Flexibility in distribution systems

EPFL

sweet swiss energy research for the energy transition

PATHFNDR

ETH zürich · Empa · PAUL SCHERRER INSTITUT PSI · zhaw · HOCHSCHULE LUZERN · UNIVERSITÉ DE GENÈVE · EPFL · TU Delft

Agenda

1. Context
2. Flexibility needs
3. Flexibility provision from distribution systems
4. Current Examples and Outlook
5. Conclusion

Definitions

- Flexibility in (distribution-level) power systems
  - *“In PATHFNDR, flexibility is defined as the ability of the energy system to manage (expected or unexpected) variability in the electricity supply and demand at different time scales, from the very short to the long term, by adjusting the energy supply, conversion, demand, storage or imports / exports from / to neighboring systems[2]”*
  - *“Flexibility is the ability of power systems to cope with variability and uncertainty at all times[1]”*

→ We distinguish three timescales

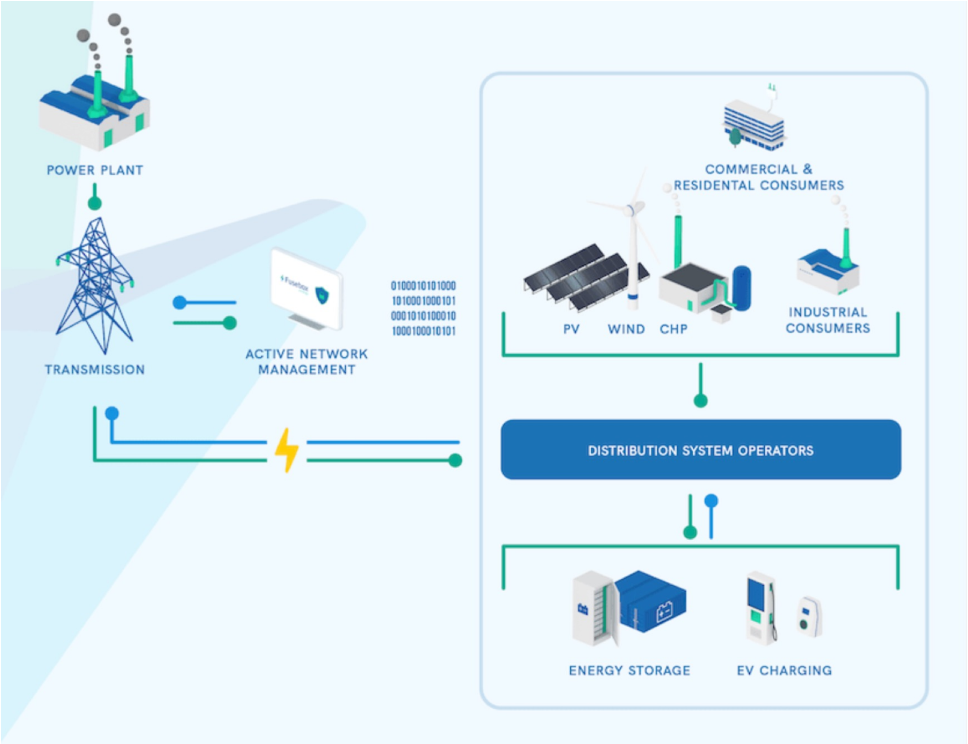
- Instantaneous
- Intraday-Intraweek
- Seasonal → Not considered here

- Distributed energy resources (DERs)

“small-scale energy resources usually situated near sites of electricity use, such as rooftop solar panels and battery storage[3]”

- Active Distribution Networks (ADNs)

“Active distribution networks is a recently developed concept that considers the move toward the management of active distribution systems, where the DSO integrates distributed generation, demand response and energy storage into the operation of the system.[4]”



Modern Power System, Adapted from [5]

1. POWER SYSTEM FLEXIBILITY – A KEY ENABLER FOR THE ENERGY TRANSITION, Hitachi Energy, 28-11-2023, https://www.hitachienergy.com/news-and-events/perspectives/2023/11/power-system-flexibility-a-key-enabler-for-the-energy-transition
2. Ruefenacht, L.A., Marcucci, A., Leenders, L. (eds.), Bardow, A., Fiorentini, M., Heer, P., Kaemper, A., Koirala, B., Knoeri, C., Marinakis, A., Markard, J., Mayer, P., Oswald, K., Peter, C., Pfenninger, S., Sansavini, G., Schaffner, C., Schlecht, I., Schuetz, P., Schwarz, M., Villasmil, W. (2023). Flexibility and sector coupling in energy systems: definitions and metrics. SWEET PATHFNDR consortium
3. Unlocking the Potential of Distributed Energy Resources, International Energy Agency, May 2022
4. Development and Operation of Active Distribution Networks, CIGRE, Technical Brochures 457, 2011
5. Virtual Power Plants: What are they and why are they important?, Fusebox Energy, https://fusebox.energy/virtual-power-plants-what-are-they-and-why-are-they-important/, Accessed 22.11.2024

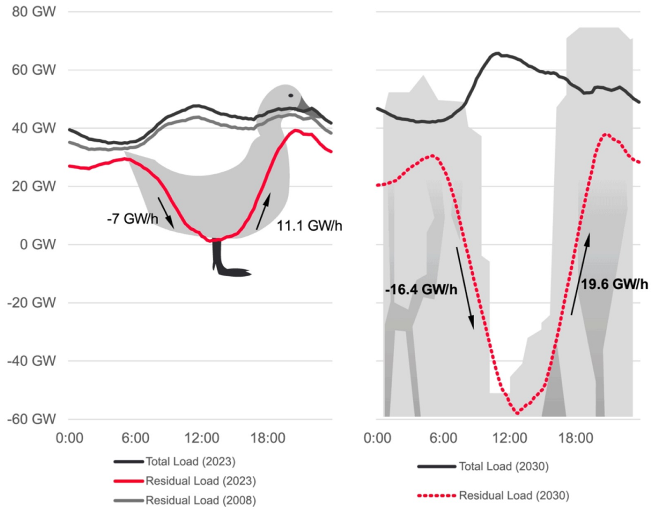
Impact of DERs on power systems

Distribution Level[2,3]

- Voltage rise due to reverse power flows, caused by PV production.
- Voltage Fluctuations
- Increasing peak demand due to EVs and higher electrification in general.
- Increasing variability in local demand
- Congestions on lines and transformers

Transmission Level[1] (Issues due to low flexibility)

- Significant curtailment of renewable energy
- Increasing difficulty to balance demand/supply
  → Leads to frequency deviations, LoL …
- Negative Electricity Prices
- Price volatility
- Area/schedule balance violations



From duck to canyon, from [4]

1. Flexibility in 21st Century Power Systems, J. Cohran et al, NREL, 2014
2. Coordinated control of automated devices and photovoltaic generators for voltage rise mitigation in power distribution circuits, J. Jung et al, Renewable Energy, 2014
3. Energy Storage Systems for Transport and Grid Application, S. Vazquez et al, IEE Transations on Industrial Electronics, 2010
4. . POWER SYSTEM FLEXIBILITY – A KEY ENABLER FOR THE ENERGY TRANSITION, Hitachi Energy, 28-11-2023, https://www.hitachienergy.com/news-and-events/perspectives/2023/11/power-system-flexibility-a-key-enabler-for-the-energy-transition

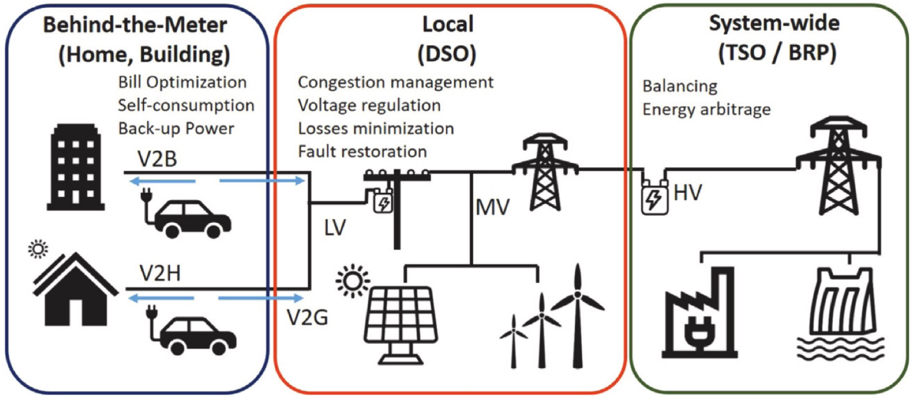
Flexibility needs at different levels

Distribution Level Needs:

- Voltage Control
- Congestion Management
- Power Quality
- Losses Reduction
- …

Transmission Level Needs:

- Balancing
- Congestion Management
- …



Flexibility Services Provided by EVs, from [1]

1. Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services, F.G.Venegas et al, Renewable and Sustainable Energy Reviews, 2021

Flexible Potential at the distribution level

Generation

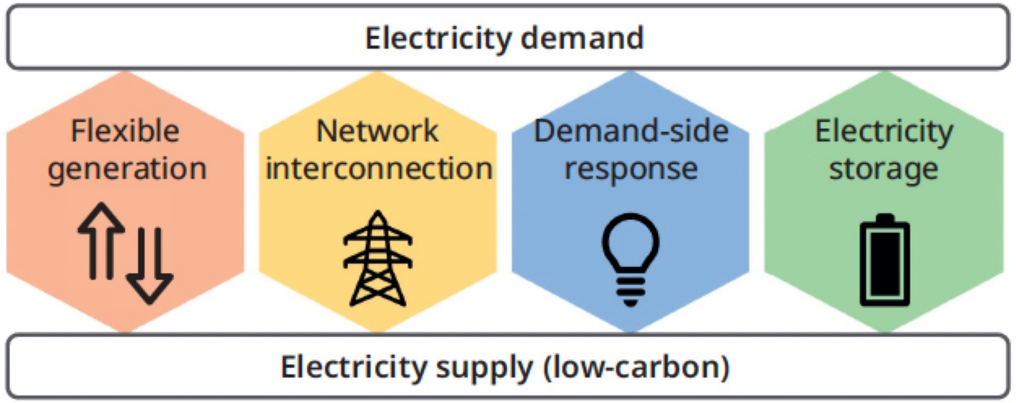
- PV/Wind (Curtailement, P-Q, P-V control)
- **Demand**
- Evs (V1G, V2G)
- Heating (district heating, heat pumps…)

Storage

- Batteries, Thermal storage …

Network Operation:

- Statcomms, tap changing transformers, phase shift transformers…

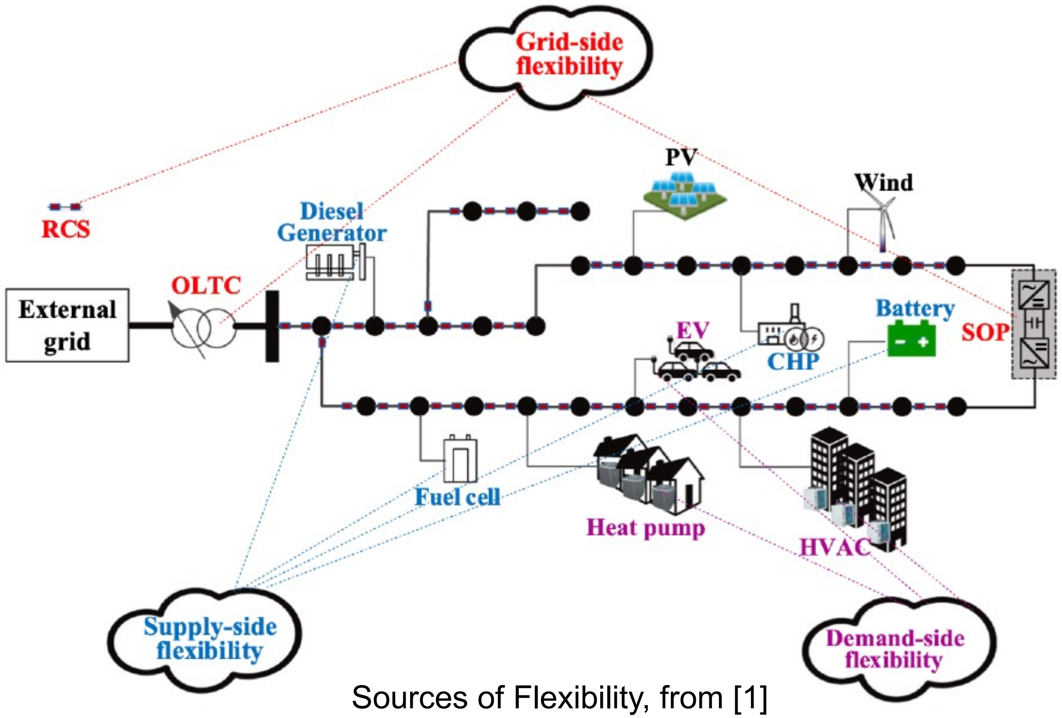


Flexibility Options, from [1]

1. Monetizing Energy Storage, Oliver Schmidt and Iain Staffell, Oxford University Press, 2023

Flexible Operation of the distribution system[2]

- Voltage Control
  - Voltage regulation devices (shunt compensators…)
  - P-V control of DERs
- Reactive Power Compensation
  - Shunt devices/ statcomms/ adaptive power factor operation
- Energy storage management
  - Economic/Technical operation optimization
  - Reduce curtailment, manage congestions…
- Curtailment of renewable energy sources
  - Last resort from energy point of view
  - Can be cheap option for renewable integration
- Demand Response
  - Shifting demand through price signals/automatic control
  - Reduce peak load

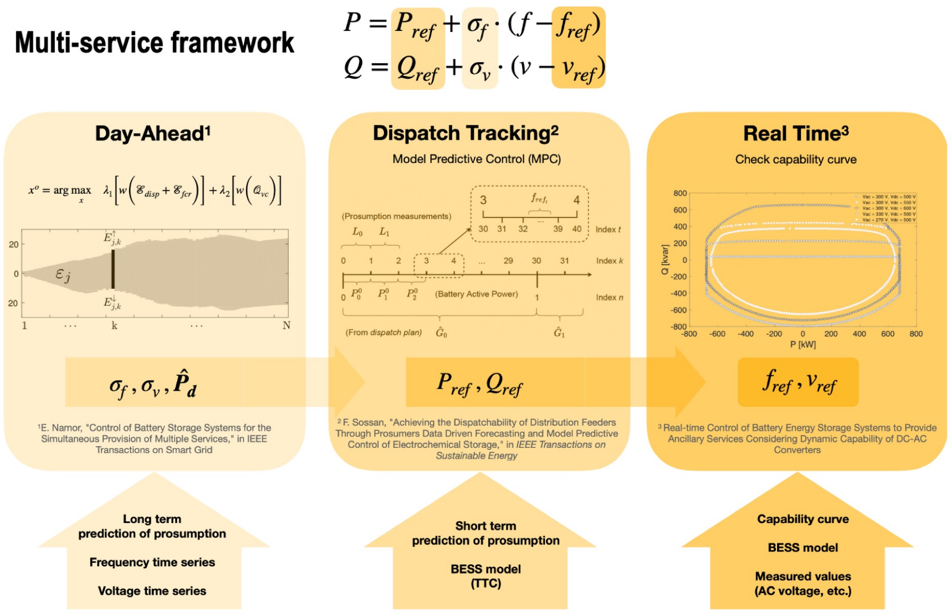


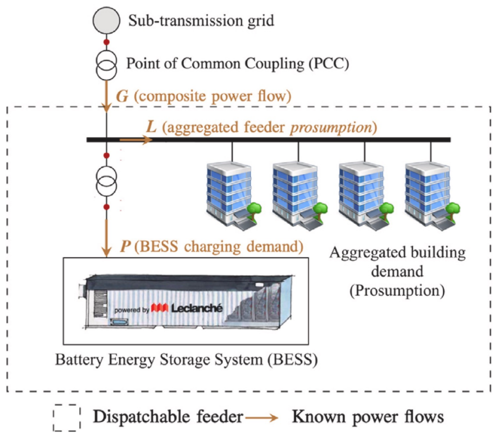
Sources of Flexibility, from [1]

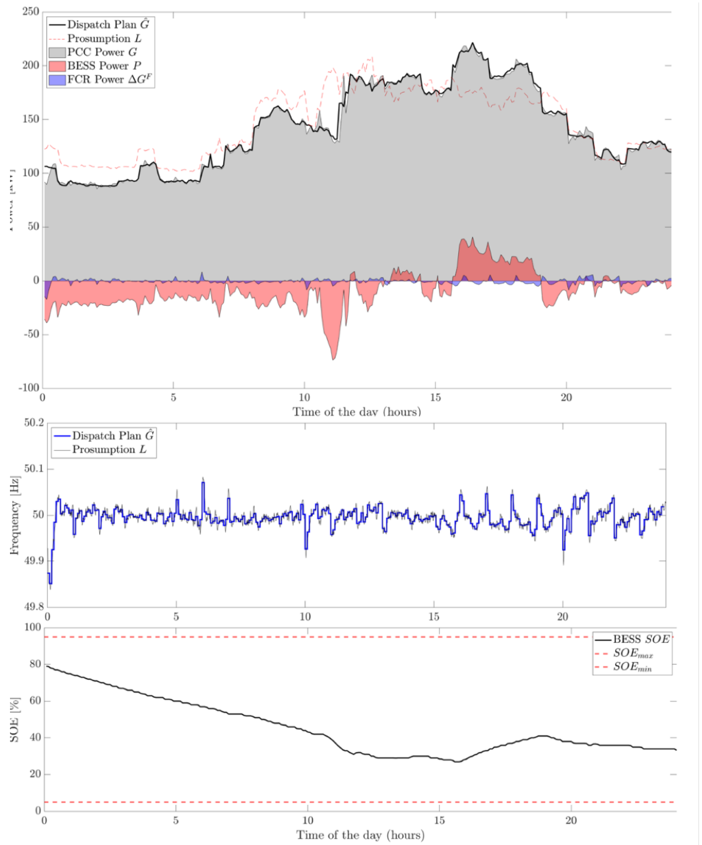
1. Local flexibility markets: Literature review on concepts, models and clearing methods, Jin et al, Applied Energy, 2020
2. Optimal operation of smart distribution networks: A review of models, methods and future research, V Evangelopoulos et al, EPSR, 2016

Flexibility surplus from distribution systems

- Optimal usage of battery energy storage systems[1]
  - Battery used to control distribution system
  - Remaining capacity can be used to provide flexibility services to transmission grid
  - Need good predictions to shrink uncertainty and enhance solution space





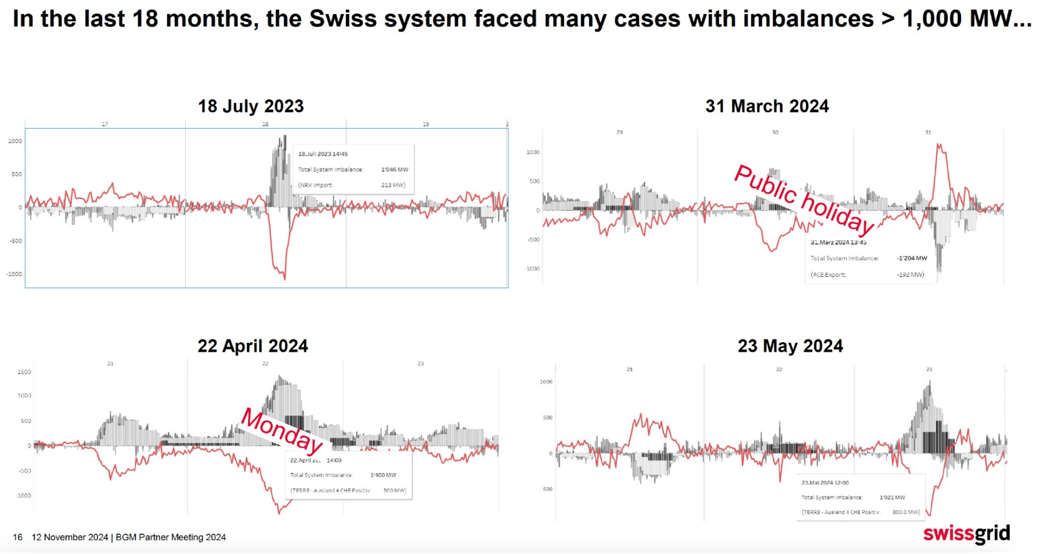


1. F. Gerini et al, Optimal grid-forming control of battery energy storage systems providing multiple services: Modeling and experimental validation, Electric Power Systems Research, 2022

Need for Flexibility Provision from the distribution level

Balancing Groups:

- An attempt to reduce the reserve requirements in the wholesale flexibility markets.
- Each balancing group attempts to adhere to schedule defined day ahead.
- But…

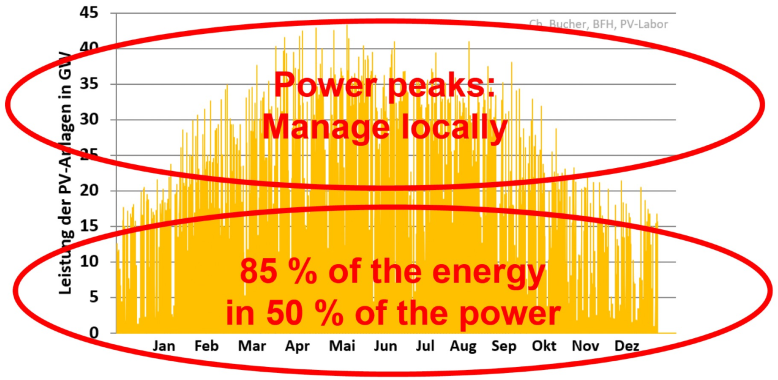


BGM Partner Meeting 2024, SwissGrid, 12.11.2024

Need for Flexibility Provision from the distribution level

Balancing Groups:

- **Strong imbalances** occur more frequently **at weekends, on public holidays and on Mondays** - coincidence?
- Balance groups make consumption and production forecasts for their own supply area
- Most sub-balance groups only report their **consumption and production forecasts** to the balance group **once a day in day ahead**
- Weather changes on weekends and public holidays are usually not considered by the sub-balance groups
- There is **no incentive**, as the **costs** for balancing energy can be passed on **to the trapped end customers**



What can suppliers/producers do to prevent such high imbalances in the future?

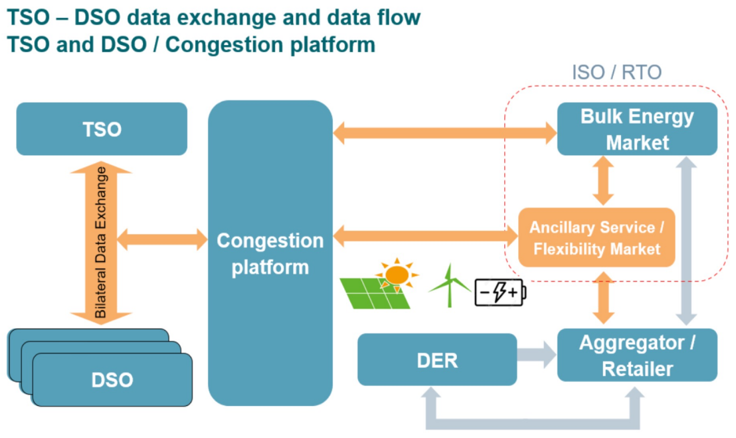
1. **Better data quality** and earlier data delivery to **increase the quality of forecasts**
2. Regular **updating of forecasts**, including at weekends and on public holidays
3. **Readout of real-time data** for rapid detection of imbalances
4. Provision of **more flexibility (e.g. battery storage)** to compensate for imbalances in real time

BGM Partner Meeting 2024, SwissGrid, 12.11.2024

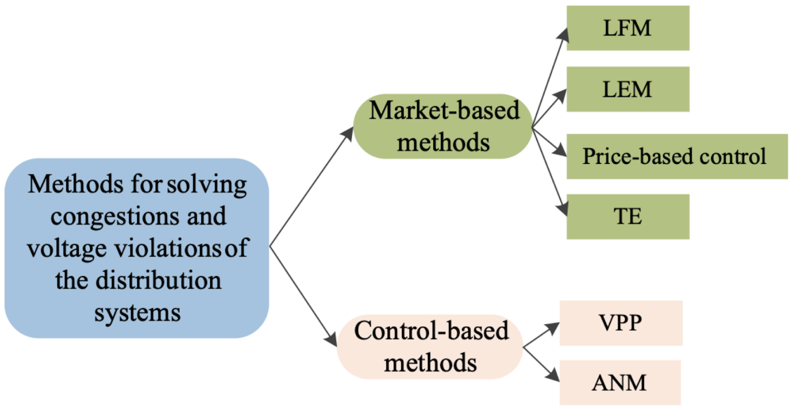
Flexibility Provision from the distribution level

Need for TSO-DSO interaction:

- Continuously increasing capacity of distributed energy resources. → Connected at the distribution level
- DERs flexibility can benefit transmission system
    - ! Coordination required to avoid flexibility causing local voltage/congestion issues !



DSO-TSO Interaction, from [1]



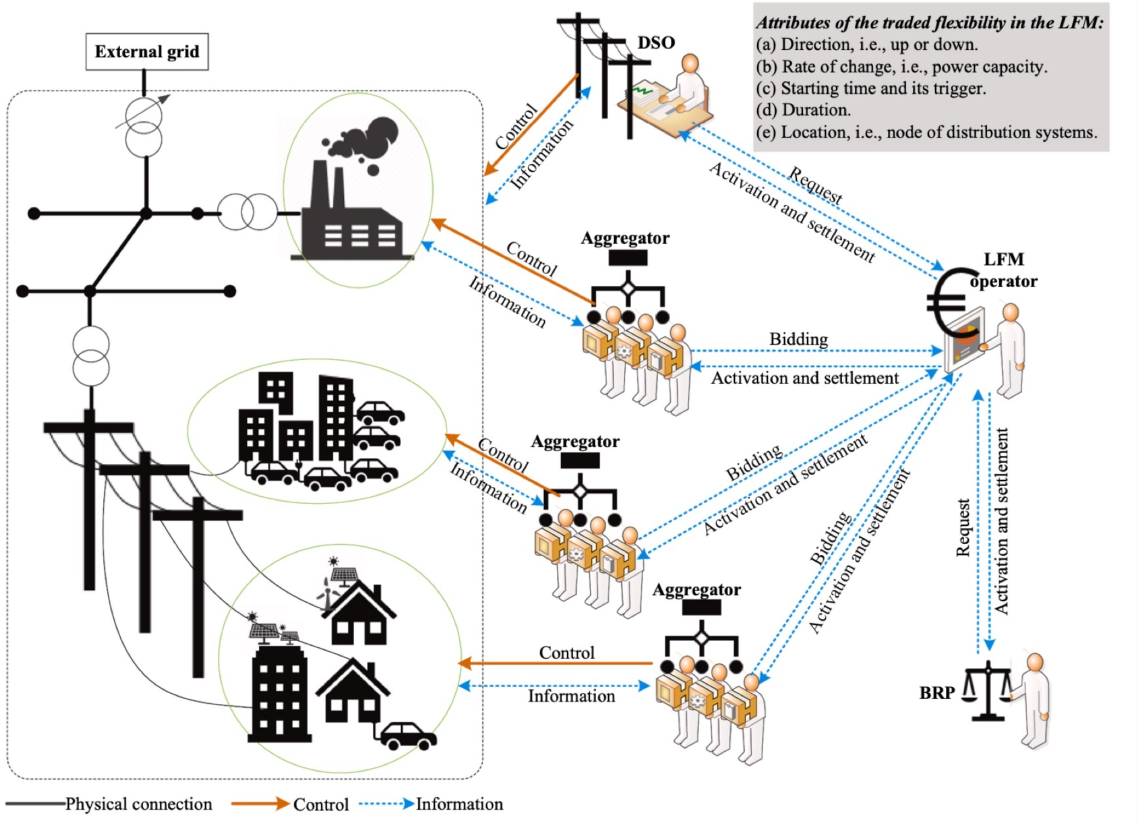
1. Spécifications des outils de coopération TSO/ DSO des centres de conduit, M. Ostermann et al, ELECTRA N°318, 2021
2. Local flexibility markets: Literature review on concepts, models and clearing methods, Jin et al, Applied Energy, 2020

Flexibility Provision from the distribution level

Flexibility through local Market Mechanisms:

- Typical Actors:
  - DSO
  - BRP
  - Aggregator
  - LFM Operator
- Different Mechanisms are possible
  - Market clearing based on operational information of participants (social welfare maximization)
  - Market clearing based on bids (actors optimize their welfare based on game theory)

EU recommendation: "*Establish and continue improving EU legislation for a clear regulatory framework for distribution networks and* ***local markets for distributed flexibility services.***"[1]



Example of a local flexibility market, from [2]

1. Challenges of the future electricity system, European Union Agency for the Cooperation of Energy Regulators, 11July 2024
2. Local flexibility markets: Literature review on concepts, models and clearing methods, Jin et al, Applied Energy, 2020

Flexibility Provision from the distribution level

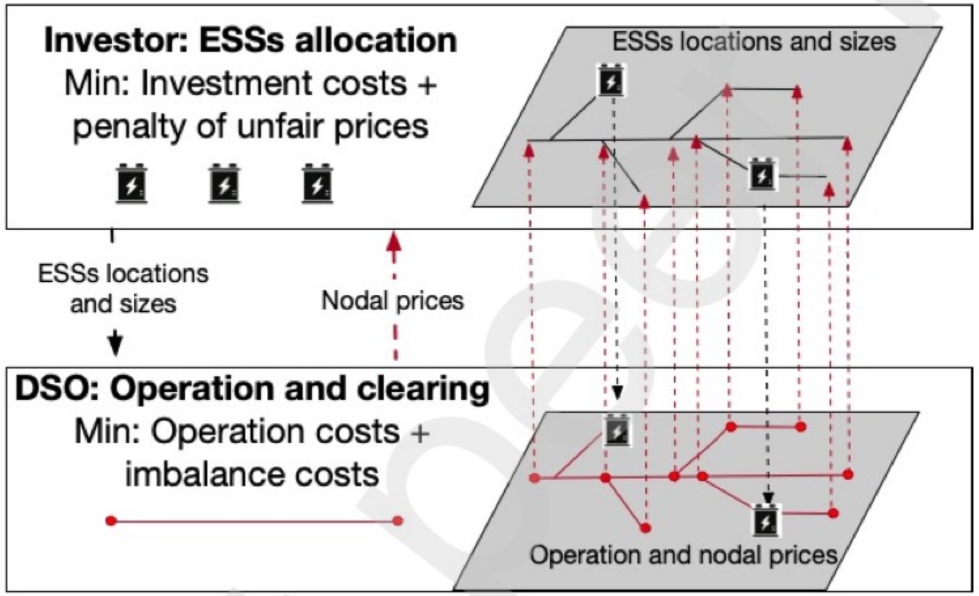
EU recommendation: "*Establish and continue improving EU legislation for a clear regulatory framework for distribution networks and **local markets for distributed flexibility services.***"[1]

Flexibility through local Market Mechanisms:

- Grid reinforcements (copper or others) should enable market participation of DERs.
- But not all prosumers are equal!

→ Need a way to fairly reinforce local networks

- Market-aware expansion problem
  - Installation of ESS for grid reinforcement
  - Coupled with market clearing problem accounting for future load evolution

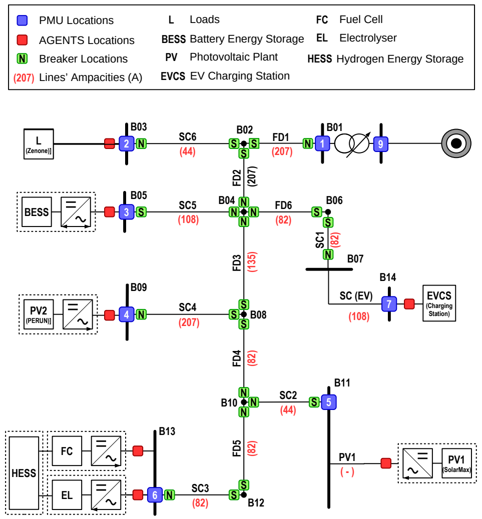


Schematic Problem Representation, from [2]

1.Challenges of the future electricity system, European Union Agency for the Cooperation of Energy Regulators, 11July 2024

2. Wang, Lu et al, Local Market-Aware Optimal Allocation of Energy Storage Systems Considering Price Fairness in Power Distribution Networks. Available at SSRN: https://ssrn.com/abstract=4992393 or http://dx.doi.org/10.2139/ssrn.4992393

Flexibility Provision from the distribution level

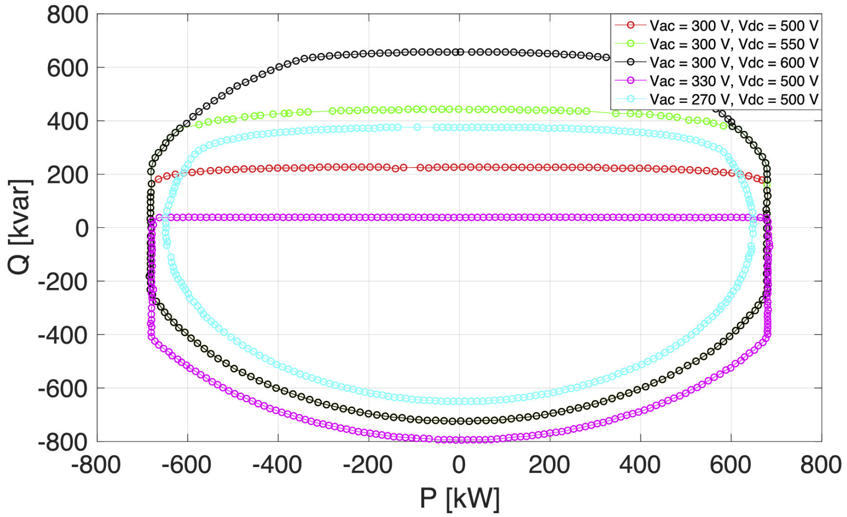


Advertising the local flexibility:

- Advertise power flexibility available at the interconnection point.
- Allow usage of distribution system flexibility for balancing at the transmission level
- Account for internal constraints, avoiding flexibility provision to the transmission level to cause local issues.

Aggregating the local flexibility:

- Obtaining the individual capabilities (per DER)
- Within an energy hub / assuming a coper plate:
  - Total flexibility capability easily computed (Minkowski sum)
- In a distribution system with binding constraints:
  - Grid constraints should be accounted for
- In a system with significant stochastic presumption:
  - Stochastic DERs have uncertain capability curves
  - Grid constraints are subject to stochastic variables



BESS Capability Example, from [1]

1. Optimal provision of concurrent primary frequency and local voltage control from a BESS considering variable capability curves: Modelling and experimental assessment, Zecchino et al, Electric Power Systems Research, 2021

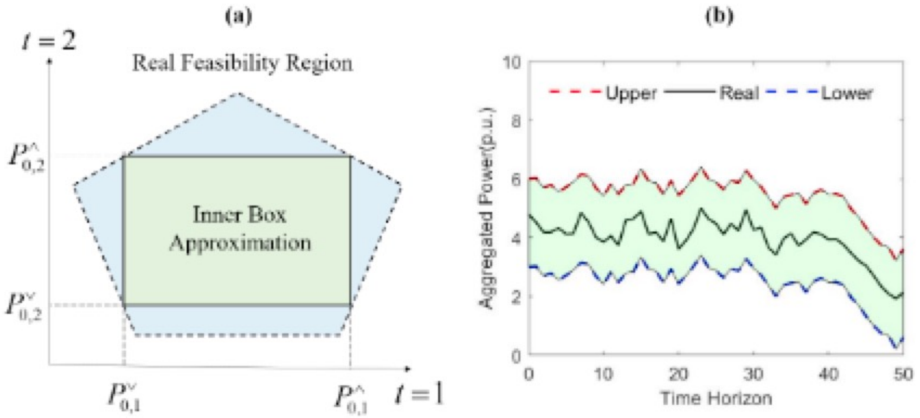
Flexibility Provision from the distribution level

Aggregating the local flexibility:

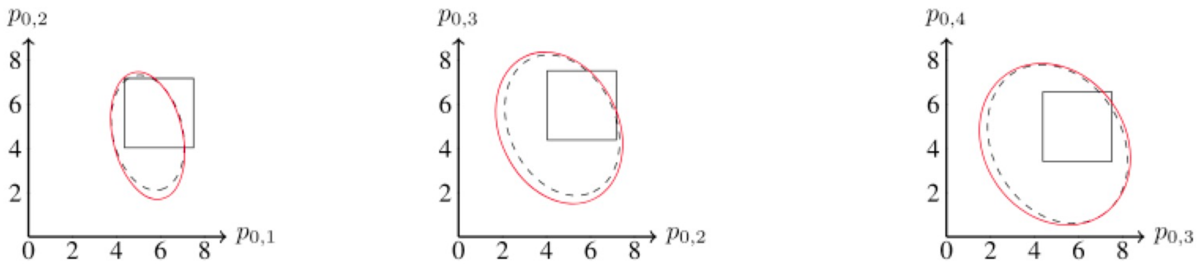
- Typically formulated in robust way: ”Determine (time-dependent) power capabilities guaranteed for any uncertain realization”
- Accounting for DER capability, grid constraints …
- Projection of high-dimensional polytope on subset: Untractable in general form

→ Approximate feasibility sets

- Hyperbox
- Ellipsoids
- Polygons of given shape



Inner Hyperbox approximation, from [1]



(a) Projected flexibility: 9:00–11:00. (b) Projected flexibility: 10:00–12:00. (c) Projected flexibility: 11:00–13:00.

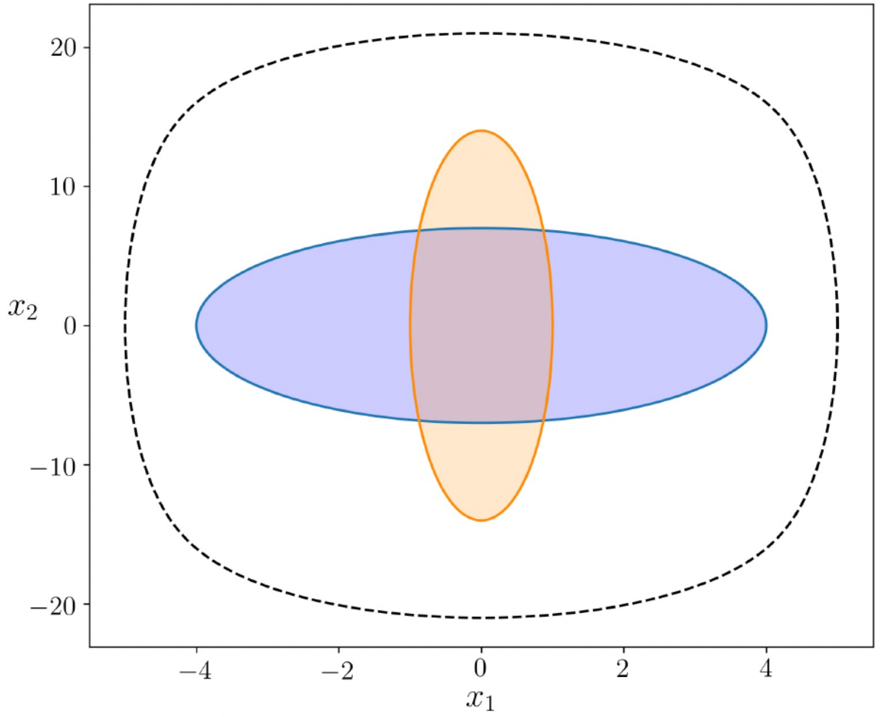
Inner Ellipsoid approximation, from [2]

1. X. Chen, E. Dall’Anese, C. Zhao, and N. Li, “Aggregate Power Flexibility in Unbalanced Distribution Systems,” May 31, 2019, *arXiv*: arXiv:1812.05990. Accessed: Nov. 07, 2023. [Online]. Available: http://arxiv.org/abs/1812.05990
2. B. C. Andrey Bernstein, “Network-Cognizant Time-Coupled Aggregate Flexibility of Distribution Systems Under Uncertainties,” 2021, Accessed: Nov. 06, 2023. [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9295337

Flexibility Provision from the distribution level

Local flexibility for multiple services:

- Accounting for DER capability, grid constraints …
- Consider multiple components that can be bid and activated independently
- Reduce conservatism by considering probabilistic uncertainty sets
- Maximize ‘flexibility value’ based on forecasted service prices



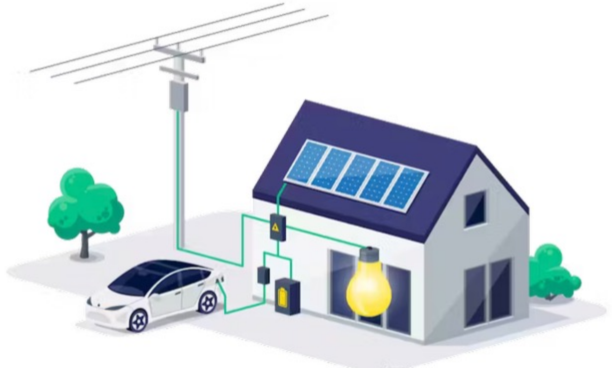
Combined flexibility requirements, figure from [1]

1. On the Parameterized Computation of Minimum Volume Outer Ellipsoid of Minkowski Sum of Ellipsoids, Abhishek Halder, 2018

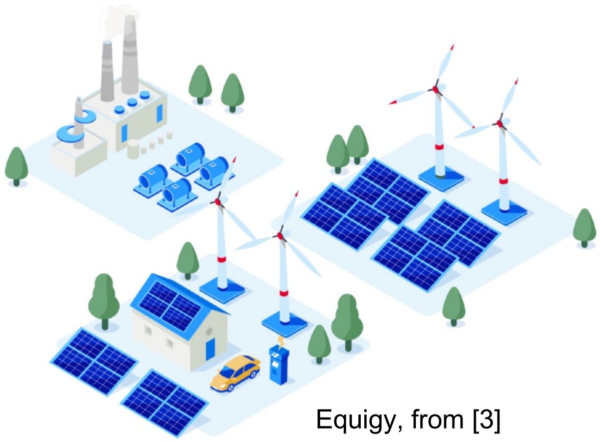
Flexibility from the distribution level: Real Examples

- Tesla VPP with ERCOT
  - 80MW pilot project
  - Aggregators bidding capacity of individual owners (Tesla Powerwall, Evs, controllable loads)
  - Current capacity capped as "ERCOT is working through information gaps on the distribution grid. These gaps are one of the biggest challenges for scaling VPPs"[1]

- Equigy
  - Crowd balancing platform
  - Assemble offers and demands
  - Series of pilot projects, providing for example aFRR in the Netherlands



Tesla VPP, from [2]



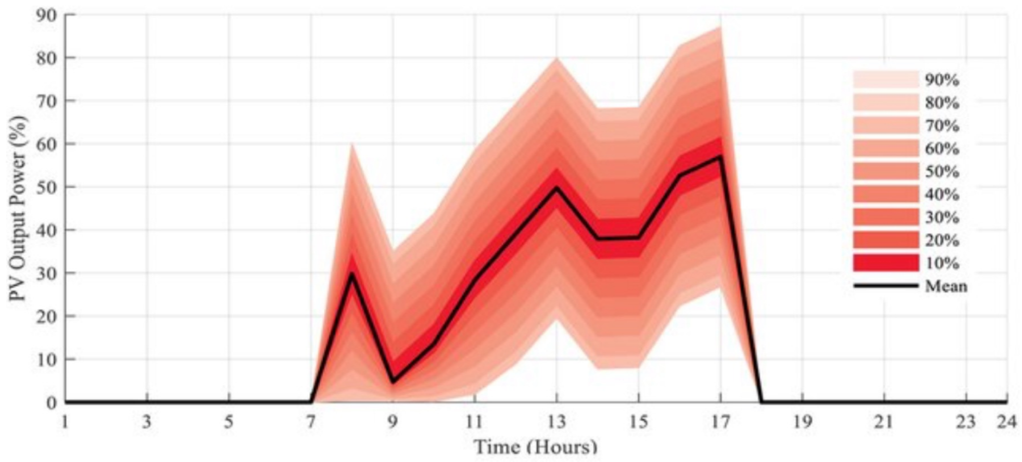
Equigy, from [3]

1. ERCOT needs more distribution data to grow VPPs, says executive, Latitutde Media, 23.04.2024, Accesses 16.11.2024, https://www.latitudemedia.com/news/ercot-needs-more-distribution-data-to-grow-vpps-says-executive
2. ERCOT Launches Two Virtual Power Plants, Kathy Hitchens, Microgrid Knowledge, 23.08.2023, accessed 16.11.2024, https://www.microgridknowledge.com/distributed-energy/virtual-power-plant/article/33010348/ercot-launches-two-virtual-power-plants
3. The crowd balancing platform, Equigy, accessed 16.11.2024, https://equigy.com/the-platform/

Future Outlook

P90 Requirement[1]:

- Allowing probabilistic ancillary service bids (Energinet)
- Opening flexibility markets to stochastic energy resources
- Applied in [1] to the aggregation of EV flexibility for grid service provision in Danmark.

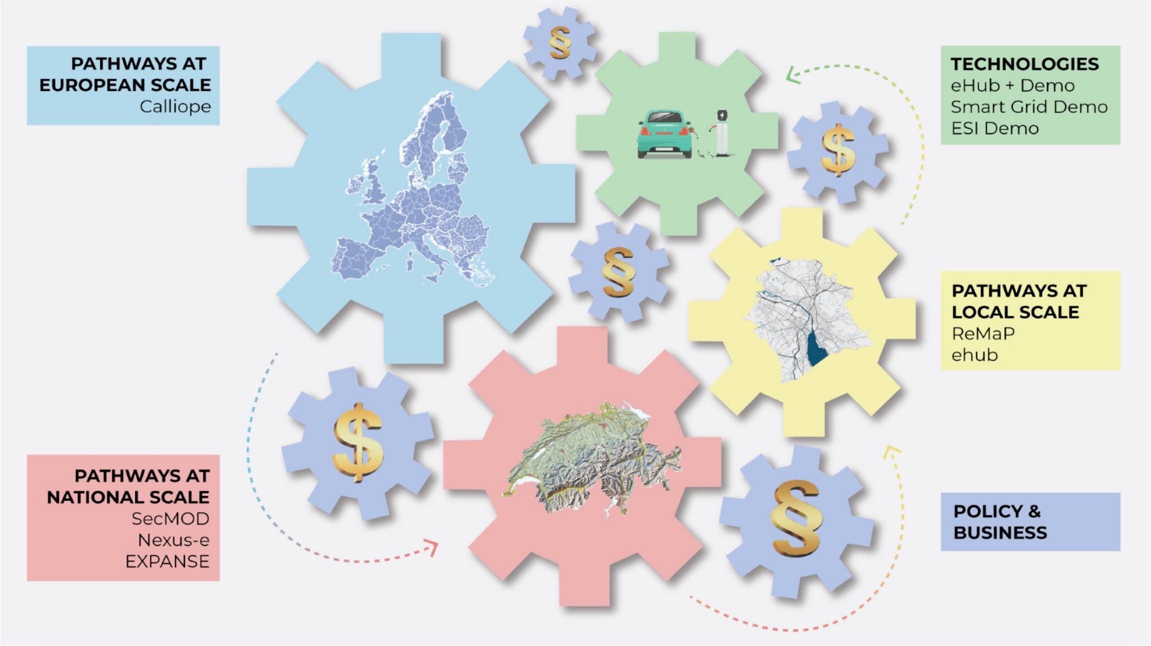


PV Power Interval Forecast, from [2]

1. Gade, Peter Alexander Vistar et al. "Leveraging P90 Requirement: Flexible Resources Bidding in Nordic Ancillary Service Markets." *2024 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm)* (2024): 505-510.
2. Modified Interval based Generator Scheduling for Primary Frequency Response Adequacy Under Uncertain Photovoltaic Generation, Vivek Prakash et al, IET Generation, Transmission and Distribution, 2019

Conclusion

- Large Flexibility Potential at Distribution Level
- Need coordination
  - Between DSO and TSO
  - Between aggregators, system operators and individual prosumers
- Good communication, forecasts and incentives are key



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