uCHP.
- Vsec = 241 Vfn (1.05*Vnom)



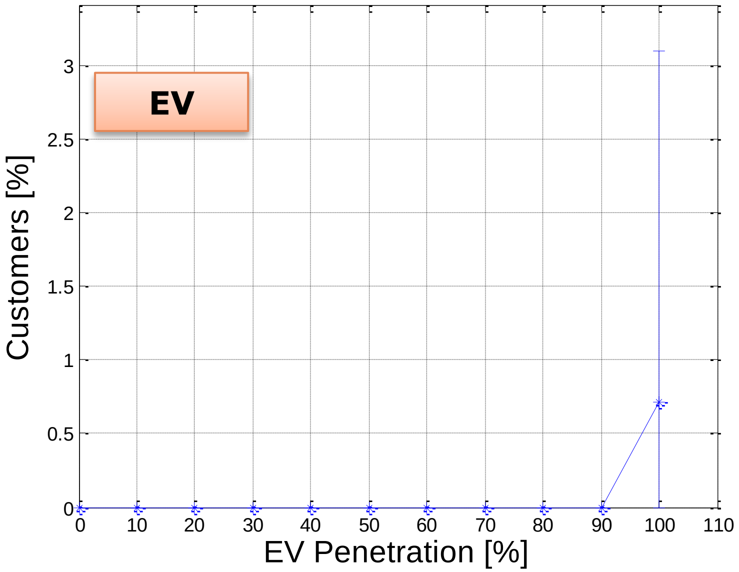
2.2 km (including services cables) and 94 loads

Impact Assessment: Voltage Problems





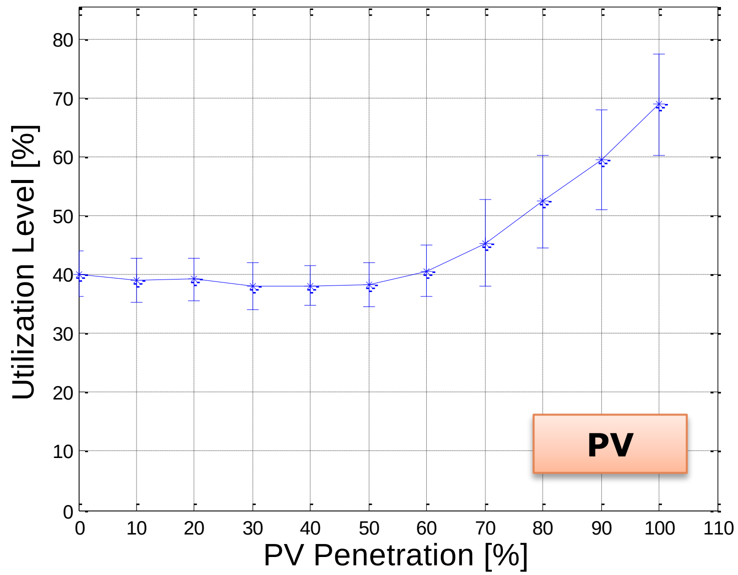
% of Customers with Voltage Problems – BS EN 50160

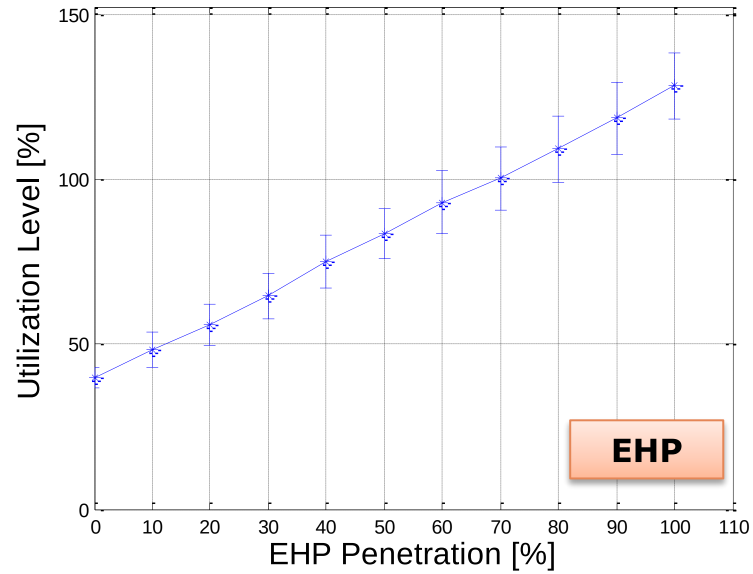


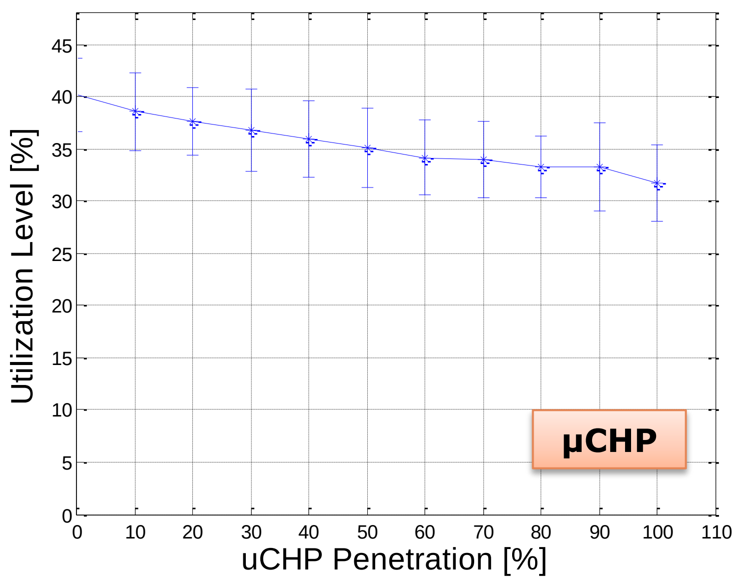
Impact Assessment: Thermal Problems

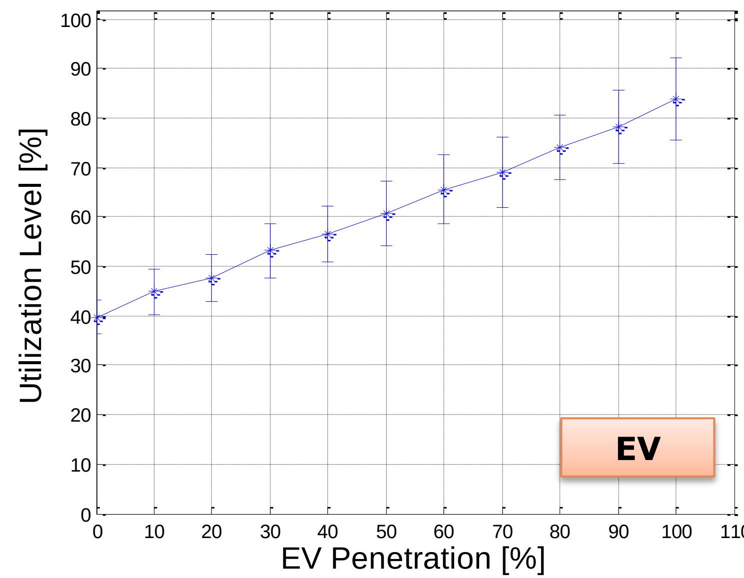
Utilization Level of the Head of the Feeder

hourly max current/ampacity



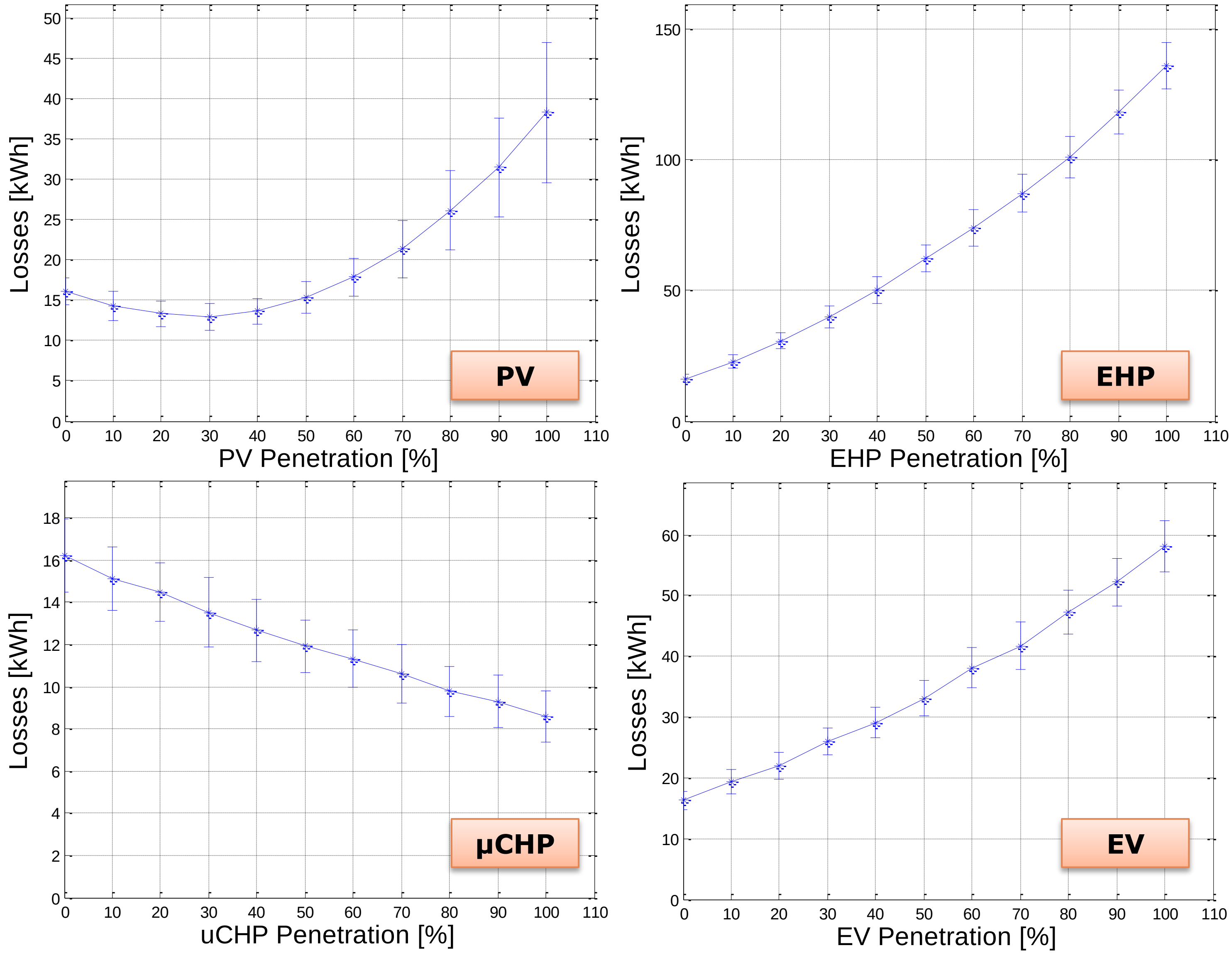






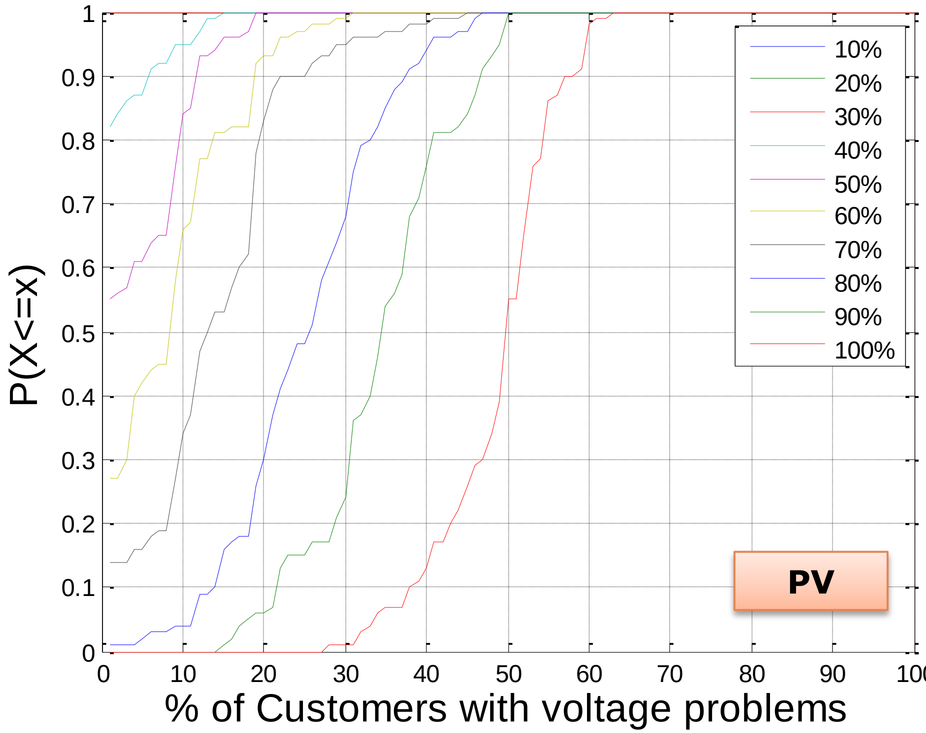
Impact Assessment: Daily Energy Losses

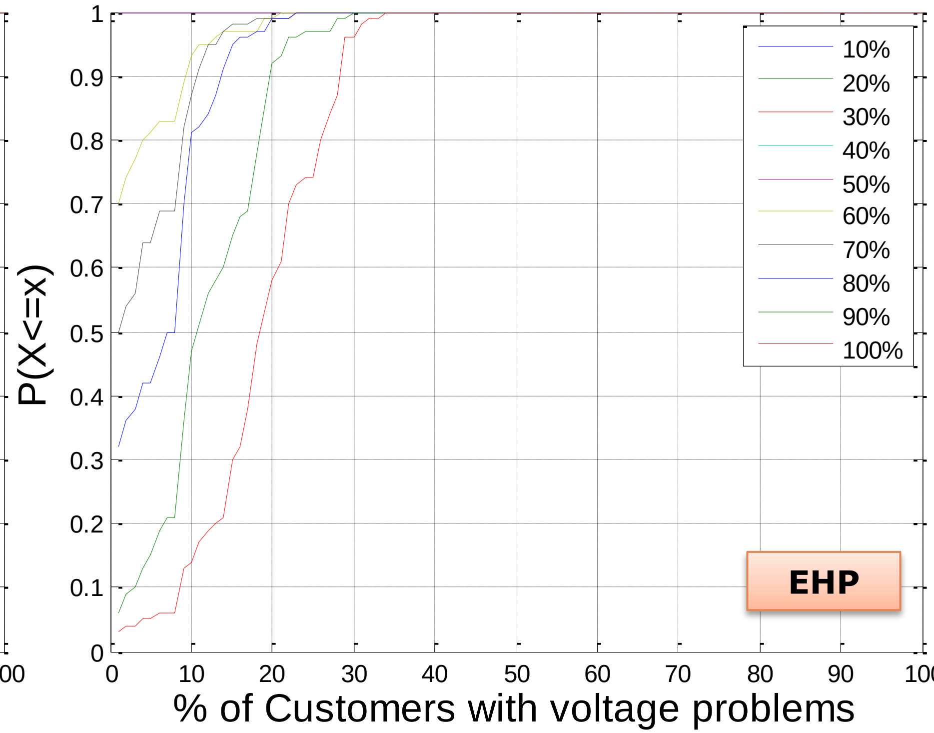
Daily Energy Losses



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

Impact Assessment: Probability Distributions

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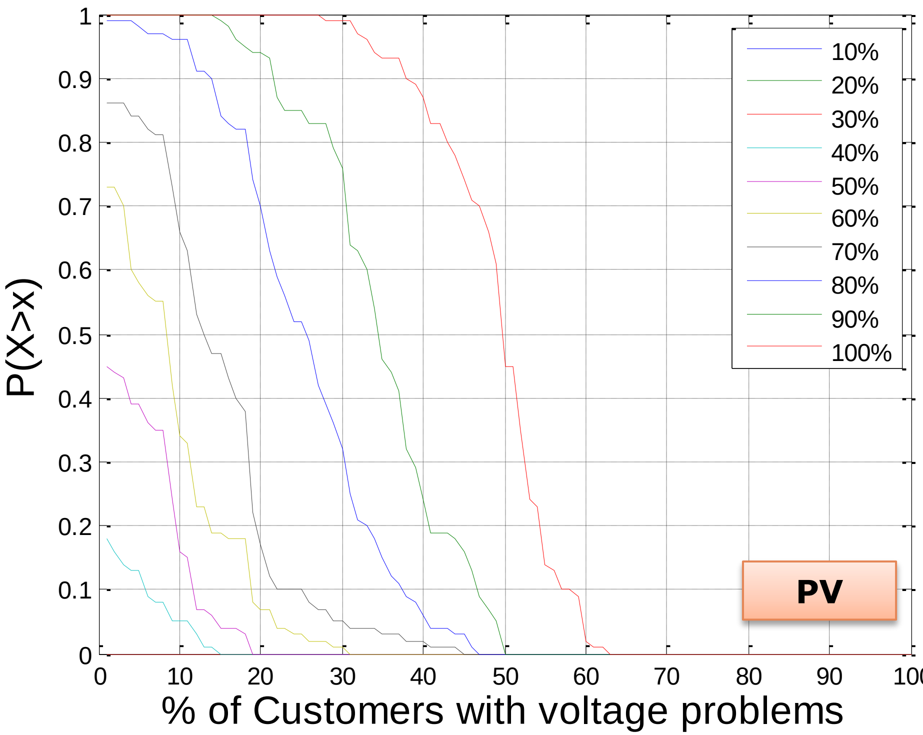
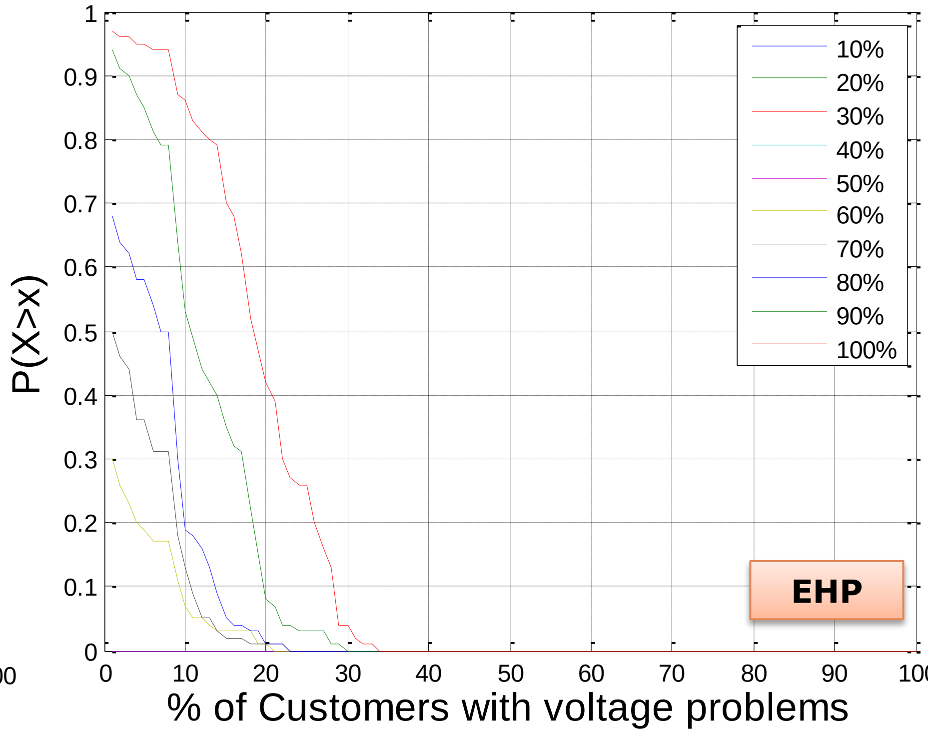
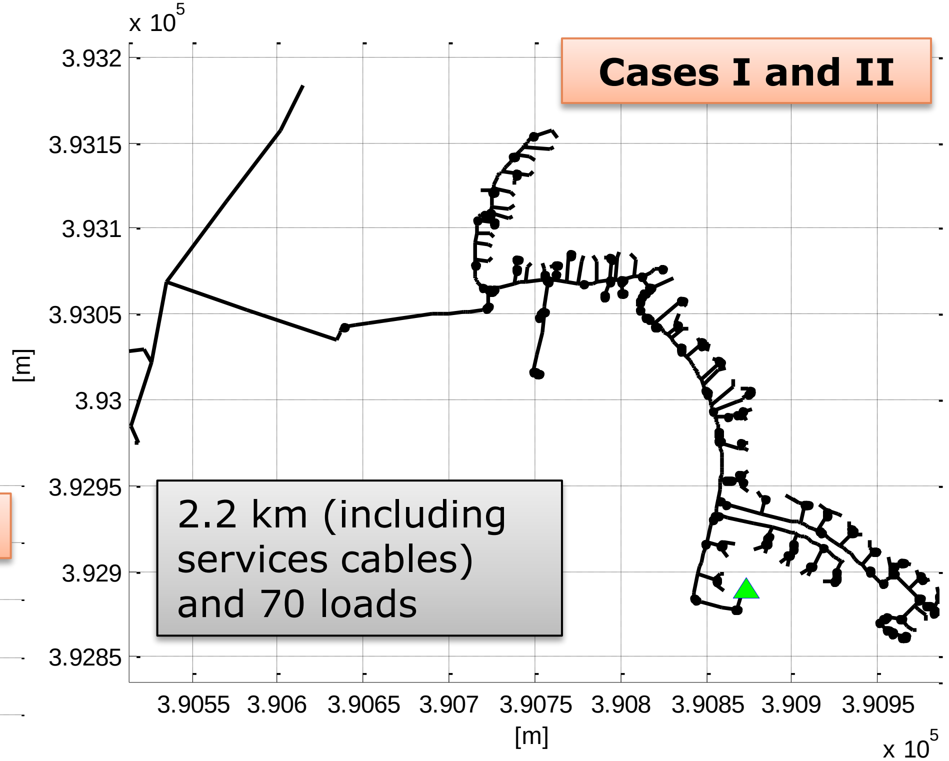


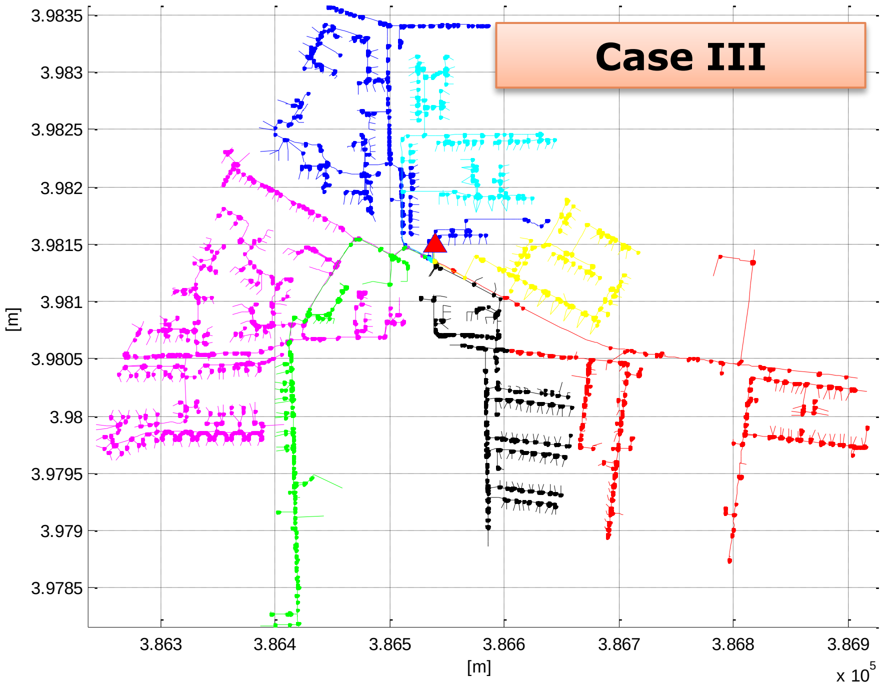


Probability to have more than X% of customers with problems

Impact Assessment: Case Studies

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

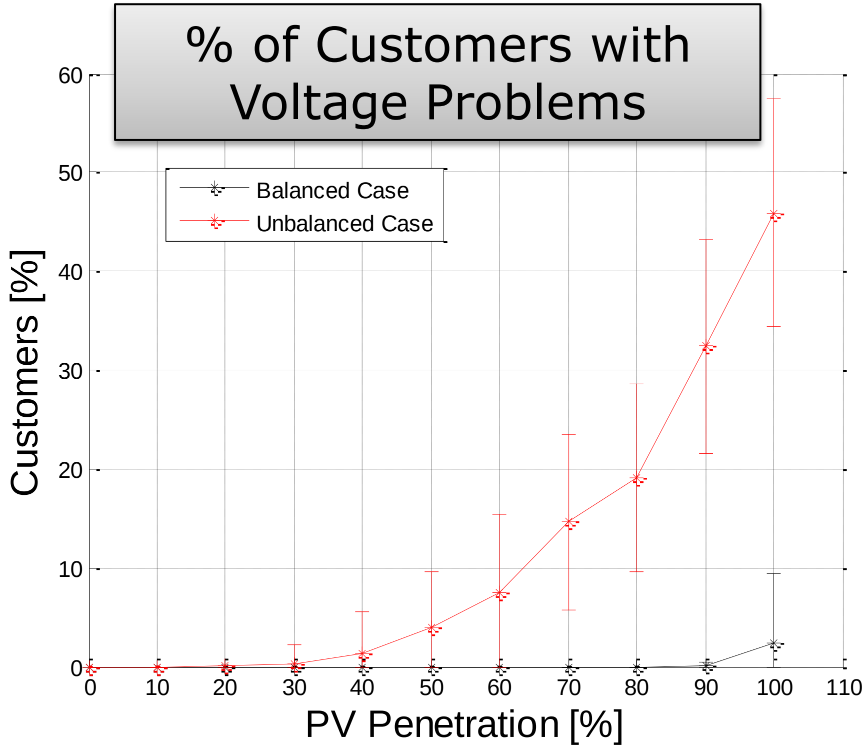


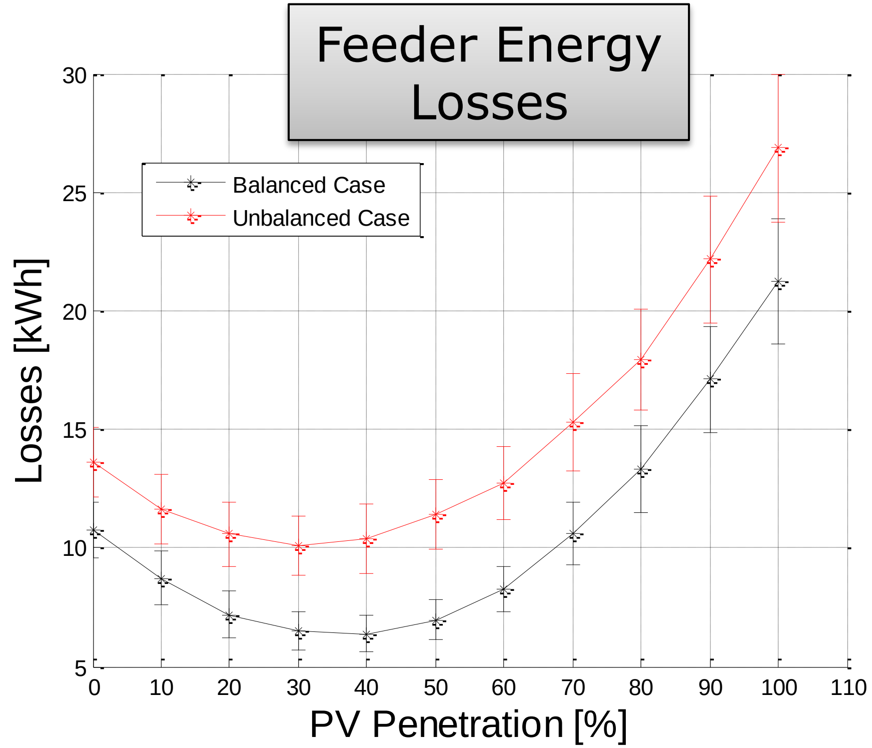


Feeder	Length (m)	No. of Customers
1	2514	77
2	2867	107
3	3981	169
4	4101	138
5	1538	23
6	1651	68
7	1300	54

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)



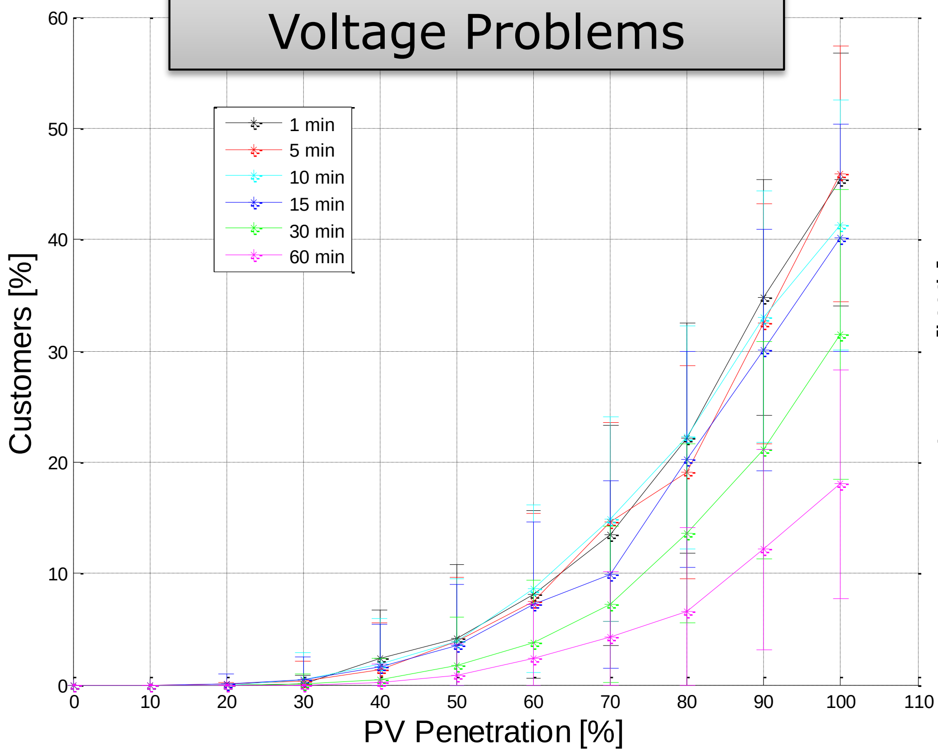


PV Analysis

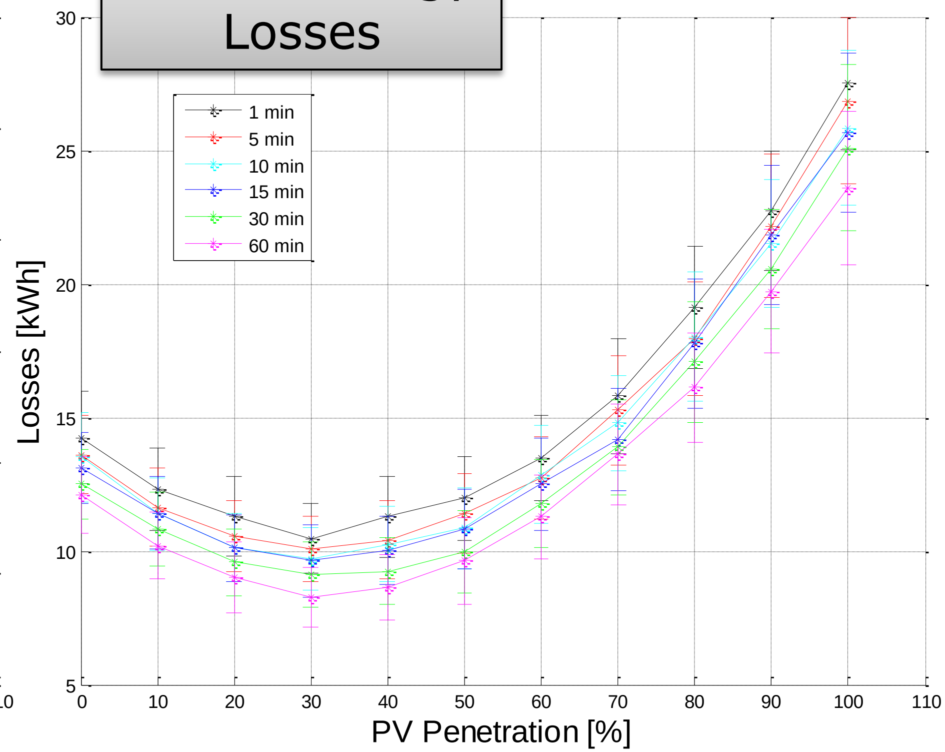
Impact Assessment: Case II

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

% of Customers with Voltage Problems



Feeder Energy Losses



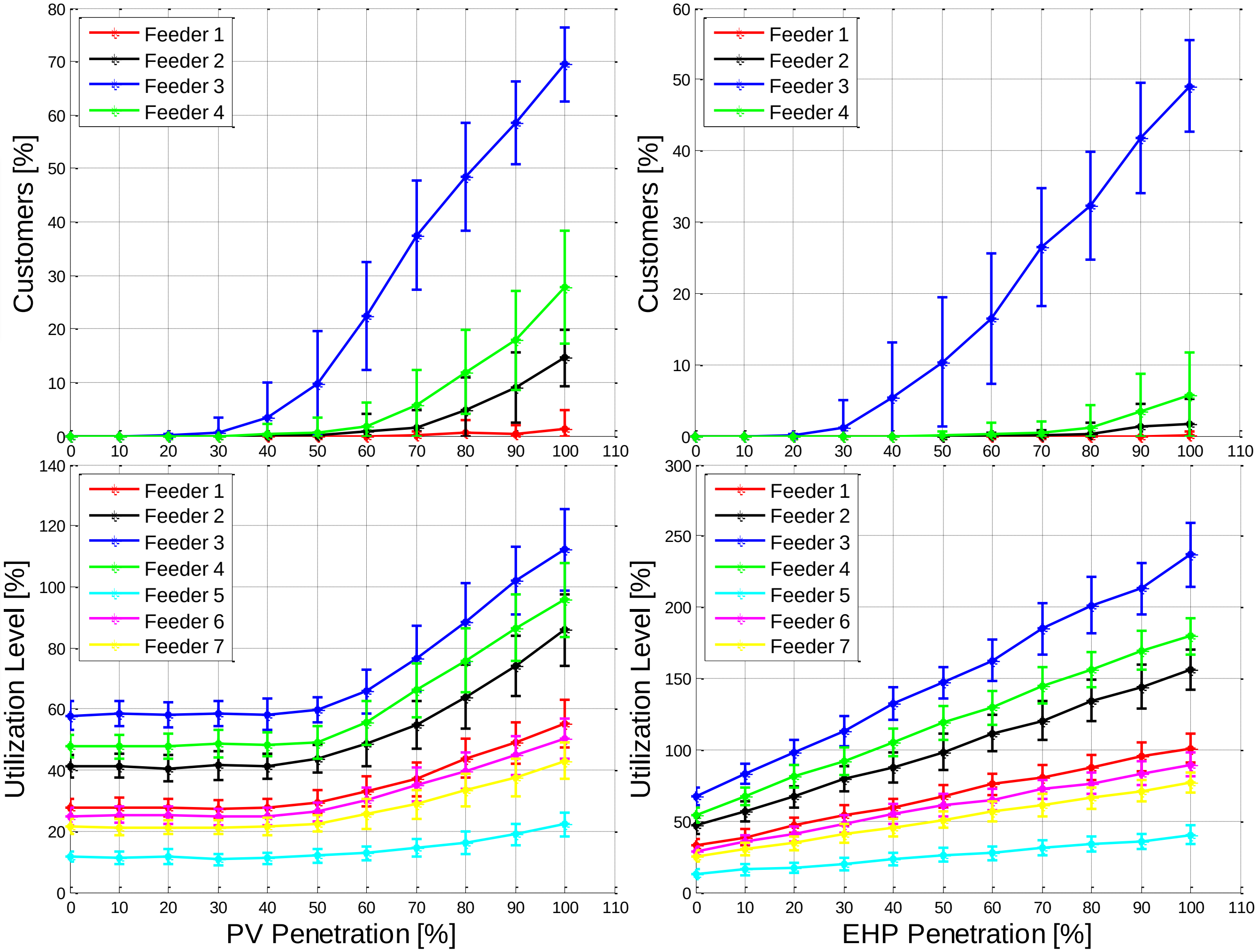
PV Analysis

Impact Assessment: Case III

- Different feeders Different Impacts:

% of Customers with Voltage Problems

Utilization Level at the head of the feeder

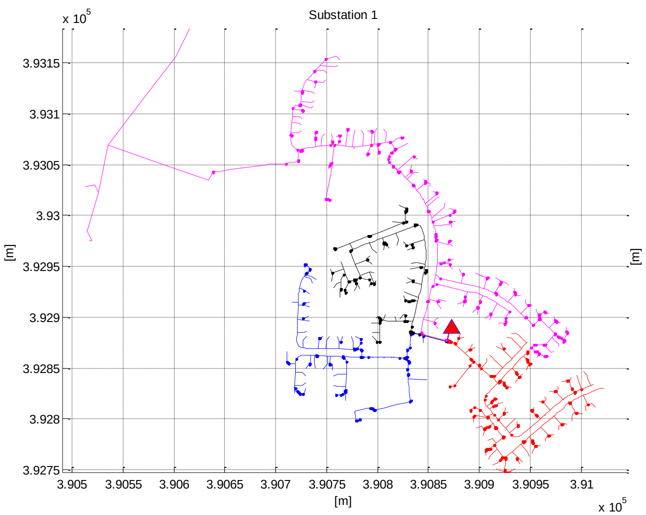


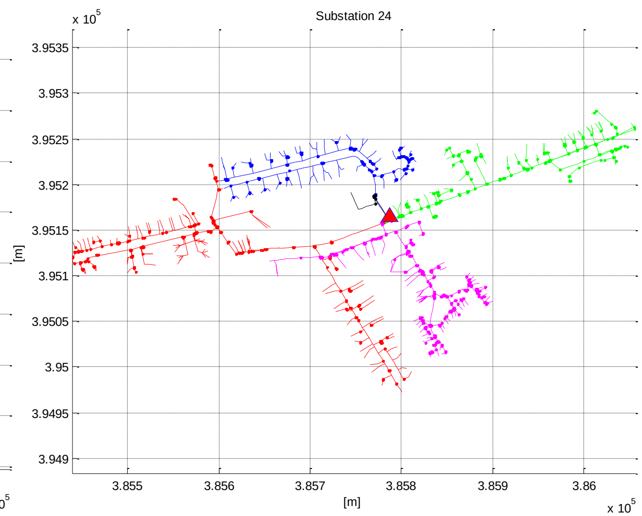
Outline

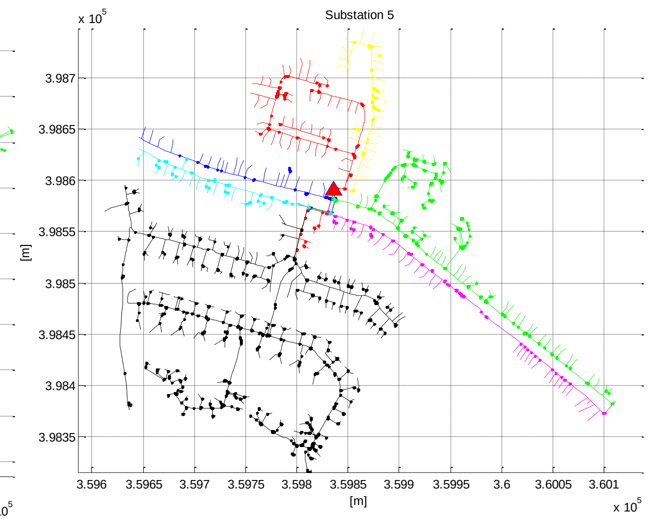
- Objectives
- Problem Description
- Profiles Creation
- Network Creation
- Impact Assessment
- Multi-Feeder Analysis
- Conclusions

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.



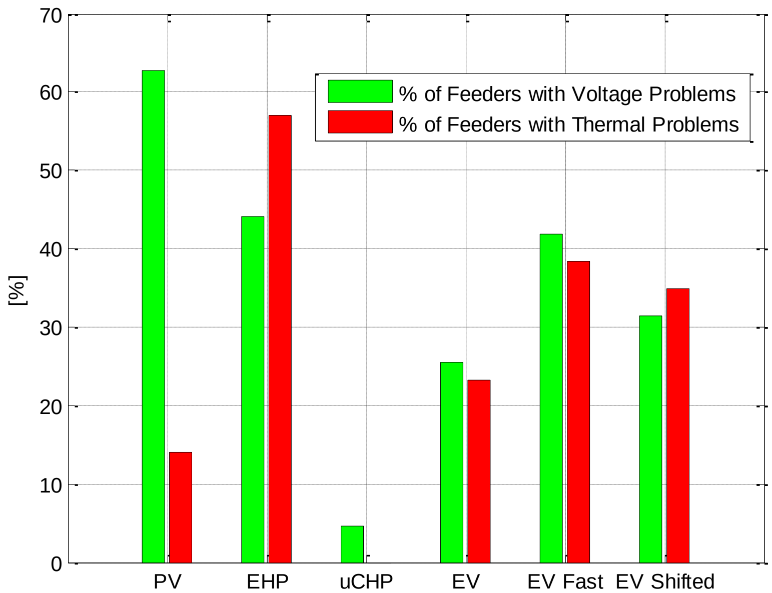




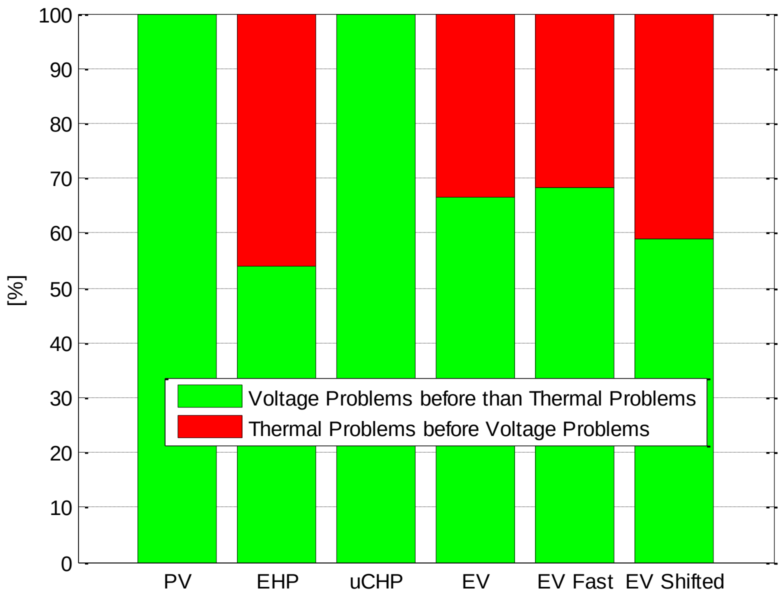
Example of Networks

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:



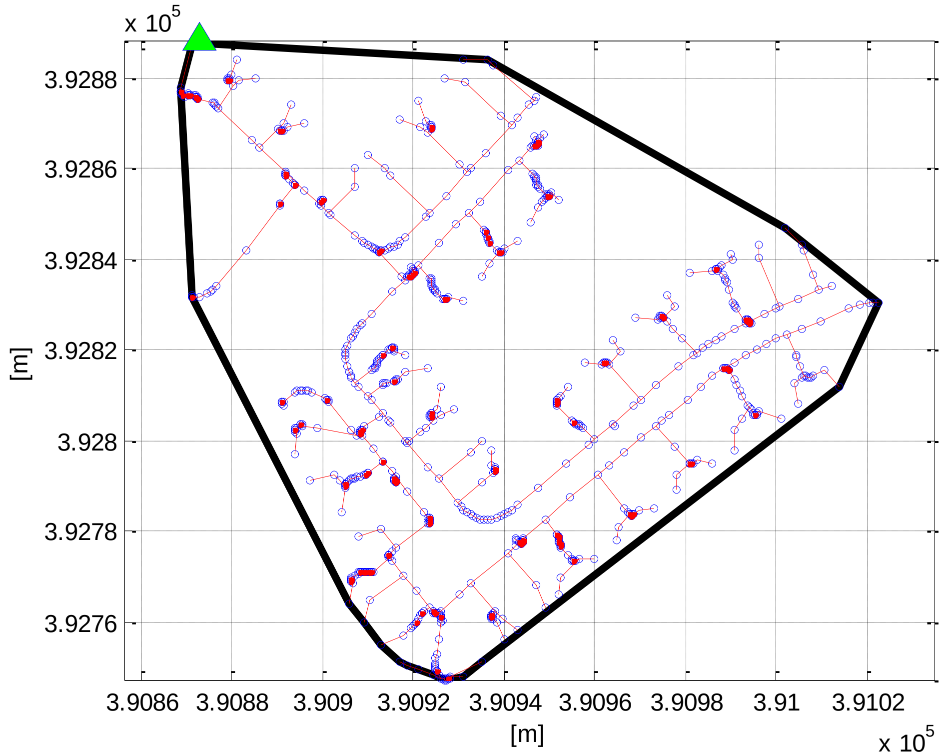
% of feeders with problems per technology



% of "Bottleneck" cases per technology

Multi-Feeder Analysis: Correlation Studies

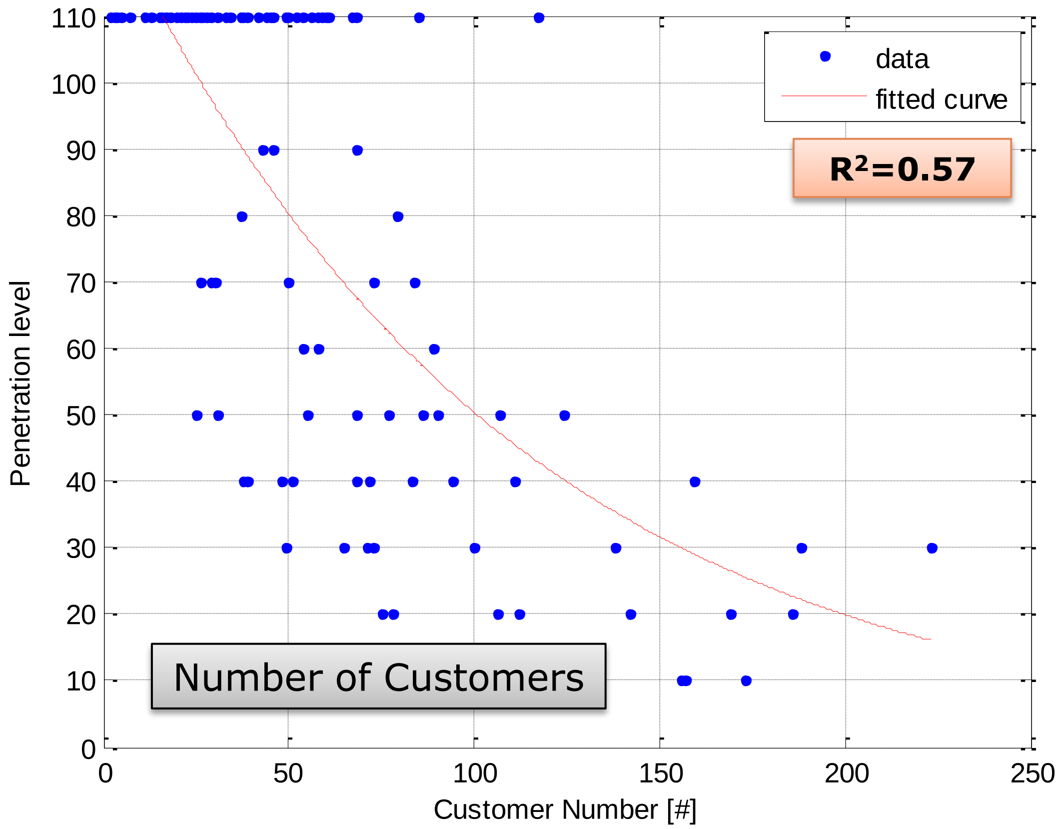
- The main characteristics of each feeder are recorded in order to find some relationship among these parameters and the apparition of the problems.
- The parameters explored are:
  - Feeder Length.
  - Customer Number.
  - Initial Utilization Level.
  - Customer per km.
  - Main Path.
  - Main Path Impedance.
  - Supplied Area.
  - Supplied Perimeter.
  - Total Impedance Aggregation.
  - Total Path Impedance



Feeder Example

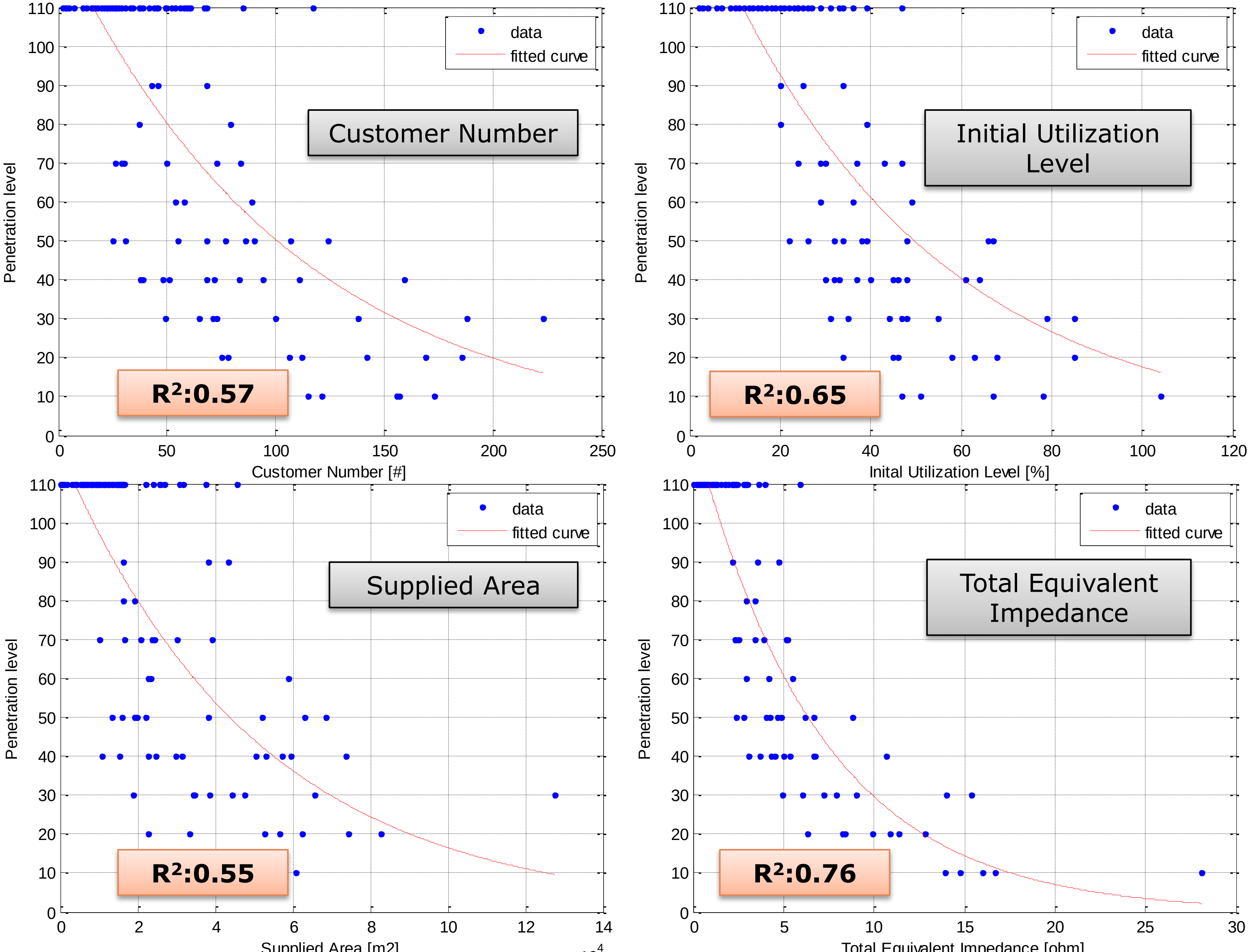
Multi-Feeder Analysis: Correlation Studies

- Example: Problems versus **Customers Number** (PV case):

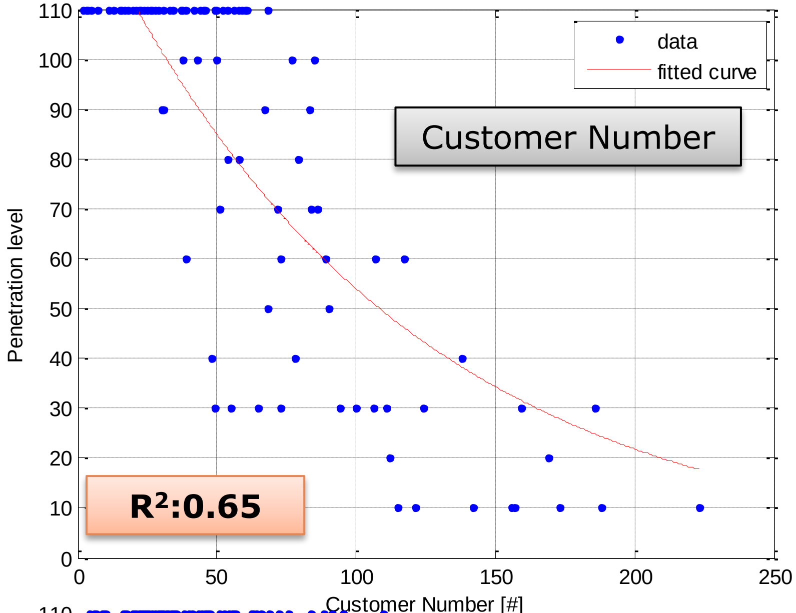


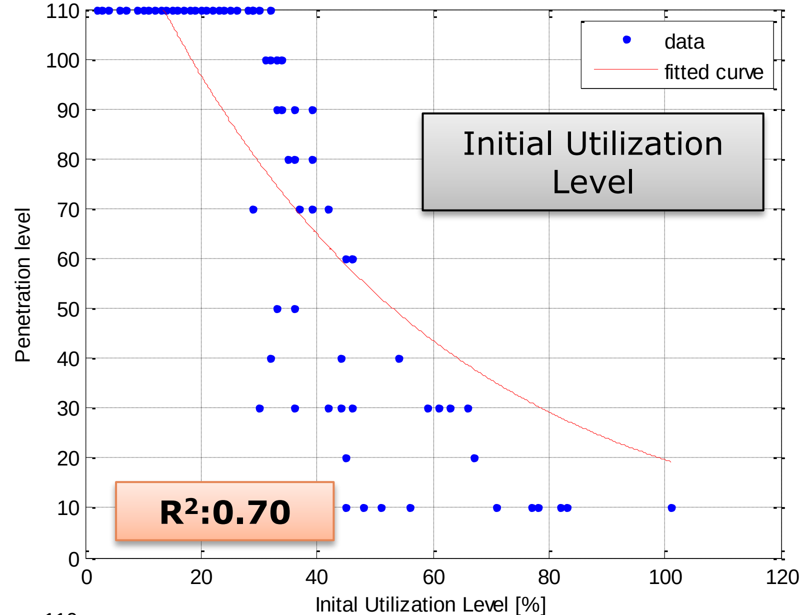
- One dot – one feeder.
- Horizontal axis: number of customers in each feeder.
- Vertical axis: average penetration level when the problems start in each feeder.
  - at least 1% of the customers with voltage problems, or
  - The average utilization level in the head of the feeder is at least 100%.

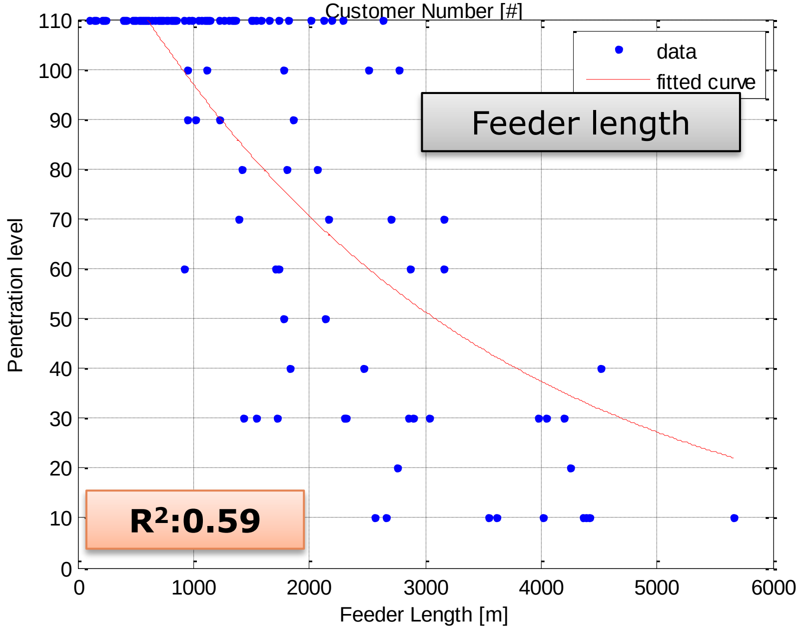
Multi-Feeder Correlation: PV Case

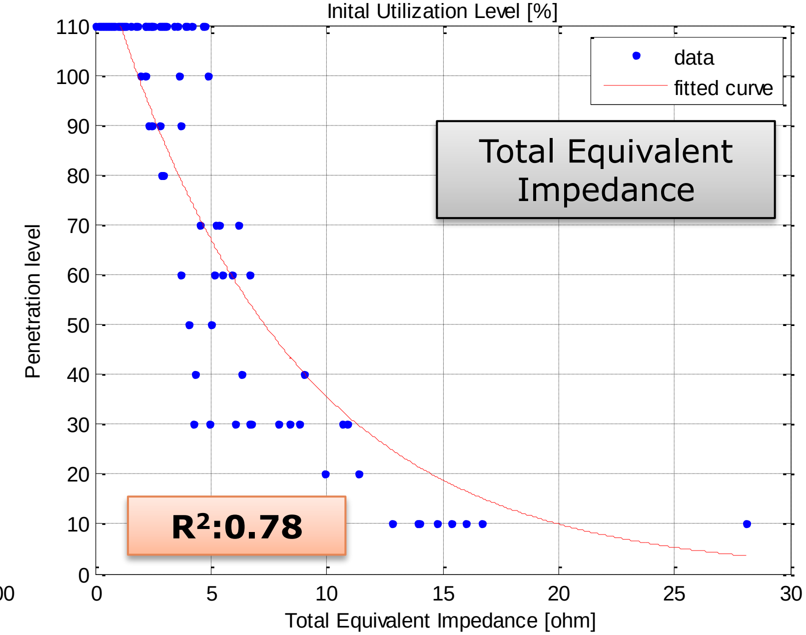


Multi-Feeder Correlation: EHP Case

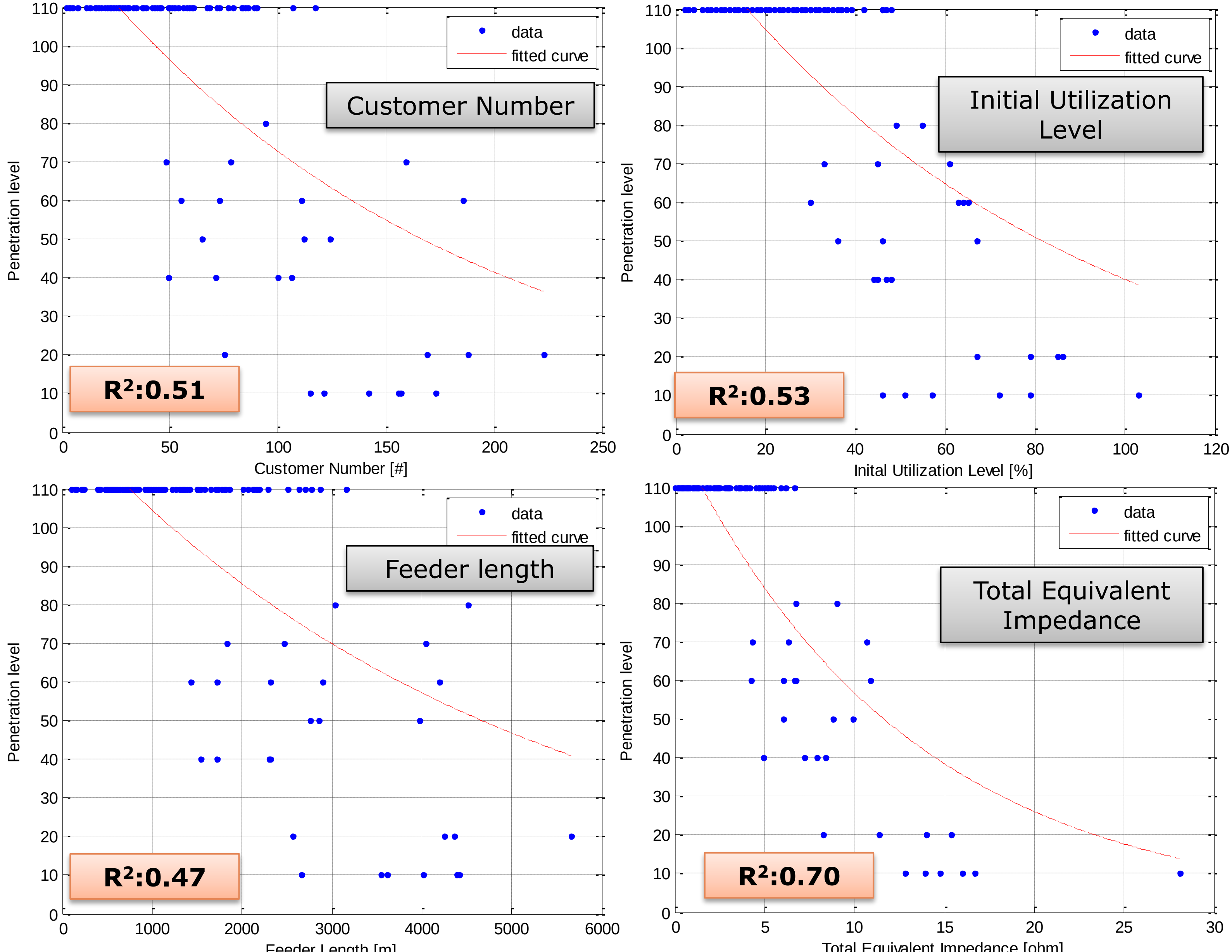








Multi-Feeder Correlation: EV Case



Multi-Feeder Analysis: Correlation Studies

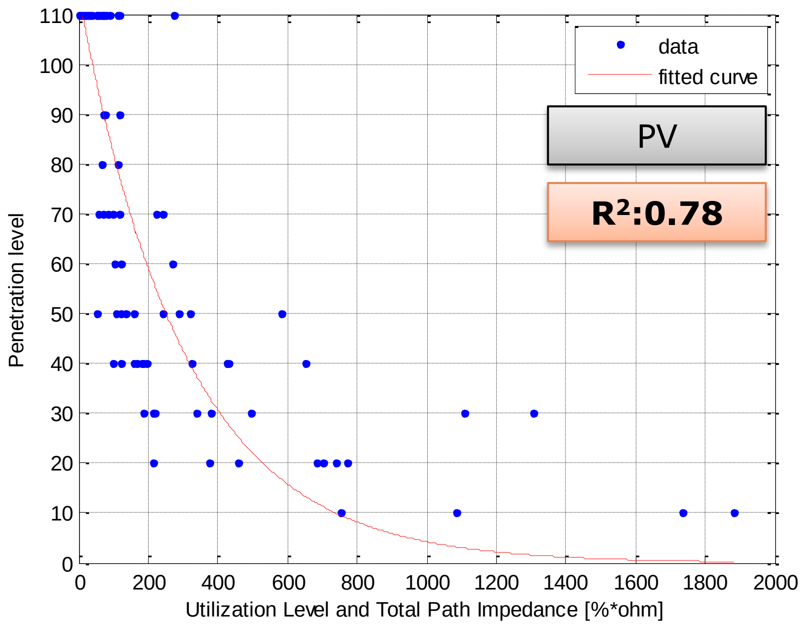
- The metrics with the highest coefficient of determination for PV, EHP and EV are Initial Utilization Level and the Total Impedance Path

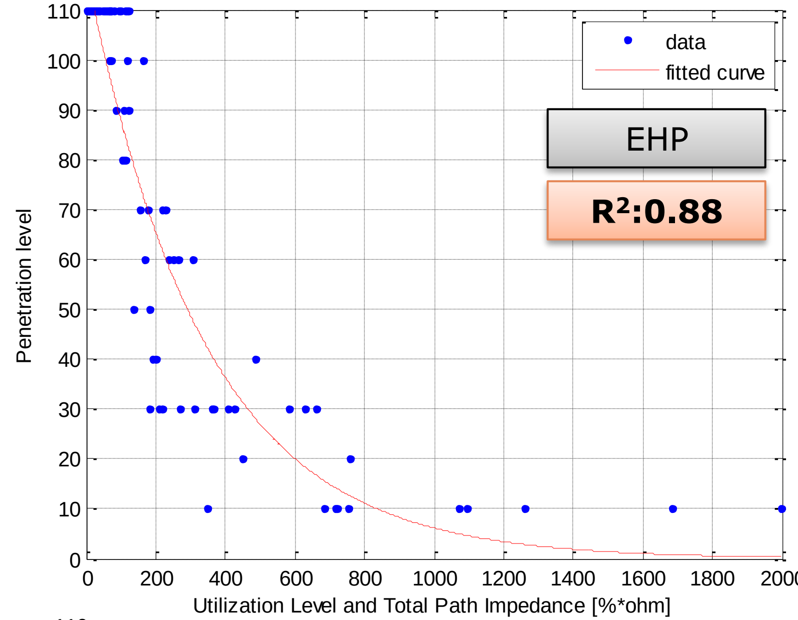
R2	Initial Utilization Level	Total Path Impedance
PV	0.65	0.76
EHP	0.70	0.78
EV	0.53	0.70

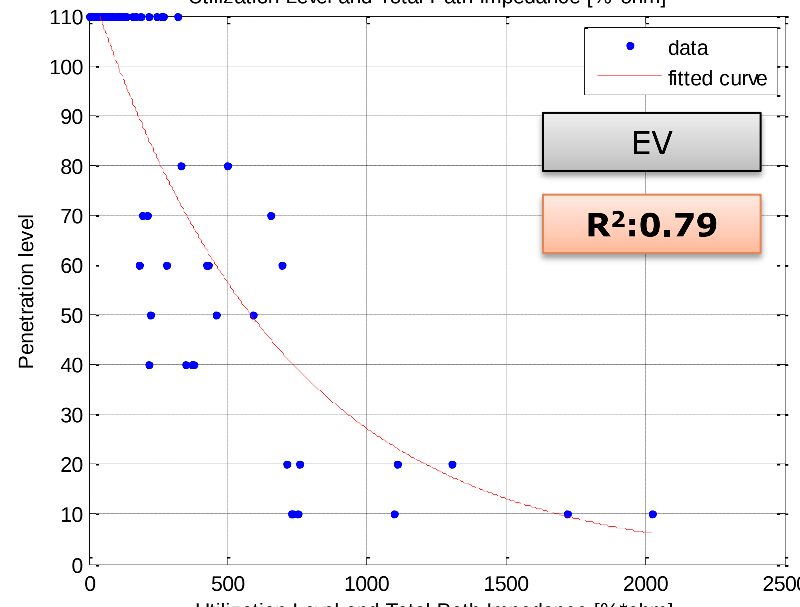
- So, what about if we combined both metrics.
- New metric: Multiplication of the Initial utilization Level and the total Path Impedance .

Multi-Feeder Analysis: Correlation Studies

- Combined Metric:

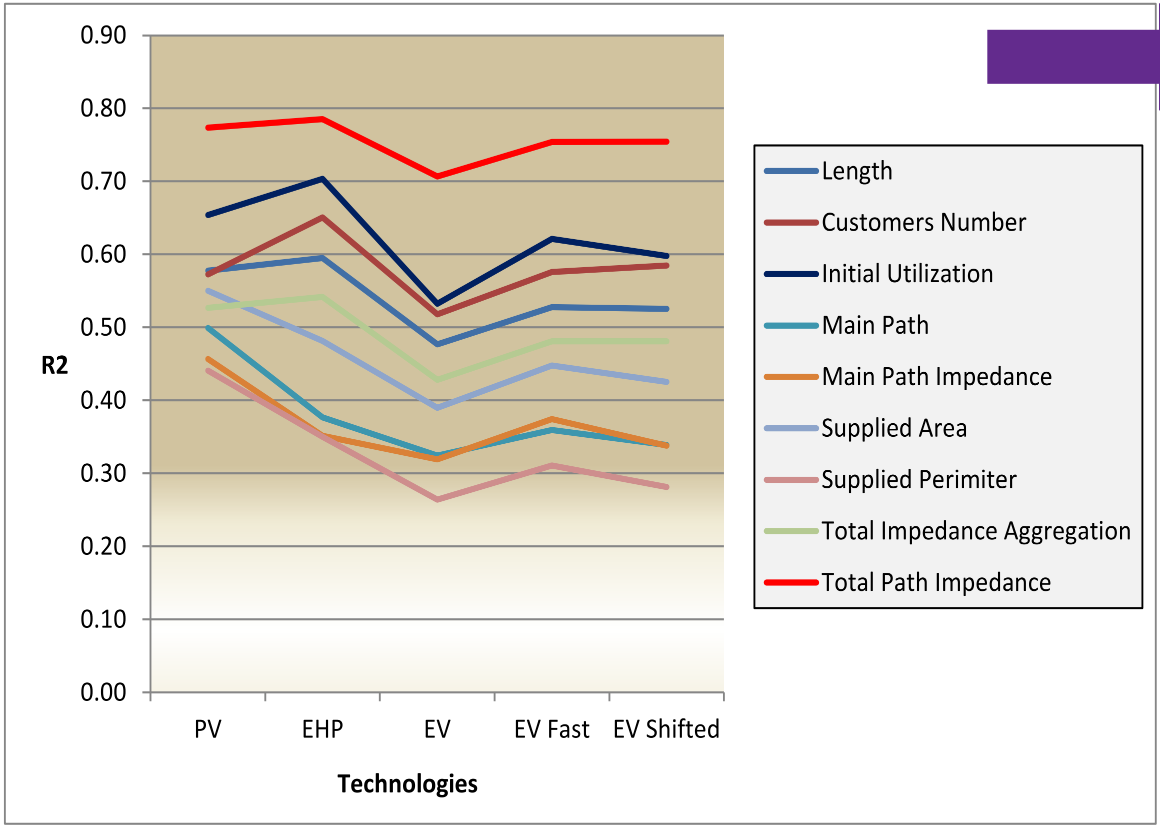






Multi-Feeder Analysis: Correlation Alternative

- 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?



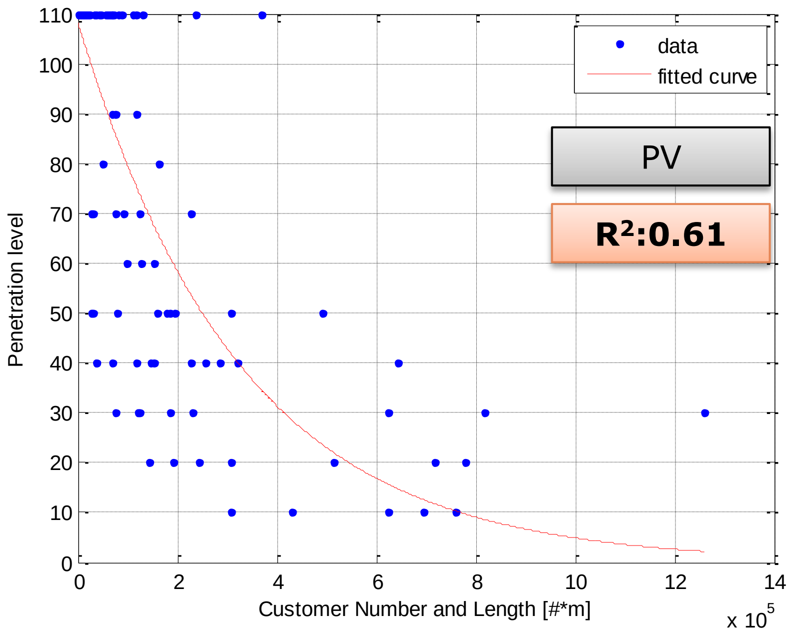
The customer number correlates better with the initial utilization level.

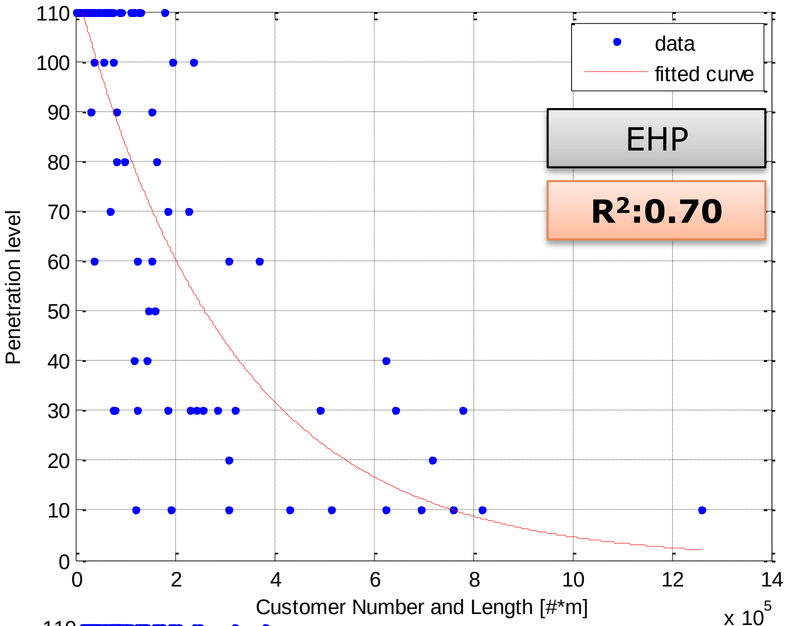
The feeder length correlates better with the Total path impedance

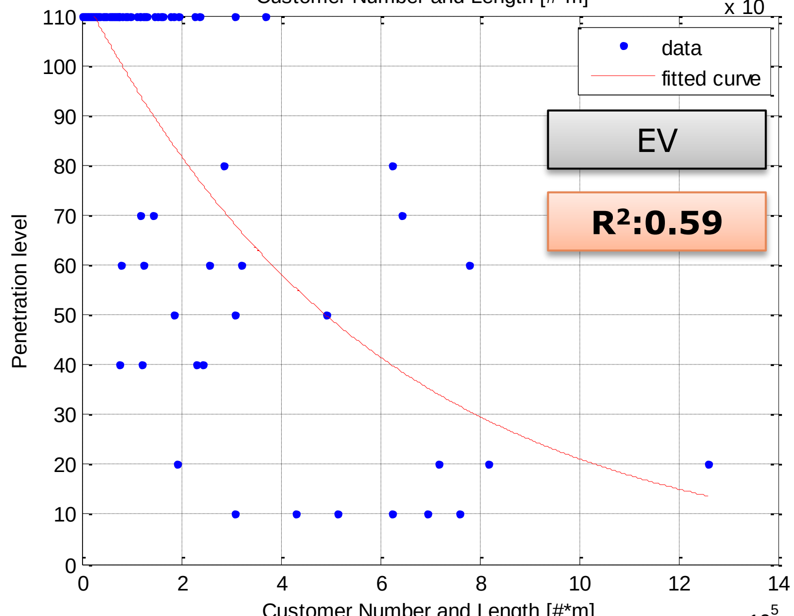
R2	Customer Number	Feeder Length
PV	0.57	0.57
EHP	0.65	0.59
EV	0.51	0.47

Multi-Feeder Analysis: Correlation Alternative

- Combined Metric: Customers and Length







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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

1. A. Navarro Espinosa and L. F. Ochoa, “On the Cascading Effects of Residential-Scale PV Disconnection Due to Voltage Rise,” **IEEE Power and Energy Society General Meeting**, **Maryland 2014**.
2. A. Navarro Espinosa, L. F. Ochoa, and Dan Randles, “Assessing the Benefits of Meshed Operation of LV Feeders with Low Carbon Technologies,” Innovative Smart Grid Technologies Conference – **IEEE PES ISGT 2014**, **Washington 2014**.
3. A. Ballanti, A. Navarro Espinosa, L. F. Ochoa, and F. Pilo, “Assessing the Benefits of PV VAR Absorption on the Hosting Capacity of LV Feeders,” in **IEEE PES 4th European Innovative Smart Grid Technologies** (ISGT 2013), **Copenhagen 2013**.
4. A. Navarro Espinosa, L. F. Ochoa, P. Mancarella, and D. Randles, “Impacts of Photovoltaics on Low voltage Networks: A Case Study for the North West of England,” in 22th International Conference on electricity Distribution (**CIRED 2013**), **Stockholm 2013**, no. June, pp. 10–13.
5. A. Navarro Espinosa, L. F. Ochoa, and D. Randles, “Monte Carlo-Based Assessment of PV Impacts on Real UK Low Voltage Networks,” in 2013 **IEEE Power and Energy Society General Meeting**, **Vancouver 2013**, pp. 1–5.
6. A. Navarro Espinosa, L. F. Ochoa, and P. Mancarella, “Learning from Residential Load Data: Impacts on LV Network Planning and Operation,” in Sixth **IEEE PES Transmission and Distribution**: Latin America Conference and Exposition, **Montevideo 2012**.

Dissemination: Publication List

Collaborations related with LCTs:

1. Y. Zhou, A. Navarro Espinosa and J. Mutale, “Security of Supply: Implication of Residential Photovoltaic Panels in Low Voltage Network” 2014 **International Conference on Power System Technology** (POWERCON2014), **Chengdu 2014** (China).
2. L. Zhang, N. Good, A. Navarro Espinosa, and P. Mancarella, “Modelling of Household Electro Thermal Technologies for Demand Response Applications” **Innovative Smart Grid Technologies Conference** (**ISGT-Europe**), **Istanbul 2014**.
3. N. Good, L. Zhang, A. Navarro Espinosa, and P. Mancarella, “Physical modeling of electro-thermal domestic heating systems with quantification of economic and environmental costs,” in **IEEE EUROCON 2013**, **Zagreb 2013**.
4. A. Navarro Espinosa and P. Mancarella, “Probabilistic modelling and assessment of the impact of electric heat pumps on low voltage distribution networks” **Applied Energy**, Volume 127, 15 August 2014, Pages 249-266.

Dissemination: Work in Progress

Publications Submitted:

1. A. Navarro Espinosa and L. Ochoa, "Techno-Economic Assessment of using OLTC in Future UK LV Networks" to the **Innovative Smart Grid Conference** – **Washington 2015**.
2. V. Rigoni, L. Ochoa, G. Chicco, A. Navarro Espinosa and T. Gozel, "Representative Residential LV Feeders: A case study for the North West of England" submitted to **IEEE Transaction on Power Systems.**

Work in progress:

1. A. Navarro and L. Ochoa, "Impacts of Low Carbon Technologies in real Low Voltage Distribution Networks: Probabilistic Assessment Methodology – Part I" for submission to **IEEE Transaction on Power Systems** (expected submission October 2014)
2. A. Navarro and L. Ochoa, "Impacts of Low Carbon Technologies in real Low Voltage Distribution Networks: Cause and Effects in a Multi Feeder Analysis – Part II" for submission to **IEEE Transaction on Power Systems** (expected submission October 2014)

Impact Assessment of LCTs on LV Networks

Appendix I

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3rd October 2014

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