CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

INTERNATIONAL SOLAR ALLIANCE

CARBON TRUST

International Solar Alliance Expert Training Course

CITCEA UPC

Planning - Distribution network with PV generators

In partnership with the Clean Energy Solutions Center (CESC)

Professor Oriol Gomis-Bellmunt

September 2019

Supporters of this Expert Training Series

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Expert Trainer: Prof Oriol Gomis-Bellmunt

- Professor in the Electrical Power Department of Technical University of Catalonia (UPC)
- Directive board member of the research group CITCEA-UPC, where he leads the group of power systems dominated by power electronics, including renewable energy (PV and wind), HVDC transmission systems and other power converter based systems (energy storage, EV chargers)
- 20+ years of experience in the fields of renewable energy, power electronics and power systems. Involved in a number of research projects and contracts of technology transfer to industry.
- Coauthor of 3 books, 7 patents and > 100 journal publications, mainly in the field of power electronics in power systems and grid integration of renewables.
- Supervision of 18 doctoral theses and >60 Bachelor and Master theses.

Overview of Training Course Modules

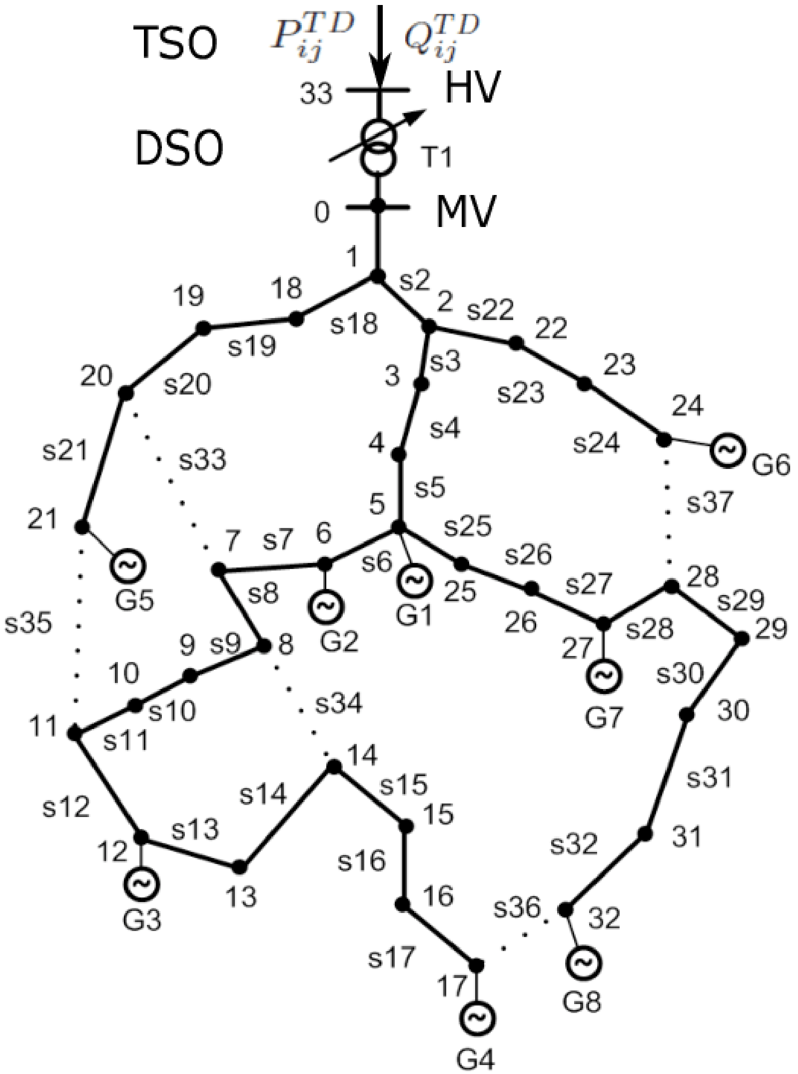
This Training is part of Module 4, and focuses on the issue of planning of distribution systems with PV.

Outline

- PV plants as distributed energy sources in the distribution network
- Distribution network planning
- Impact on line loading and system voltages.
- Integration with storage and flexible loads.
- Example studies

Electrical power distribution systems

- Connected to the transmission system
- Bidirectional power flow is possible
- Medium and low voltage levels
- Typically meshed design
- Typically radial operation



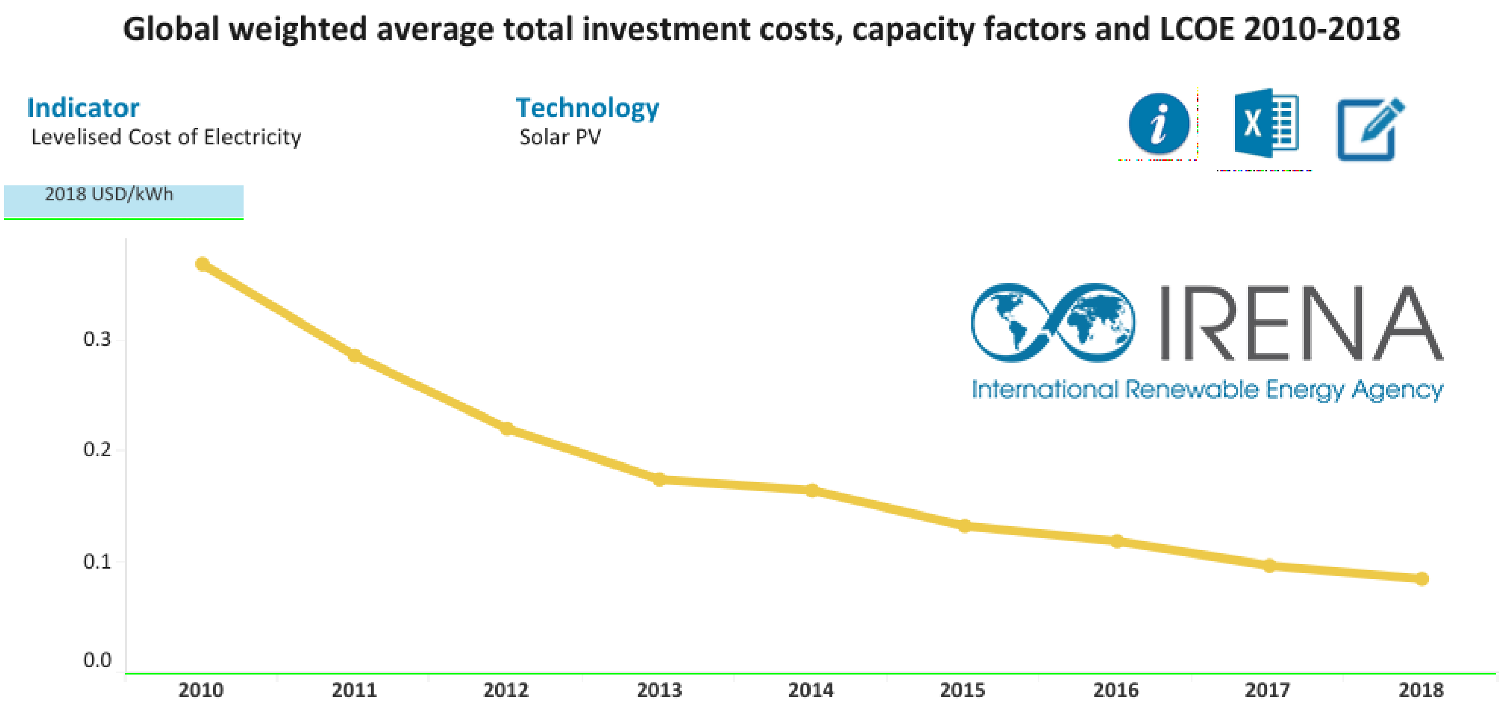
F Capitanescu, TSO-DSO Interaction: Active Distribution Network Power Chart for TSO Ancillary Services Provision, Electric Power Systems Research

PV plants as distributed energy sources in the distribution network

- PV power plants can be installed in the distribution network as distributed energy sources
- Distributed generation (DG) is based on small or medium scale units to generate electricity close to the loads.
- DG project definition and execution times are lower compared to large power plants.
- DG is normally modular and renewable (but not always)

PV plants as distributed energy sources in the distribution network

- The trend in PV (and DG in general) costs is reducing, clearly more than costs in transmission and distribution.

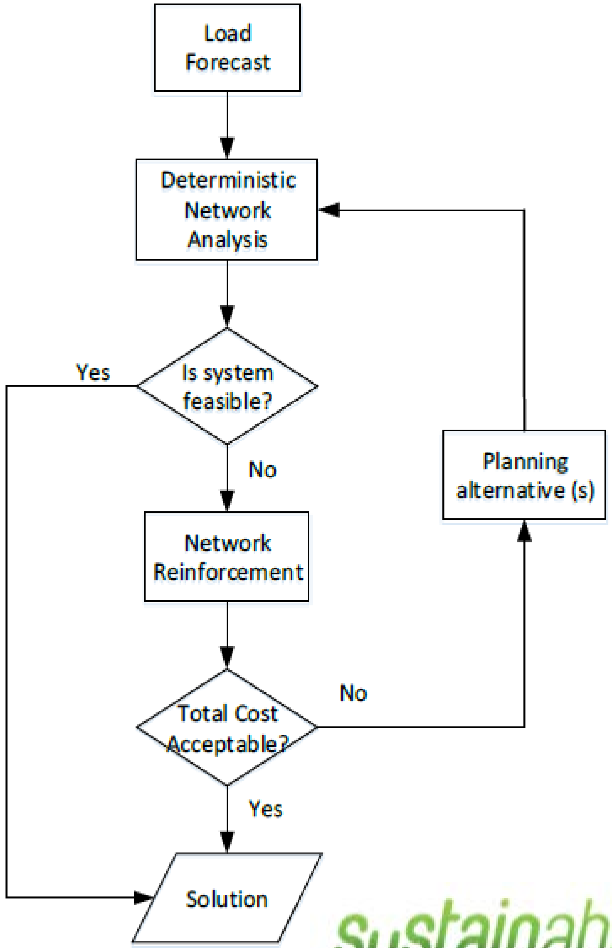


PV plants as distributed energy sources: Possible benefits

- DG technologies offer important potential benefits:
  - DG **can** provide lower-cost electricity
    - Direct cost of energy generation
    - Lower cost associated to reduced transmission and distribution losses
  - DG **can** increase reliability and security
  - DG **can** reduce environmental impact
  - DG **can** postpone/eliminate investments in transmission and distribution
  - DG **can** postpone/eliminate investments in conventional plants
  - DG **can** increase power quality and grid support enhancement / (Distributed) voltage control
  - DG **can** enhance resiliency (distributed nature)

Distribution network planning

- Process repeated for each year of a long-term planning horizon (e.g. 15–20 years):
  - Load forecasting determines the load conditions for the corresponding year.
  - Steady state power flow and short circuit analysis are performed to calculate the power flow in the distribution lines, the voltage variations and the short circuit current flows.
  - If the distribution network does not meet the power system's technical and operational constraints (i.e., the system is not feasible), the distribution network has to be reinforced.



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http://www.sustainableproject.eu

Distribution network planning

- The acceptability criteria of the solution, representing the DSO's policies and the obligations to the consumers, are:
  - Service continuity
  - The maximum allowable peak-load voltage drop to the most remote customer
  - The maximum allowable peak load
  - Service reliability
  - Power losses
- Consideration of additional system elements:
  - Distributed Storage Devices (DSD)
  - Flexible Loads (FL)
  - Electrical Vehicles (EV)

Power system flexibility

- According to EPRI, **Power system flexibility** is the ability to adapt to dynamic and changing conditions, for example, balancing supply and demand by the hour or minute, or deploying new generation and transmission resources over a period of years.

Distribution network planning

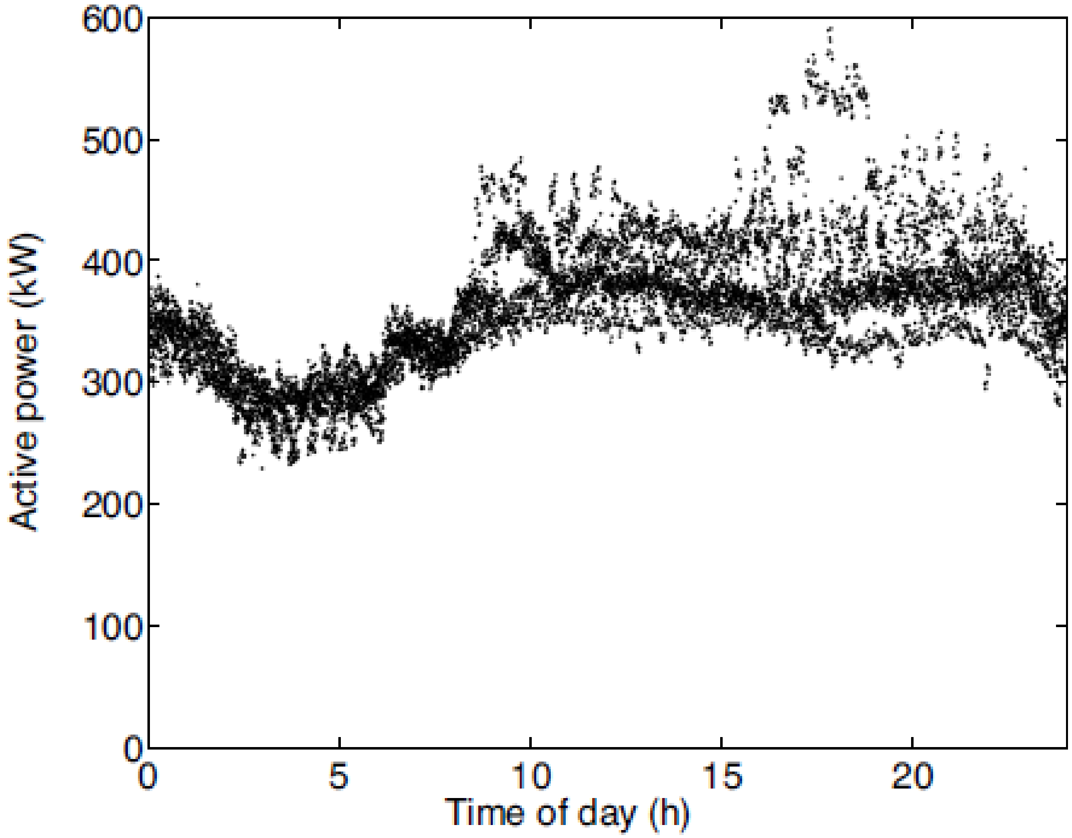
- Optimized system planning can be achieved considering additional units providing flexibility.
- Multiple different optimization methodologies can be used to optimize the planning.
- The optimization methodology is chosen depending on the constraints and objective function defined.

Distributed PV to reduce distribution loading

- The use of PV generation can reduce line overloads in many cases, but not always (it depends on the system power flows)
- Studies need to identify the relevant cases (including the worst) to understand how PV plants can impact the system.
- The main quantity impacting the grid is the difference between load and generation. The ideal case is when PV generation equals the load.

Distributed PV to reduce distribution loading – Example

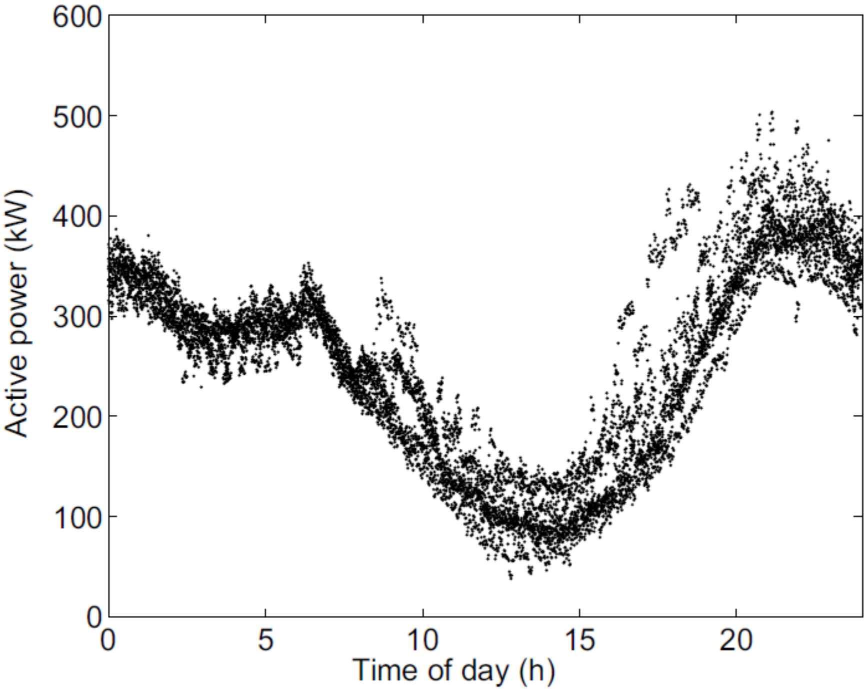
Load in a distribution line connecting a large hotel without PV generation

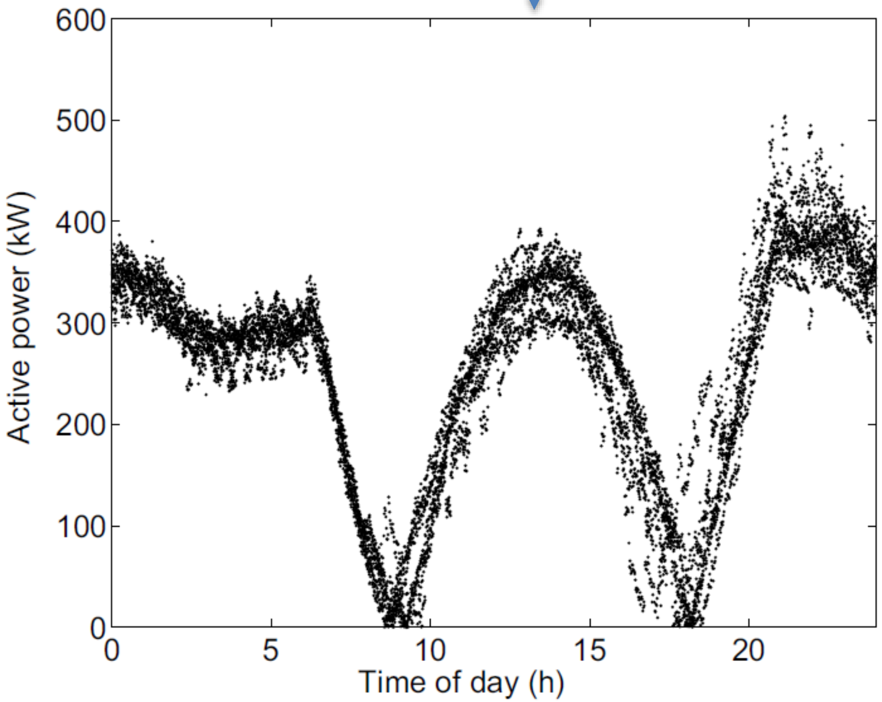


Bollen and Hassan, *Integration of Distributed Generation in the Power system*

Distributed PV to reduce distribution loading – Example

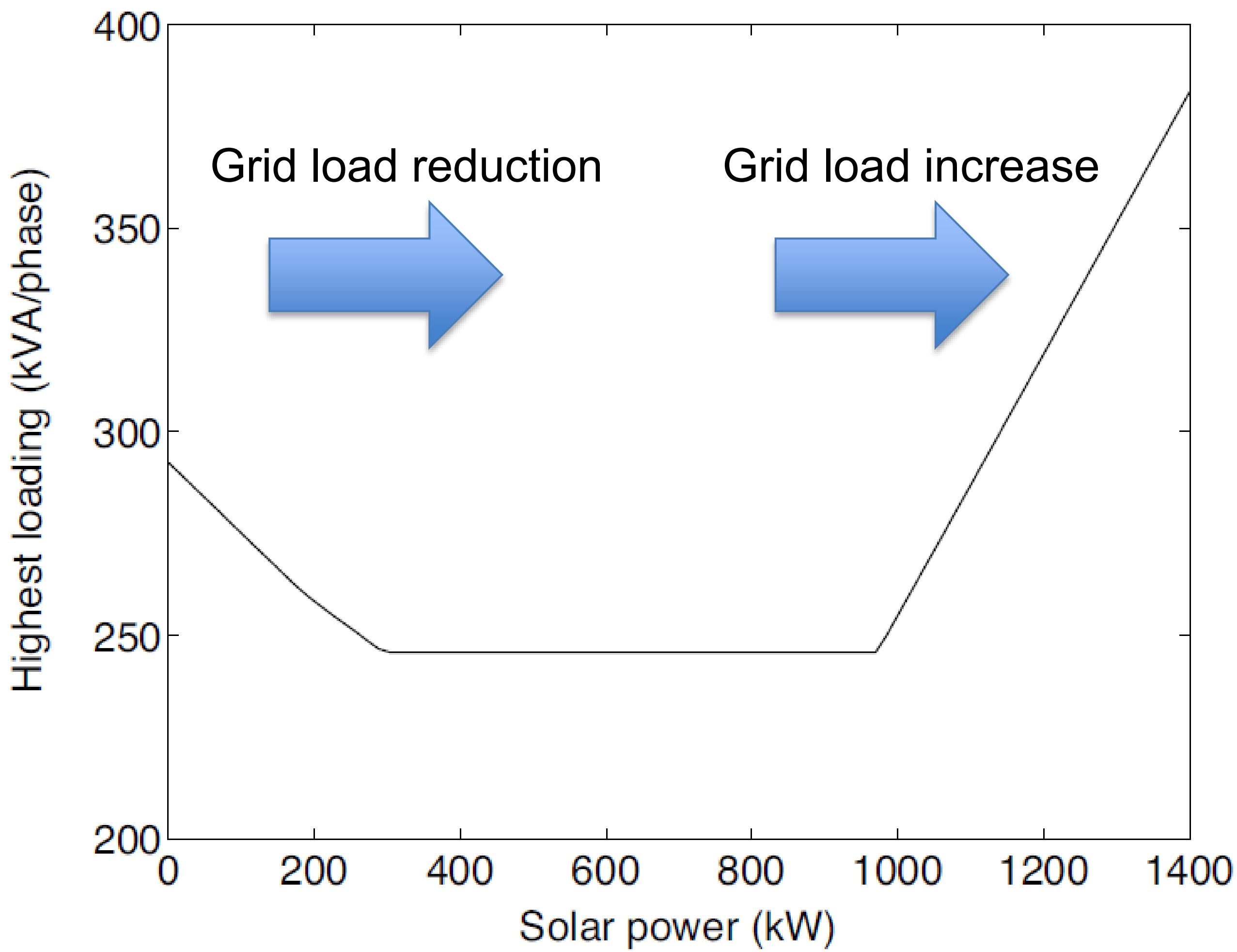
Load in a distribution line connecting a large hotel with 300 and 750 kW-peak PV generation





Bollen and Hassan, *Integration of Distributed Generation in the Power system*

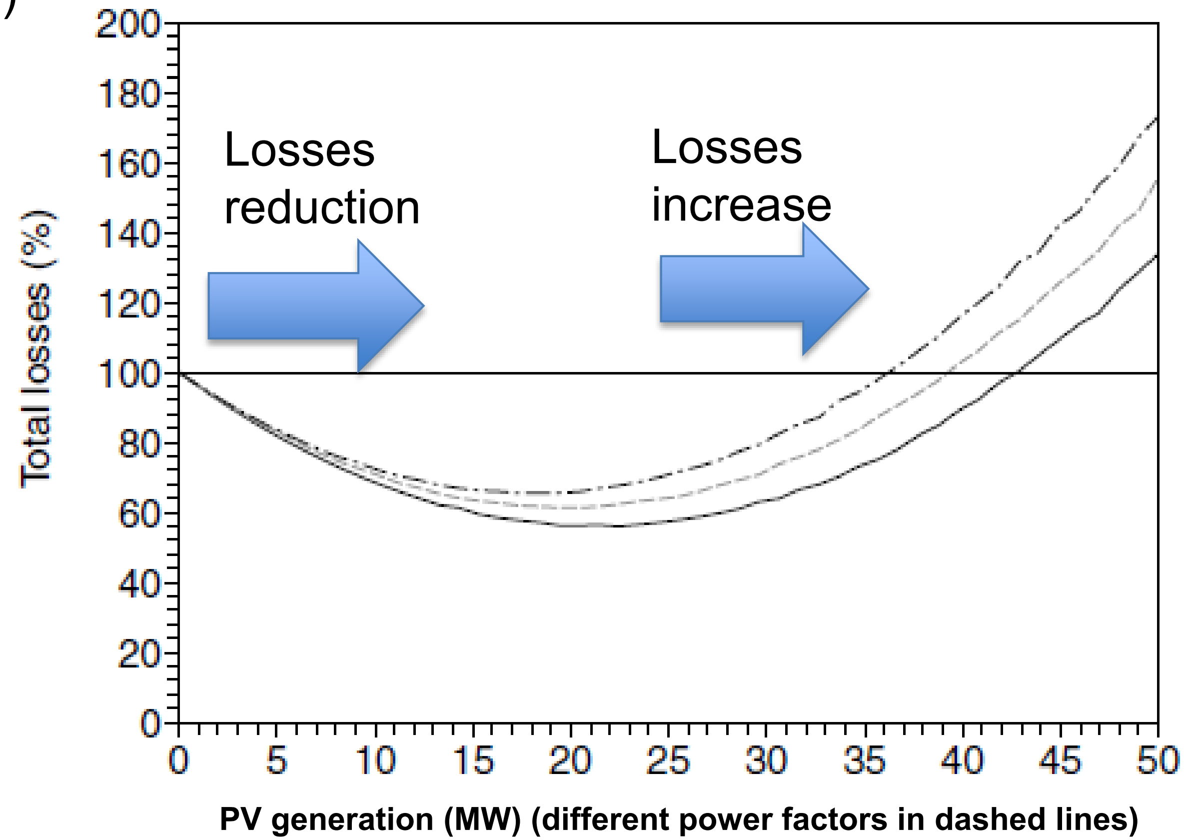
Distributed PV to reduce distribution loading – Example



Bollen and Hassan, *Integration of Distributed Generation in the Power system*

Distributed PV – system losses

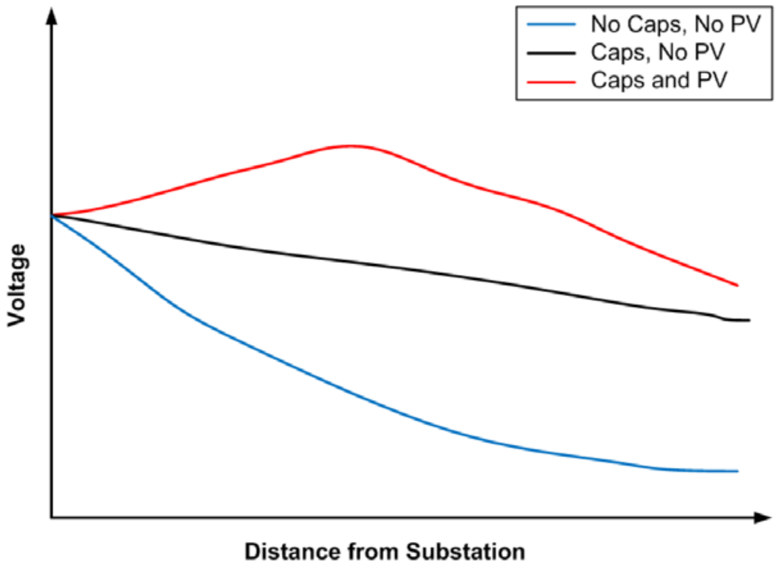
Distribution losses with different levels of PV generation (and different power factors)



Bollen and Hassan, *Integration of Distributed Generation in the Power system*

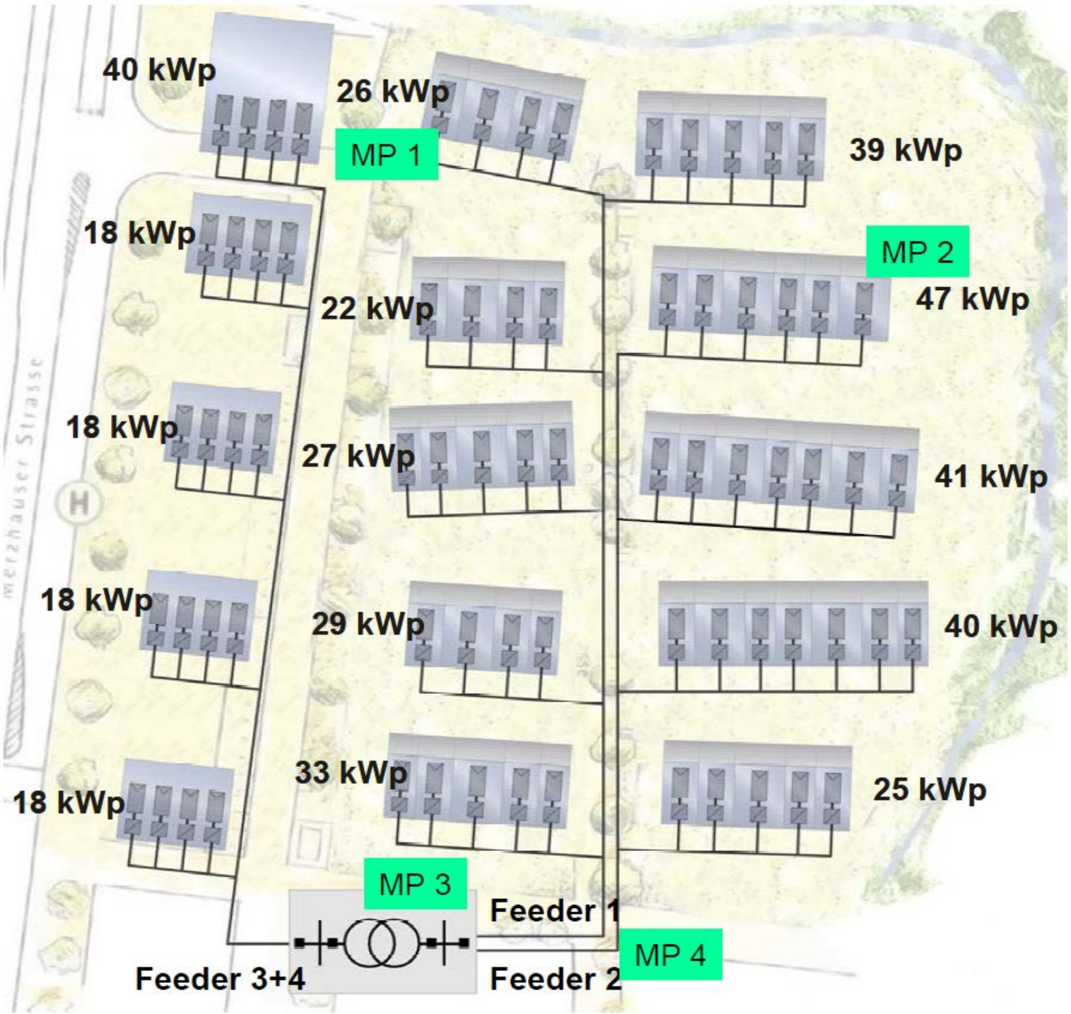
Voltages in distribution network with PV

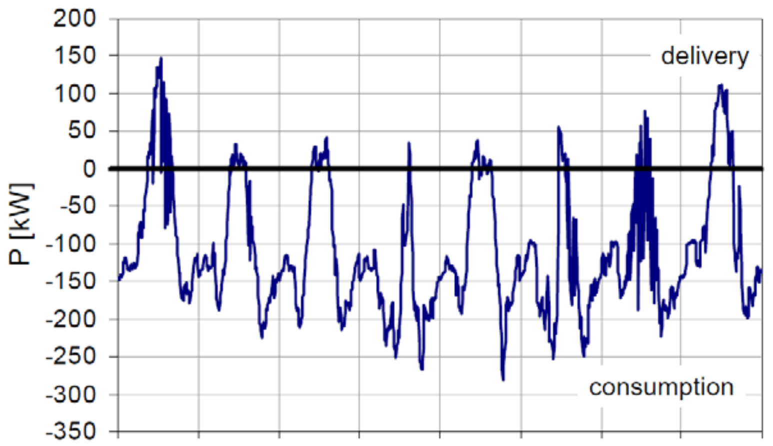
- PV impacts voltages (active and reactive power flows change with the presence of PV generation
- It needs to be coordinated with distribution network equipment for voltage control:
  - Capacitors
  - Transformers
  - Elements with reactive power control capability



High-Penetration PV Integration Handbook for Distribution Engineers , NREL 2016

Voltages in distribution network with PV

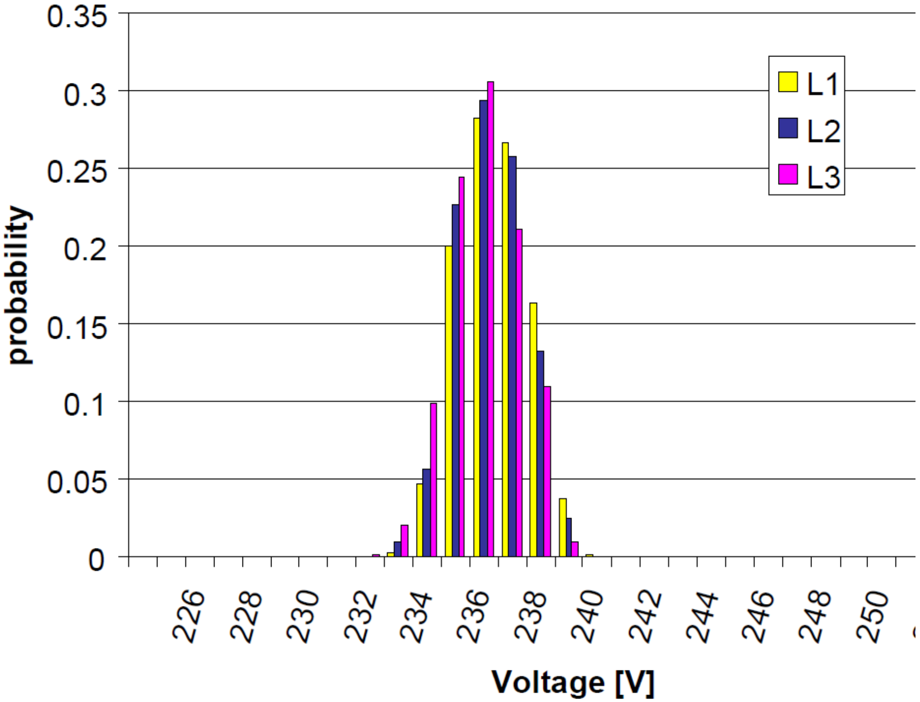




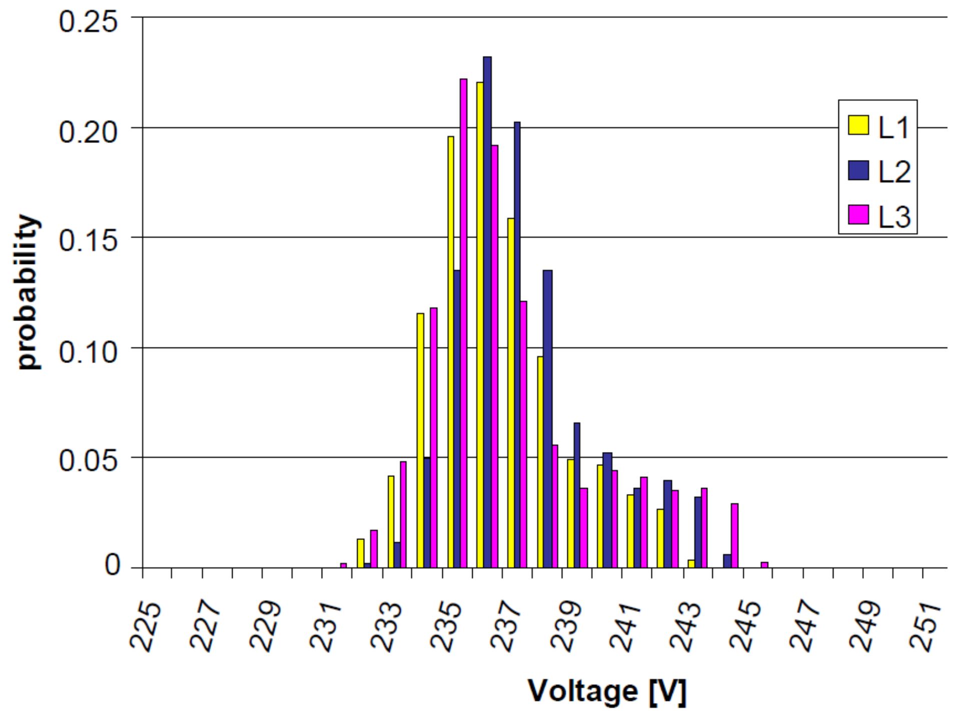
PV in Urban Policies- Strategic and Comprehensive Approach for Long-term Expansion EIE/05/171/SI2.420208

Voltages in distribution network with PV

Transformer secondary side



End of line, MP1



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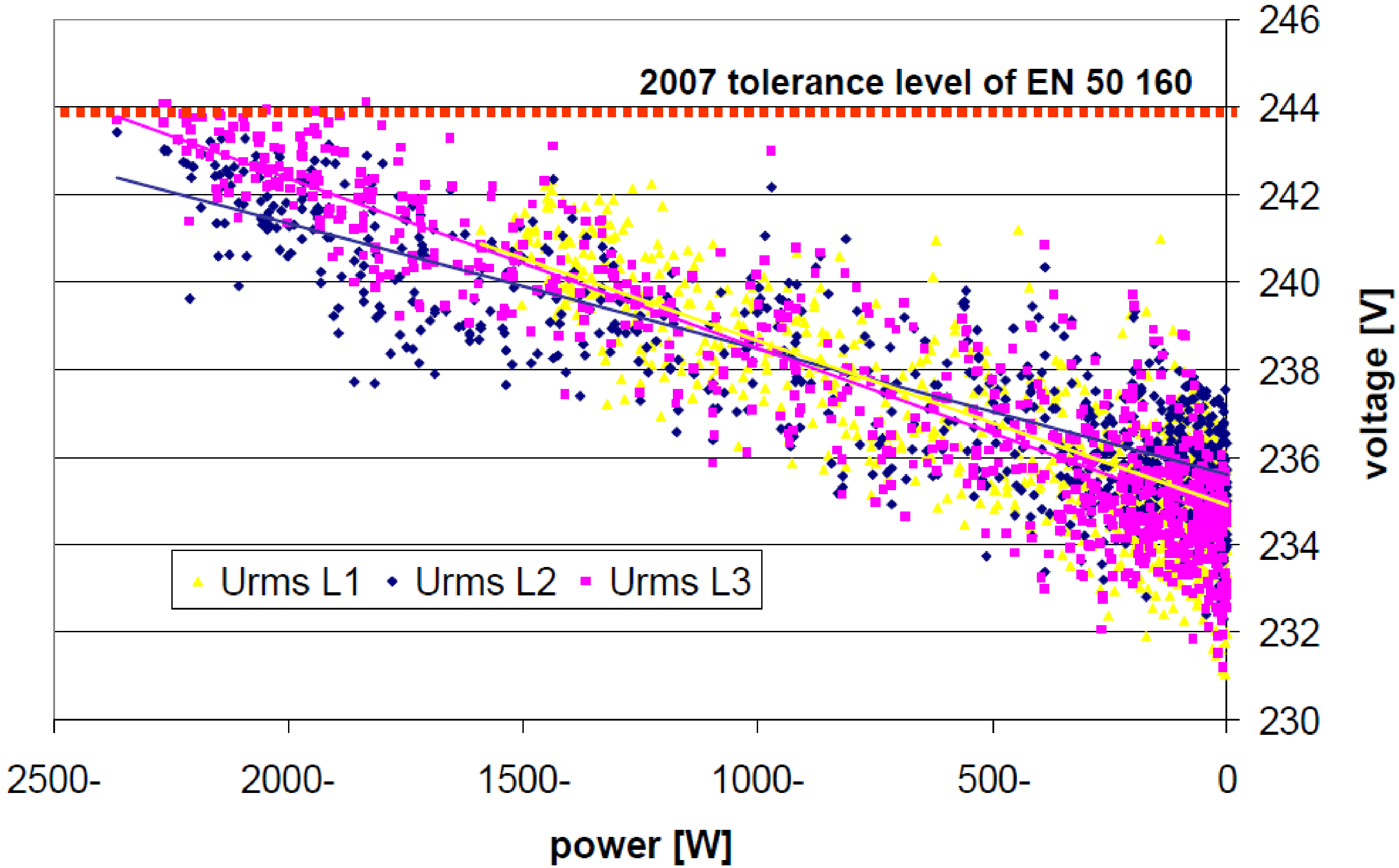
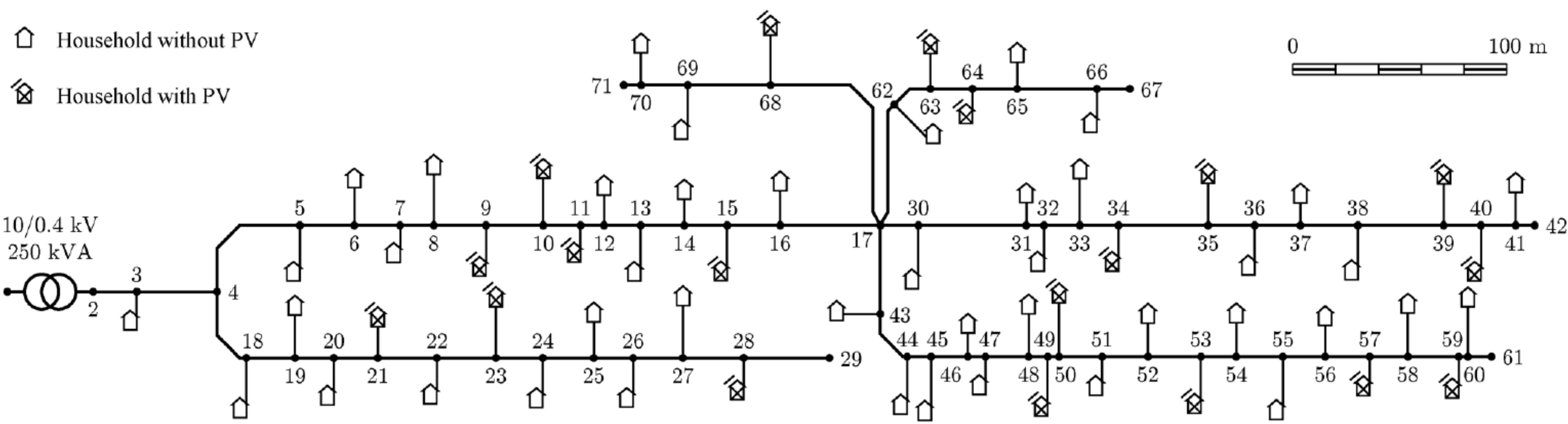
Voltages in distribution network with PV



PV in Urban Policies- Strategic and Comprehensive Approach for Long-term Expansion EIE/05/171/SI2.420208

Using energy storage combined with distributed PV

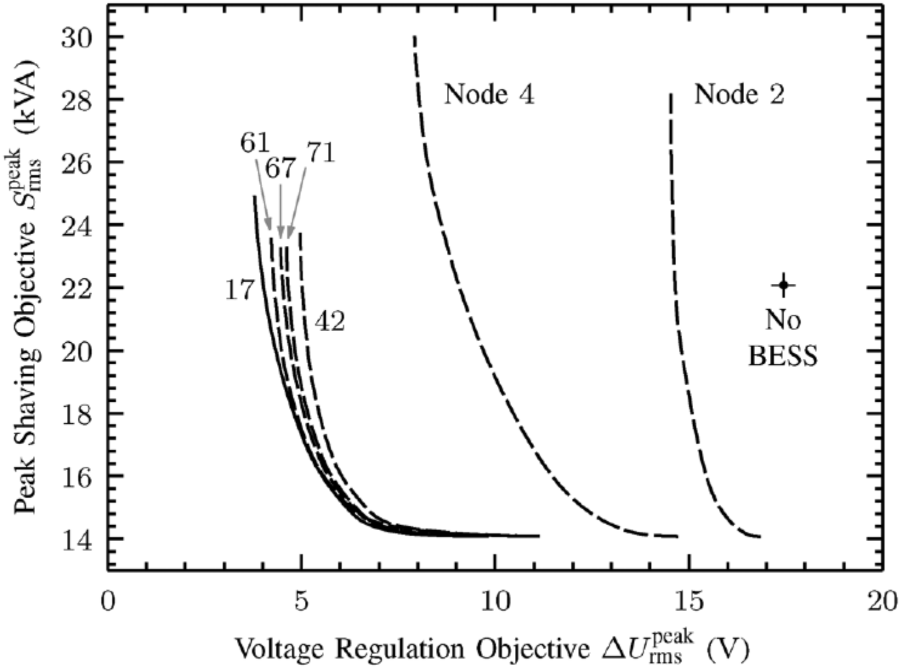
- Energy storage can be useful to reduce overloads in the distribution network, while providing support to the voltage control in the distribution system.
- Additionally, the inverter can help with reactive power support.
- This can be analyzed as an optimization problem addressing multiple objectives: peak shaving and voltage control.
- The optimization can help to select the technology, locate and size the energy storage system and inverter.

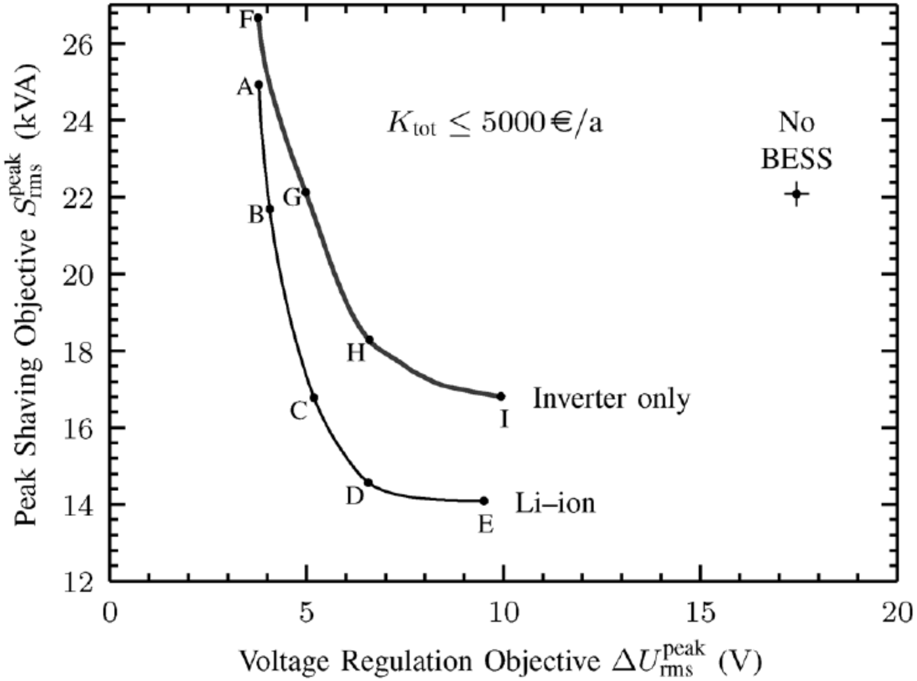


Tant et al. "Multiobjective Battery Storage to Improve PV Integration in Residential Distribution Grids" IEEE Trans Sustainable Energy

Using energy storage combined with distributed PV

- Pareto fronts show the trade off between peak shaving (maximum grid apparent power) and voltage regulation (voltage deviations of the nodes):
  - Optimal location of the energy storage system (fixed cost and technology)
  - Comparison between nothing, inverter only and inverter with Li-ion battery (fixed cost and location)

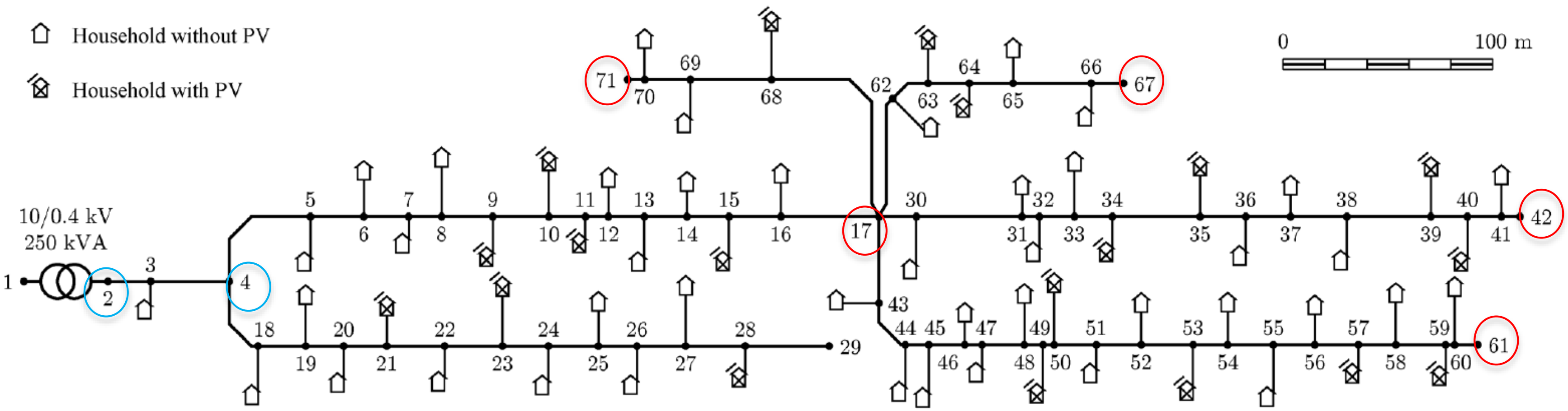




Tant et al. "Multiobjective Battery Storage to Improve PV Integration in Residential Distribution Grids" IEEE Trans Sustainable Energy

Using energy storage combined with distributed PV

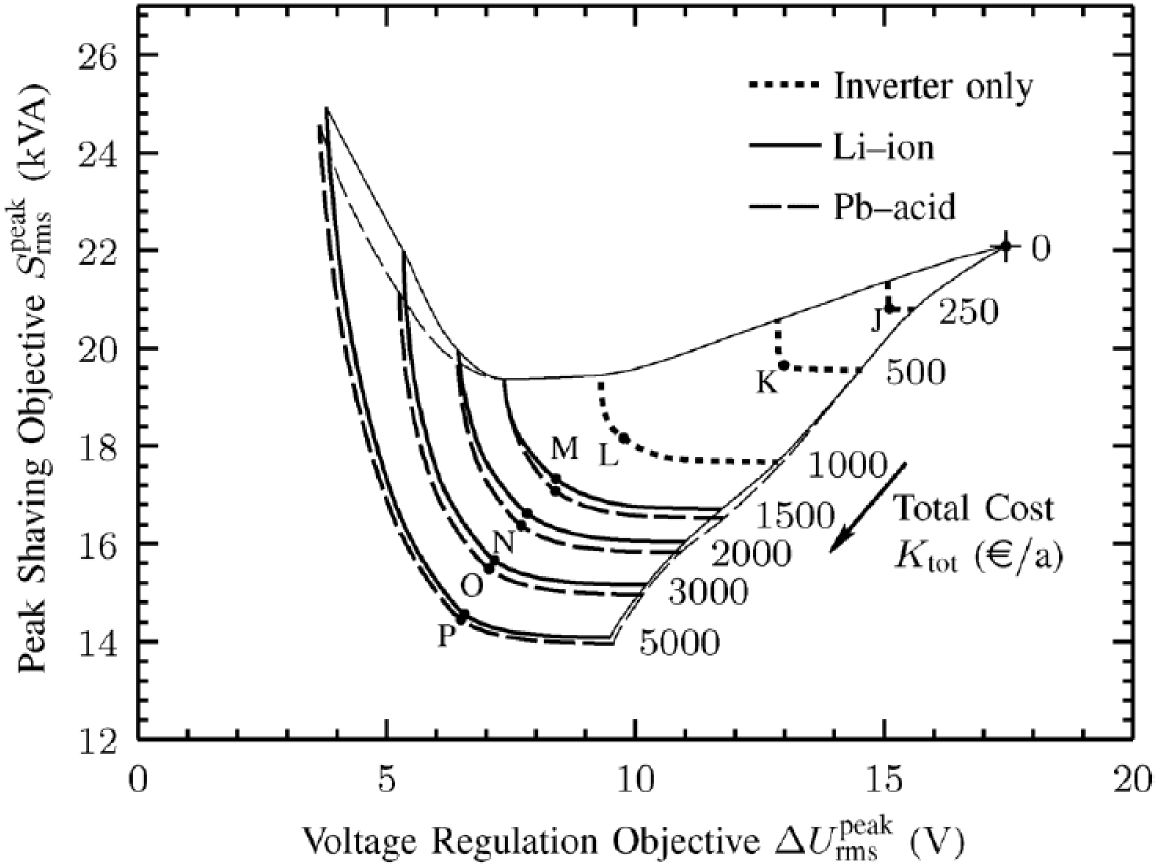
- Candidate nodes are 17, 61, 67, 71, 42, much better than nodes 2 or 4.



Tant et al. "Multiobjective Battery Storage to Improve PV Integration in Residential Distribution Grids" IEEE Trans Sustainable Energy

Using energy storage combined with distributed PV

- Pareto fronts show the trade off between peak shaving and voltage regulation for different costs per year. (fixed location)



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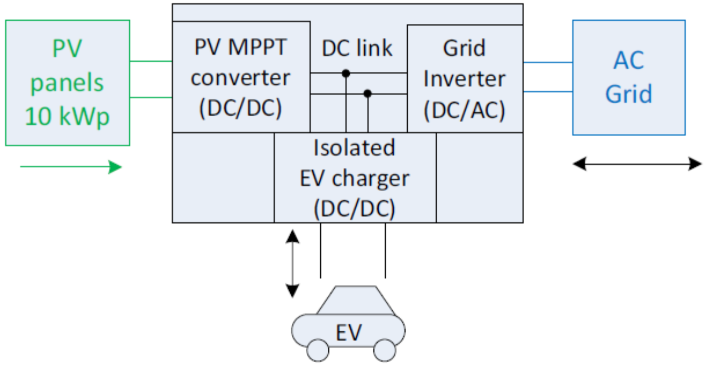
Solar and electrical vehicles



Energy delivered and occurrence of different PV output power.

	PV power output (kW)			
	>2 kW	>5 kW	>7 kW	>9 kW
% Daylight time	41.3	16.5	7.7	0.95
% Annual energy	82.7	48.8	26	3.8

Reduction in annual PV yield due to oversizing of PV array compared to PV converter.

	Inverter size for 10 kW PV array			
	2 kW	5 kW	7 kW	9 kW
% Energy lost in year	47.5	13.84	3.2	0.16

G.R. Chandra Mouli et al, System design for a solar powered electric vehicle charging station for workplaces, Applied Energy 168 (2016) – TU Delft

Solar and electrical vehicles

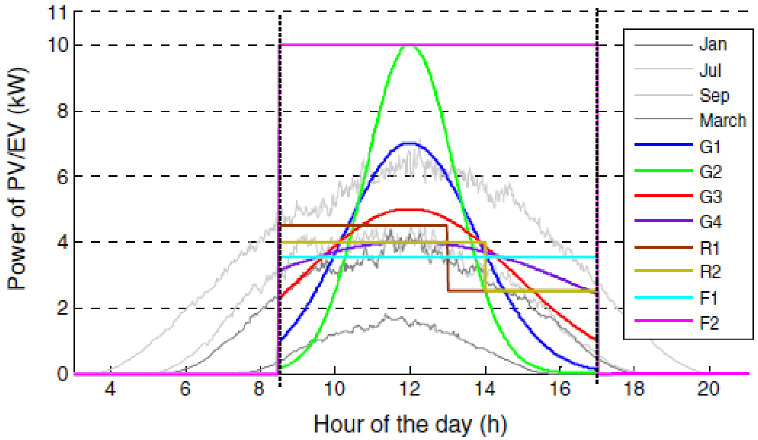


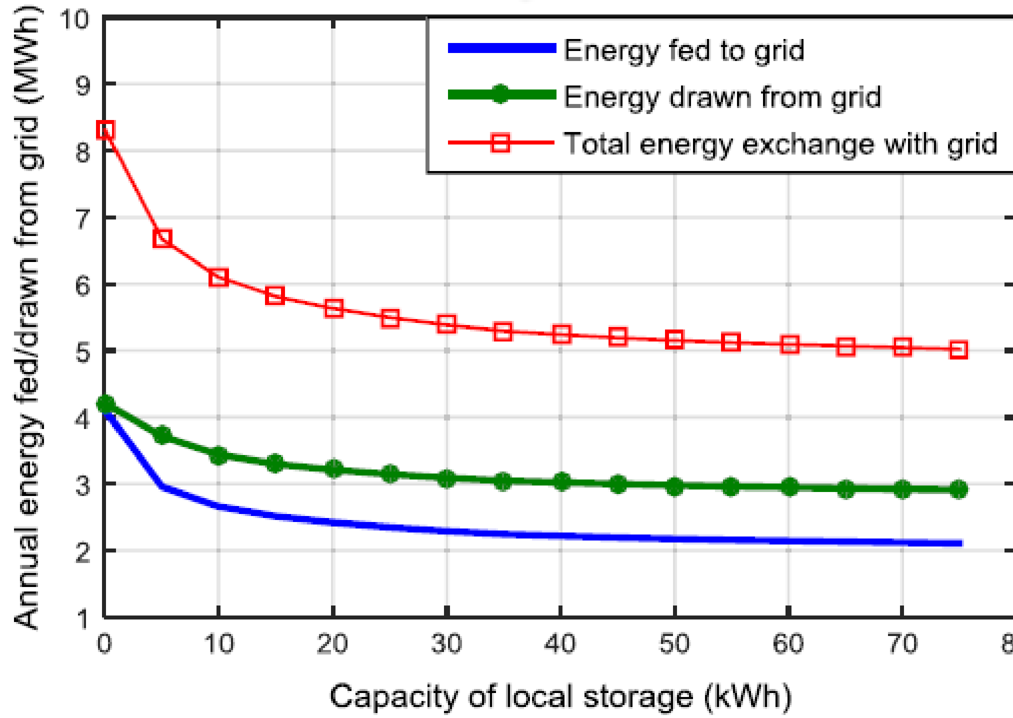
Fig. 11. Various EV charging profiles compared with the average daily PV array output for different months of 2013.

Charging strategy?

Storage?

Energy exchanged with grid for 7 days/week EV load.

EV charging profile	Annual energy exchange with grid (kW h)			Rank
	Fed to grid $\lvert E_{fed}^{grid} \rvert$	Draw from grid E_{draw}^{grid}	Total E_{ex}^{grid}	
G1	5248	5350	10,598	7
G2	4455	4544	8999	6
G3	4113	4213	8326	1
G4	4119	4214	8333	2
R1	4297	4402	8699	5
R2	4180	4282	8462	3
F1	4198	4295	8493	4
F2	1336	21,546	22,882	8



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Summary

- PV power plants can be installed in the distribution network as distributed energy sources.
- PV plants can contribute to reduce or increase the loading of the lines.
- PV plants have an impact on the overall system voltage, which needs to be studied.
- Energy storage system or flexible loads can be integrated with PV systems.
- Some examples have shown practical cases:
  - Example 1 has shown how distributed PV can reduce (or increase if not well sized) distribution loading
  - Example 2 has shown how PV can contribute to control the voltage in a distribution network
  - Example 3 has shown how using energy storage combined with distributed PV can provide improved results both on voltage regulation and peak shaving
  - Example 4 has shown how PV can be hybridized with electrical vehicles

Thanks for your attention!