Time and Locational Value of PV on Distribution Feeders in Spain

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Rationale for a Study on the Value of Solar PV

- Policy makers are interested in the promotion of DER
- It is generally assumed that DER provide added value due to proximity to load
- In some locations, solar PV is likely to be deployed in distribution networks
- It is important for regulators and stakeholders in general to have analytical references on the value of DER

Analysis Approach

Objective: *Evaluate the long-term costs and benefits of both guided and unguided deployments of distributed PV, at varying penetration levels, on a number of MV distribution feeders in Spain and compare results with conventional network reinforcements.*

Hosting Capacity Analysis

- Perform a global hosting capacity analysis on the studied network
- Provides guidance in choosing substations for further detailed analysis

Base Case

- Calculate a base case of grid and demand
- Long term (10 year) analysis of impacts of load growth on distribution feeders

Scenario 1

- Guided deployment of PV to mitigate the impacts observed in the base case analysis

Scenario 2

- Unguided deployment of PV at the same penetration as Scenario 1

Scenario 3

- Both guided and unguided deployments of PV at a specified high penetration level

Cost Benefit Analysis

- Compare the costs and benefits associated with the PV scenarios and the traditional grid alternatives

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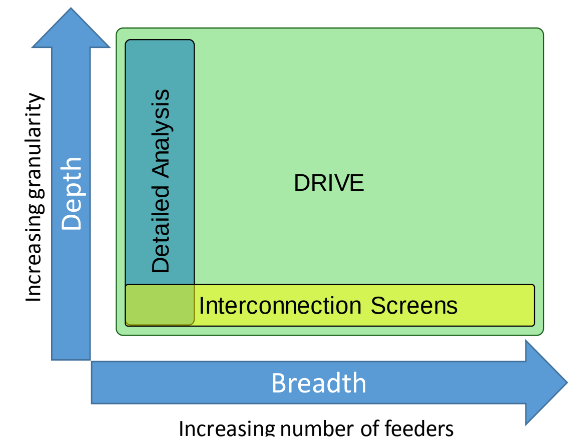
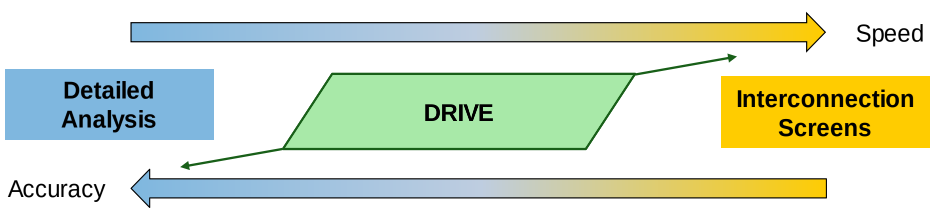
Hosting Capacity Analysis – EPRI's DRIVE tool

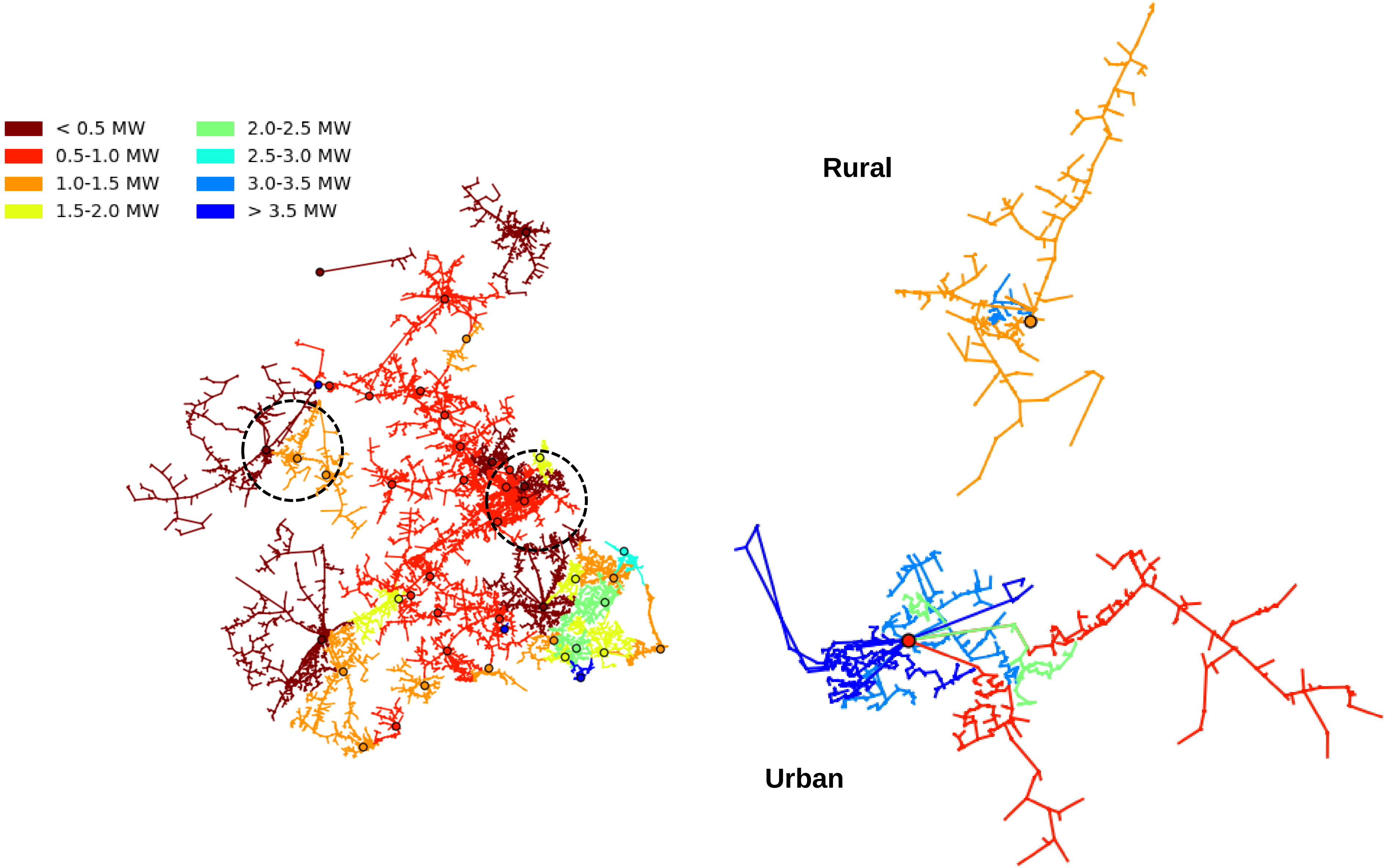
- EPRI has developed a software tool for calculating the hosting capacity of networks in a fast and efficient way, without the need for detailed studies
- Definition:
  - Hosting Capacity is the amount of DER that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades.
- Hosting Capacity is
  - Location dependent
  - Feeder-specific
  - Time-varying
- Hosting capacity considers DER interconnection without allowing
  - Voltage/flicker violations
  - Protection mis-operation
  - Thermal overloads
  - Decreased safety/reliability/power quality

Distributed **R**esource **I**ntegration and **V**alue **E**stimation





Hosting Capacity Analysis



Available Data and Analysis Process

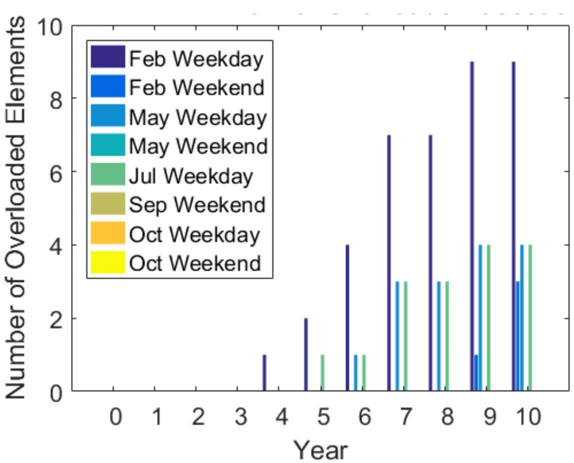
- 10 individual years will be analysed
  - 8 load days for each year
  - Load growth per year
    - 3% for urban substation
    - 6% for rural substation
- Violations monitored
  - Thermal overloads – elements with current/power greater than 100% of normal rating
  - Voltage violations – nodes with voltage above 1.07 pu or below 0.95 pu
- Considered network operations for solving problems
  - Substation tap change
  - Reconfiguration – performed using Iberdrola's reconfiguration tool
  - Reinforcement – As advised by Iberdrola planners

PV Assumptions and Deployments

- Distributed PV developed in the form of rooftop
  - PV at each node is an aggregation of downstream PV located on LV system
- Maximum PV capacity that can be installed at each node is the result of the rooftop solar that could grow on the downstream network
  - Assumption hat customers are installing rooftop PV under a net metering scheme, aiming for their annual energy consumption to be zero
  - Installed PV to peak load ratio calculated
  - PV that can be installed on urban feeders scaled down to 20%
- PV deployments
  - <u>Scenario 1 (Guided)</u>: PV to solve base case problems, guided to feeders with violations that can be solved with PV, on nodes with highest hosting capacity up to a maximum of each node's peak load times the installed PV to peak load ratio, located after violated nodes
  - <u>Scenario 2 (Unguided):</u> Same penetration in the same year as Scenario 1, located at random nodes across the feeder up to a maximum of each node's peak load times the installed PV to peak load ratio

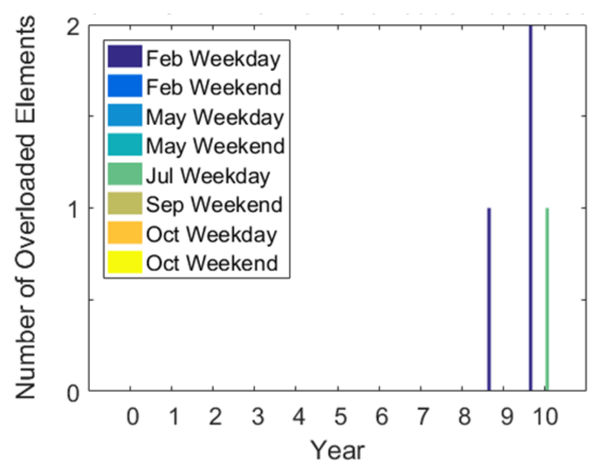
Base Case Violations

Urban	Rural



3 feeders with overloads. Multiple days with February (winter) weekday having most overloads. 9 overloaded elements in total. Largest overload is 1.4 MW

Just 2 overloaded lines in years 9 and 10. Largest overload for those lines is 0.3 MW



Base Case Violations with Reinforcements

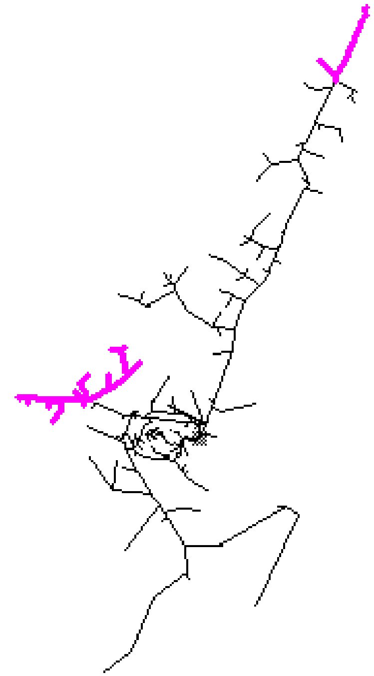
Urban	Rural

Overload

Section moved to new substation

If overloads for all seasons are considered, reconfiguration and 1.6 km of reconductoring in Year 4 is needed to eliminate all overloads.

If only summer overloads are considered, reconfiguration in Year 5 and 0.36 km of reconductoring in Year 9 is needed*



Reconfiguration is the only reinforcement needed to eliminate the overloads

Scenario 1 (Guided) – Use PV as Mitigation

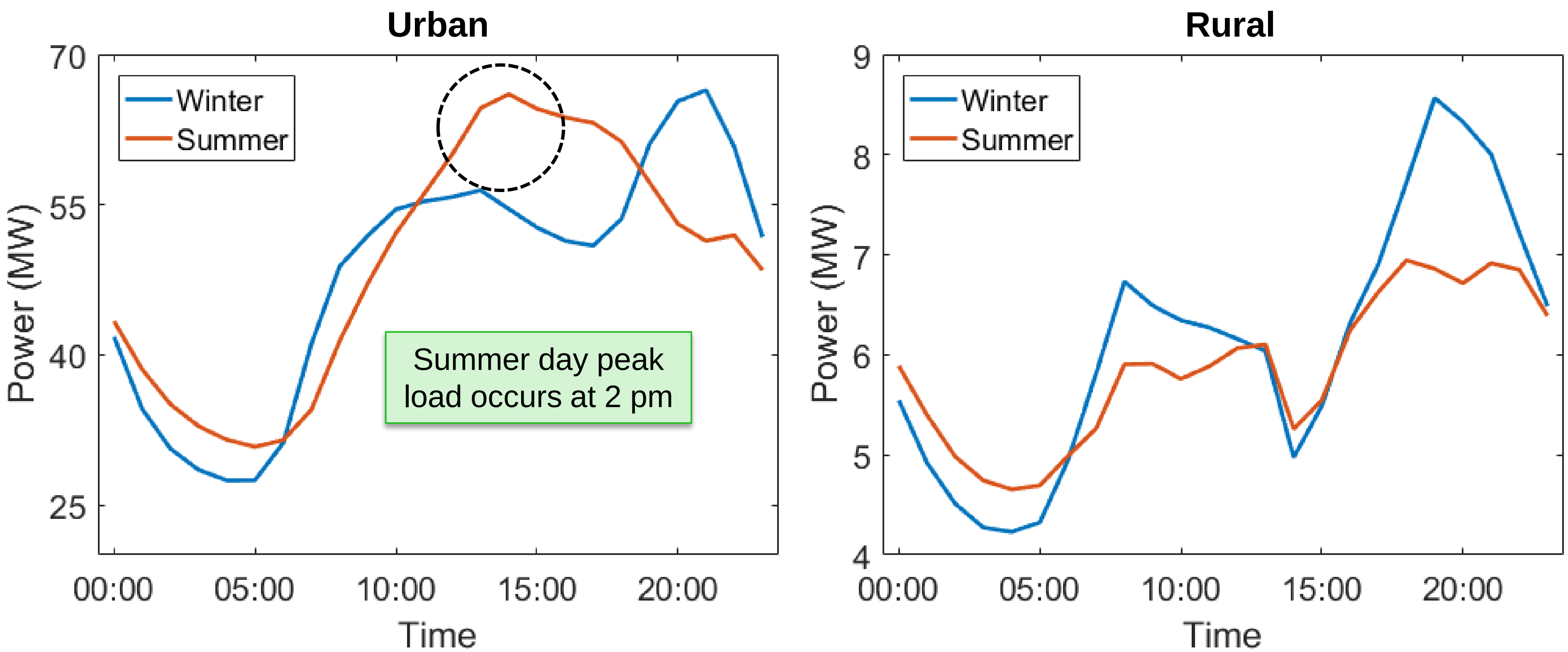
Is there potential for PV to solve base case violations?

- *PV output is compared with load shape to determine effectiveness. Then a procedure for deployment is applied*

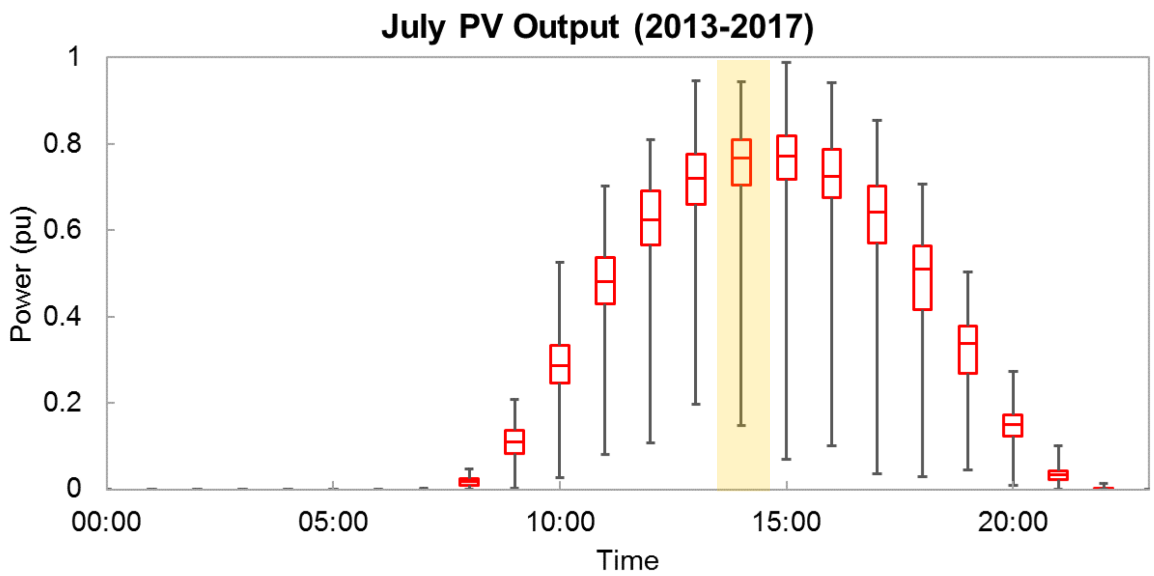
Solution procedure:

- When should PV be added? *Earliest year overloads occur*
- Where should PV be added? *At nodes after the violation with the highest hosting capacity*
- How much PV should be added? *Depends on size and time of overload, and hosting capacity for that location*

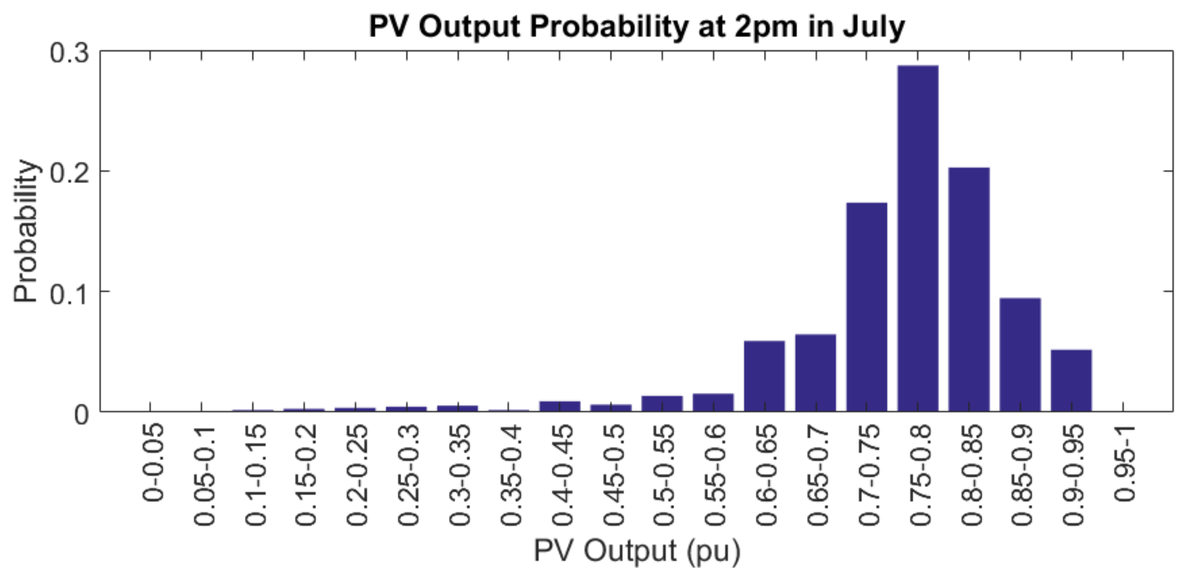
Load Profile Analysis



PV Output Analysis – Summer Day

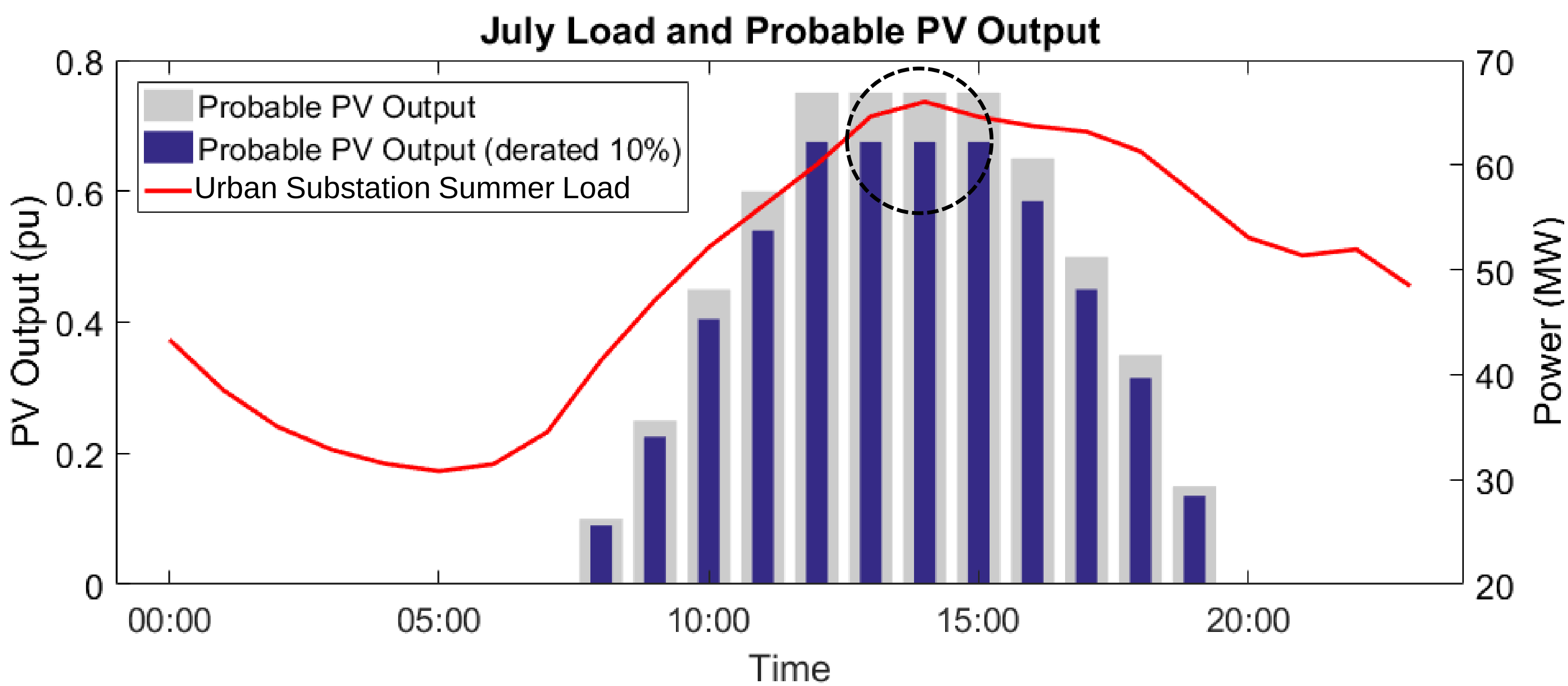


- 8 PV systems in region over 4 years
- What PV output should be assumed?



- Assumption is to take most probable PV output
- Therefore for at 2 pm a PV output of 0.75 pu should be used
- To include headroom, values will be de-rated by 10%

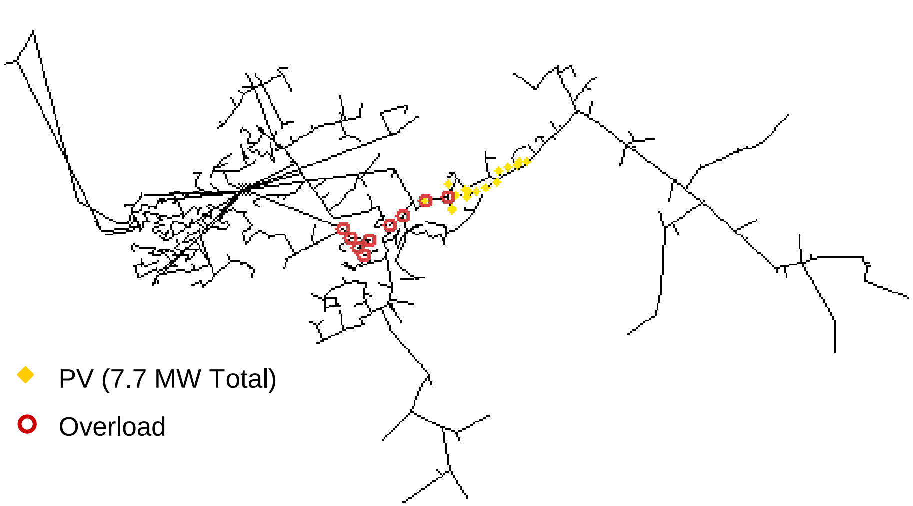
PV Output Analysis

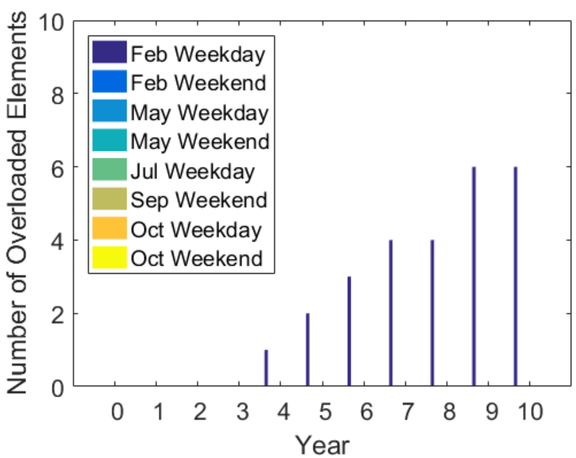


If an overload occurs, the amount of PV needed to mitigate that overload will be based on the de-rated probable PV output at that time. For example, if there is an overload of 100 kW at 2 pm, 147 kW of PV will be needed to mitigate that overload (100/(0.9*0.75))

Scenario 1 (Guided) Violations

Urban



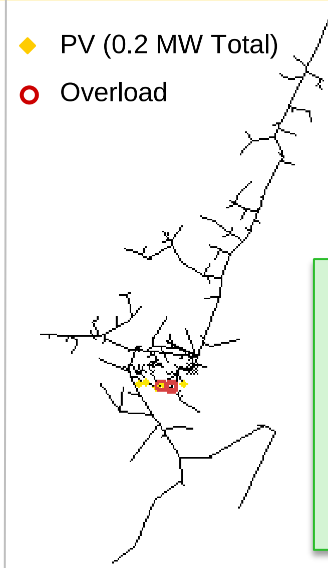


11.4 MW of PV needed if all overloads are considered, hosting capacity limits installed PV to 7.7 MW

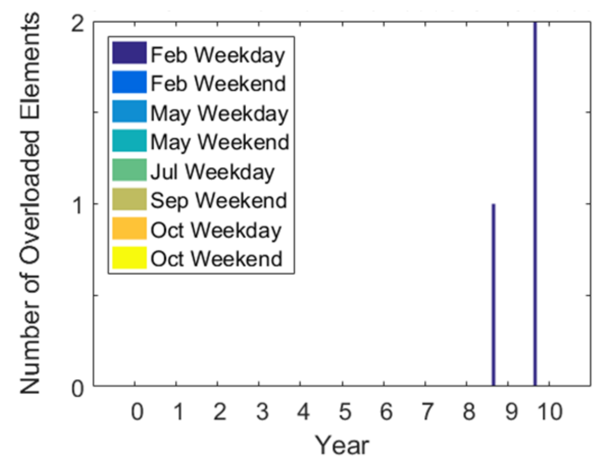
If only summer overloads considered, PV required to mitigate is just 1.9 MW

Installing the 7.7 MW, there are 3 fewer overloaded elements than the base case (6 total). PV mitigates all overloads that occur during summer

Rural

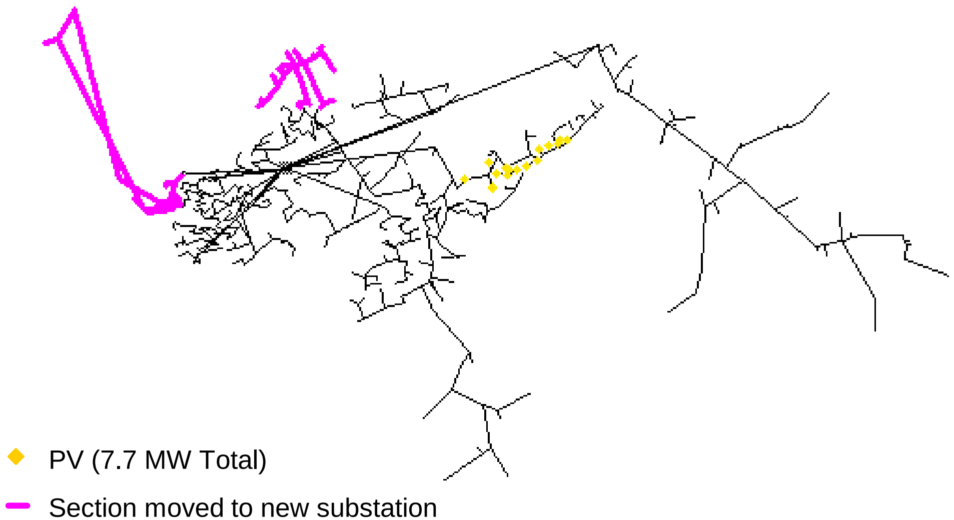


0.2 MW of PV is needed. Base case overload on July weekday is eliminated but overloads on February weekday remain



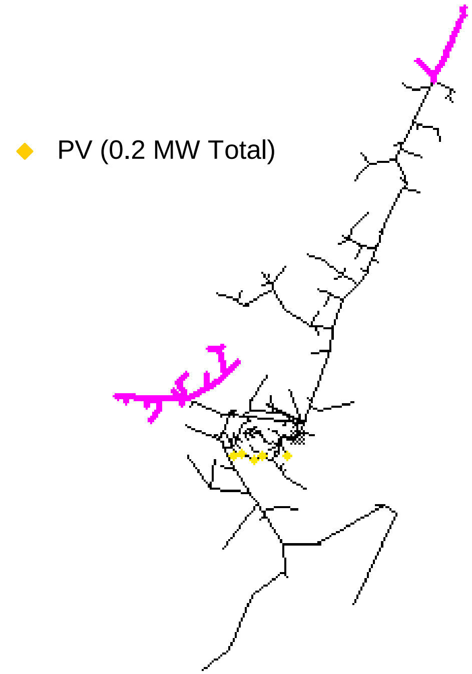
Scenario 1 (Guided) Violations with Reinforcements

Urban	Rural



If only summer overloads are considered, PV alone can eliminate all summer overloads

However, since guided PV is not effective all year round, when overloads for all seasons are considered, reconfiguration and 1.6 km of reconductoring in Year 4 are needed to eliminate all overloads, which is the same as the base case



Reconfiguration solves all overloads. No guided PV would be needed

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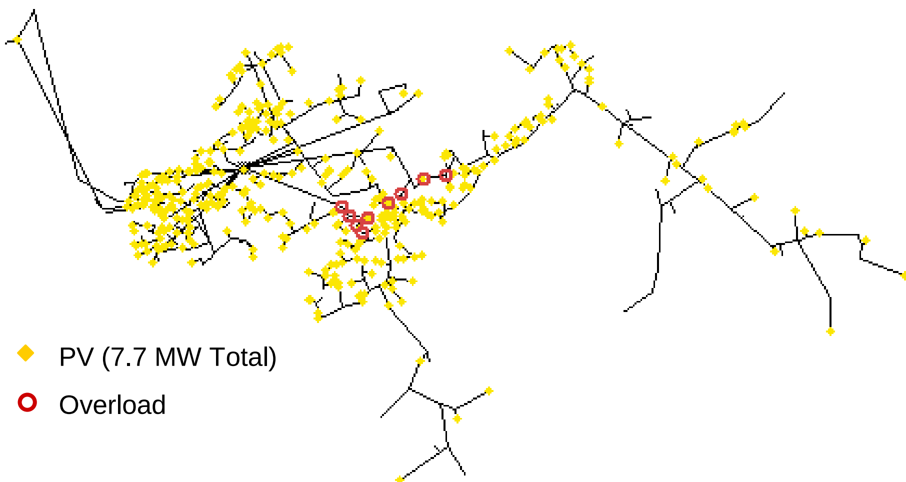
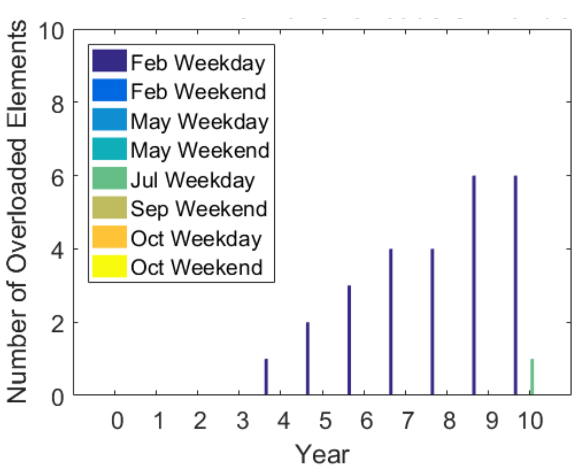
Scenario 2 (Unguided) Violations

Urban



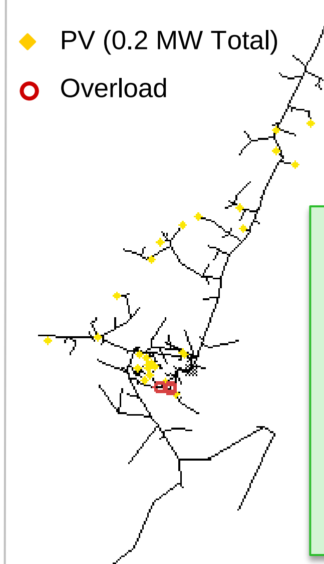


7.7 MW deployed in an unguided fashion across all feeders.

3 fewer overloaded elements than the base case (6 total).

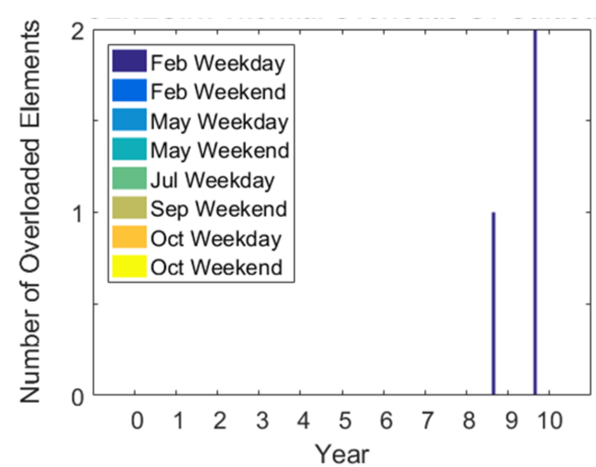
However, summer overloads that were eliminated by the guided deployment of PV in Scenario 1, are not entirely mitigated with this unguided deployment

Rural



0.2 MW (same capacity as Scenario 1) of PV is randomly deployed across all feeders

Resulting overloads are the same as the base case. Unguided PV produces no benefit



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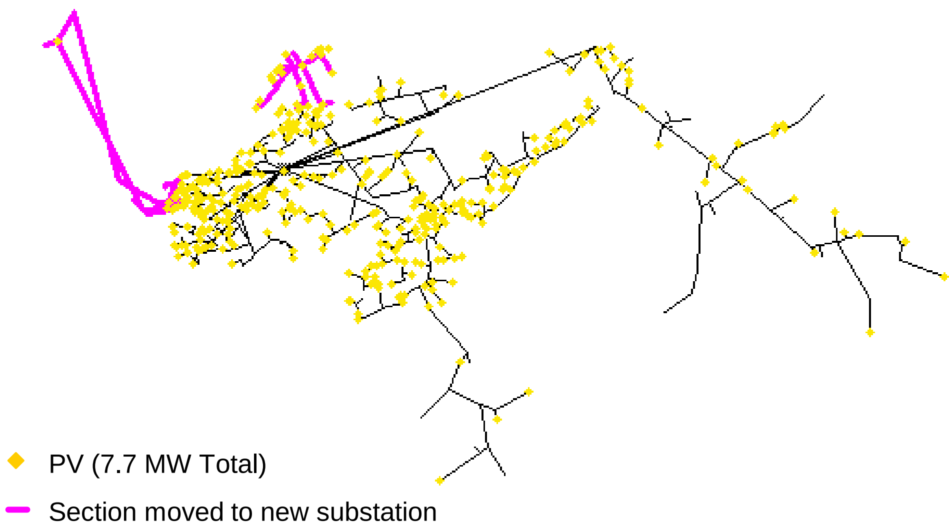
Scenario 2 (Unguided) Violations with Reinforcements

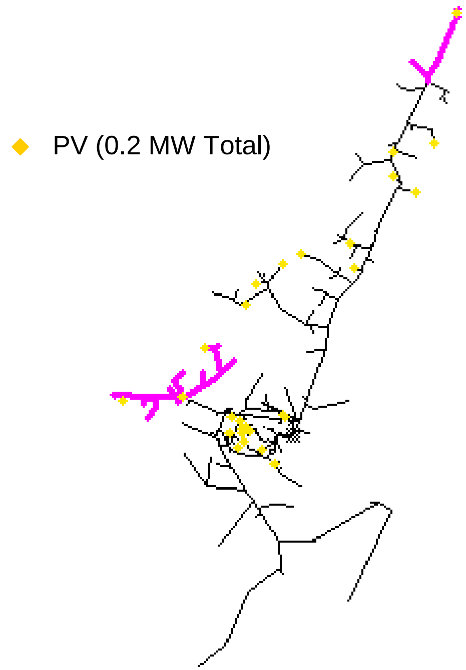
Urban



Reconfiguration and the same reconductoring, 1.6 km in Year 4, as the base case is needed to eliminate all overloads.

The same happens if only summer overloads are considered, reconfiguration in Year 4 and 0.36 km of reconductoring in Year 9 is needed, despite the addition of unguided PV

Rural



As in Scenario 1, reconfiguration is the only reinforcement needed to eliminate remaining overloads

Scenario Comparison

Urban

	Scenario	Total number of overloaded elements in Year 10 before reconfiguration	Reconfiguration needed	Total number of overloaded elements in Year 10 after reconfiguration	Reconductoring needed	Cost of Reconductoring
All Months	Base case	9	Y	5	1.6 km Year 4	€162,000
	Scenario 1	6	Y	5	1.6 km Year 4	€162,000
	Scenario 2	6	Y	5	1.6 km Year 4	€162,000
Summer Months Only	Base case	4	Y	1	0.36 km in Year 9	€26,000
	Scenario 1	0	N	0	N	€0
	Scenario 2	1	N	1	0.36 km in Year 9	€26,000

Rural

	Scenario	Total number of overloaded elements in Year 10 before reconfiguration	Reconfiguration needed	Reconductoring needed
All Months	Base case	2	Y	N
	Scenario 1	2	Y	N
	Scenario 2	2	Y	N
Summer Months Only	Base case	1	Y	N
	Scenario 1	0	N	N
	Scenario 2	1	Y	N

Cost Comparison – Urban Substation

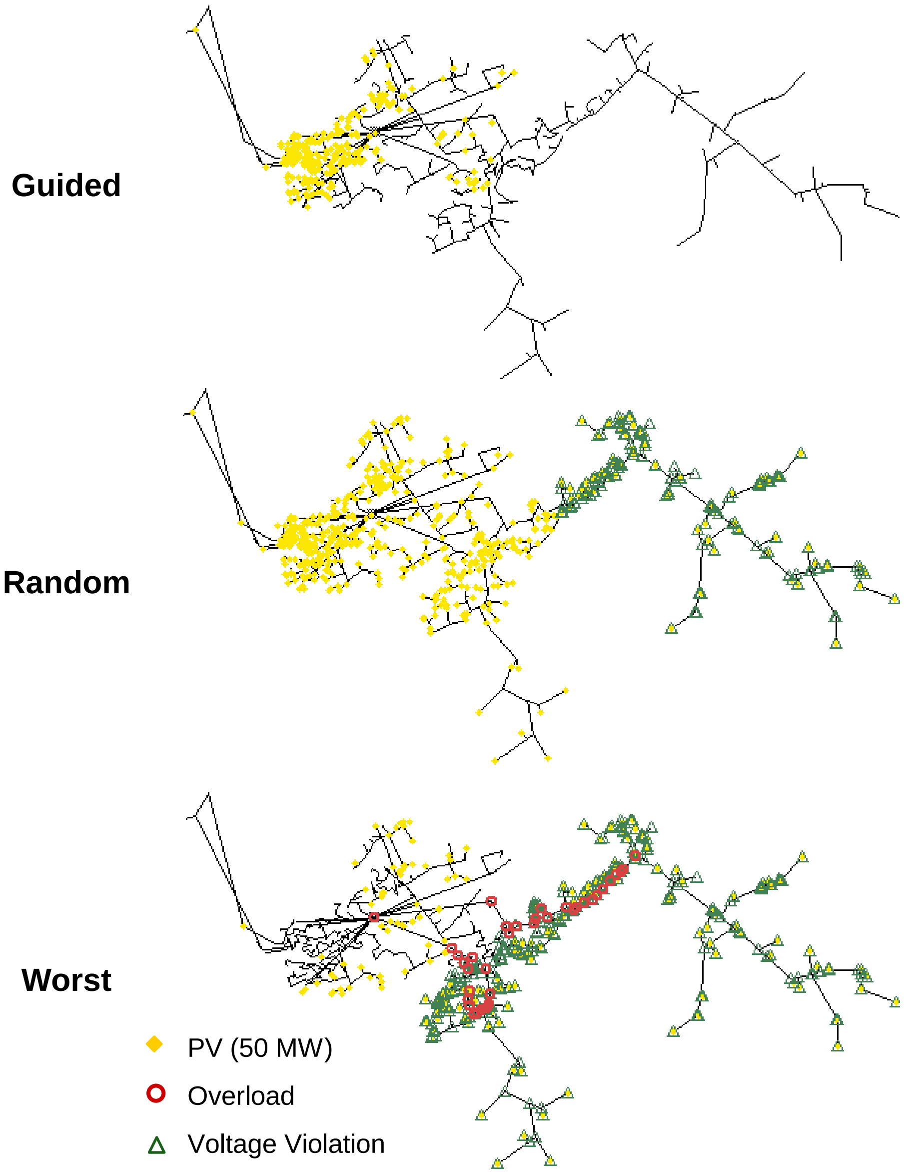
- PV alone cannot eliminate all the overloads that on the urban station, because PV is not very effective against winter peaks
  - Without any PV, 1.6 km of reconductoring is required to eliminate all overloads
  - Even if PV is added up to the 7.7 MW limit, 1.6 km of reconductoring is still required
  - The PV is ineffective for deferring any distribution cost.
- Just considering summer overloads
  - With no PV, 0.36 km of reconductoring eliminates summer overloads, costing €26,000
  - With 1.9 MW of guided PV, costing €3.8 million, no reconductoring would be required
  - Not a cost effective alternative

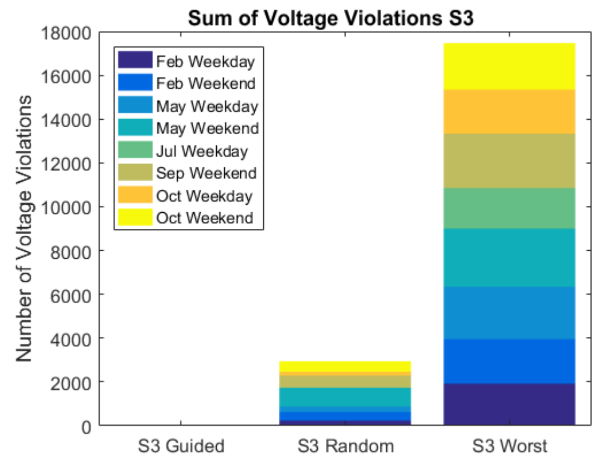
Objective	With PV	Without PV
Eliminate all overloads, all months	1.6 km reconductoring required @ €162,000 (despite PV at 7.7 MW limit)	1.6 km reconductoring required @ €162,000
Eliminate overloads only in summer	1.9 MW of PV @ up to €1.9 million (1 €/W)	0.36 km reconductoring required @ €26,000

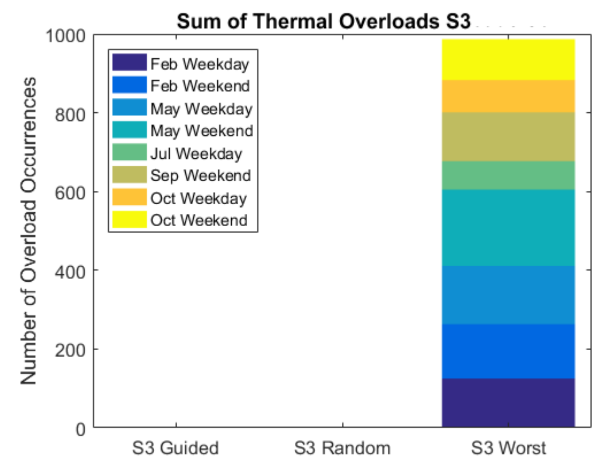
Scenario 3 High PV Penetration Analysis Overview

- Year 0 analysis only
  - Load growth is not considered, no reinforcements from prior analysis have been applied
- High PV penetration
  - 40% of customers adopting PV with a zero net energy goal
- 3 deployments
  - <u>Guided</u>: PV located at nodes with highest hosting capacity first, up to a maximum of each node's peak load times the load to PV ratio, or hosting capacity for that node, whichever is lower
  - <u>Random</u>: PV located at random nodes across the feeder up to a maximum of each node's peak load times the load to PV ratio
  - <u>Worst</u>: PV located at nodes with lowest hosting capacity first, up to a maximum of each node's peak load times the load to PV ratio

Urban Substation Scenario 3 – 50 MW of PV







Tap change is all that is needed to mitigate random voltage violations. For the worst case deployment, a tap change, reconfiguration and 0.07 km of reconductoring is needed, costing €29,000

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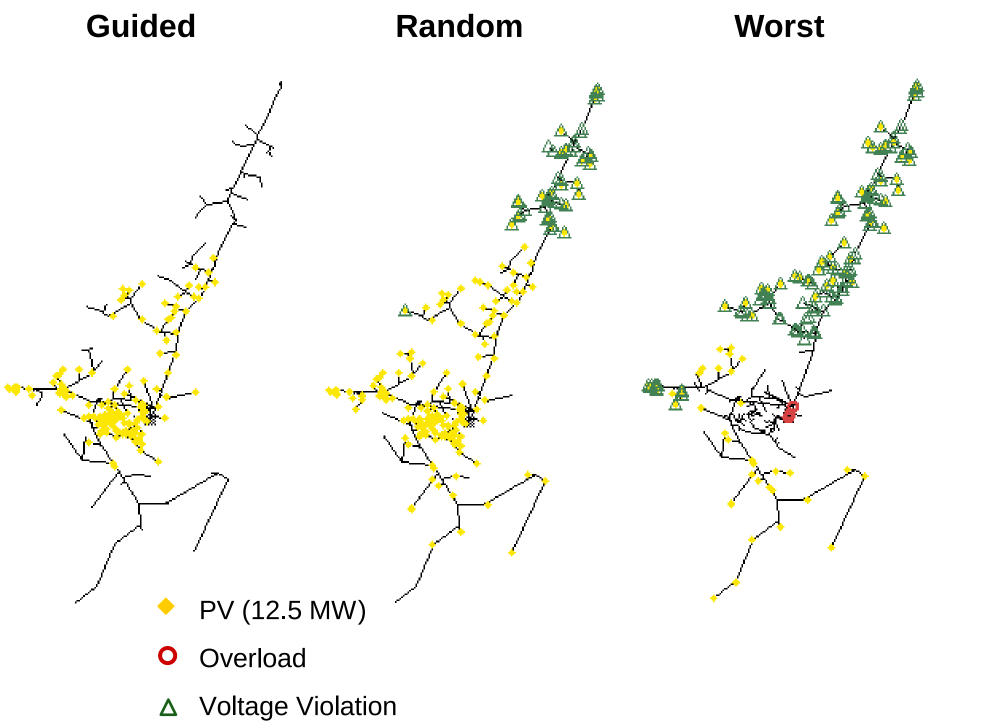
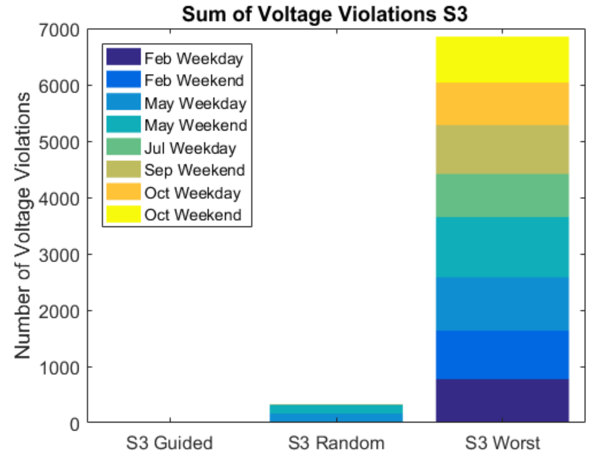
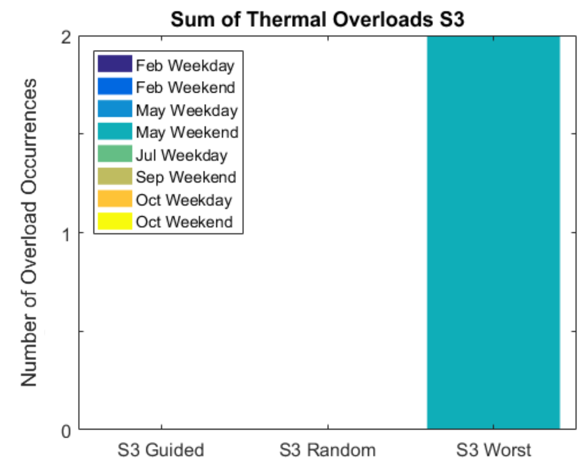
Rural Substation Scenario 3 – 12.5 MW of PV







Substation tap change solves voltage violations in the random deployment

Reconfiguration and substation tap change solves the voltage violations and the overloads in the worst case deployment

Scenario 3 Comparison

Urban

Scenario	Total number of overloaded elements	Total number of voltage violations	Tap Change Needed	Reconfiguration needed	Reconductoring needed	Cost of Reconductoring
Guided	0	0	N	N	N	€0
Random	0	2942	Y	N	N	€0
Worst	34	17469	Y	Y	0.07 km	€29,000

Rural

Scenario	Total number of overloaded elements	Total number of voltage violations	Tap Change Needed	Reconfiguration needed	Reconductoring needed
Guided	0	0	N	N	N
Random	0	321	Y	N	N
Worst	2	6854	Y	Y	N

Conclusions and Key Findings

- PV gives very little help in winter, and the region's winter peak is as large as its summer peak. Therefore, PV is a poor alternative to grid reinforcements.
- If the most probable PV output is assumed, overloads that occur during summer can be mitigated with guided PV. However, economic results show that PV is not a cost effective alternative to conventional grid reinforcement solutions.
- High penetration level of PV can be accommodated with minimal reinforcements (tap change) in a guided and random fashion, however a worst case unguided deployment could result in reinforcements being required.
- As observed during previous EPRI studies, PV alone might not be sufficient to meet system and customer needs and defer traditional assets cost-effectively. It may take a portfolio of DER, depending on customer characteristics and grid needs.

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