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DIPARTIMENTO DI ENERGIA

Future electric grids: smart, flexible and resilient

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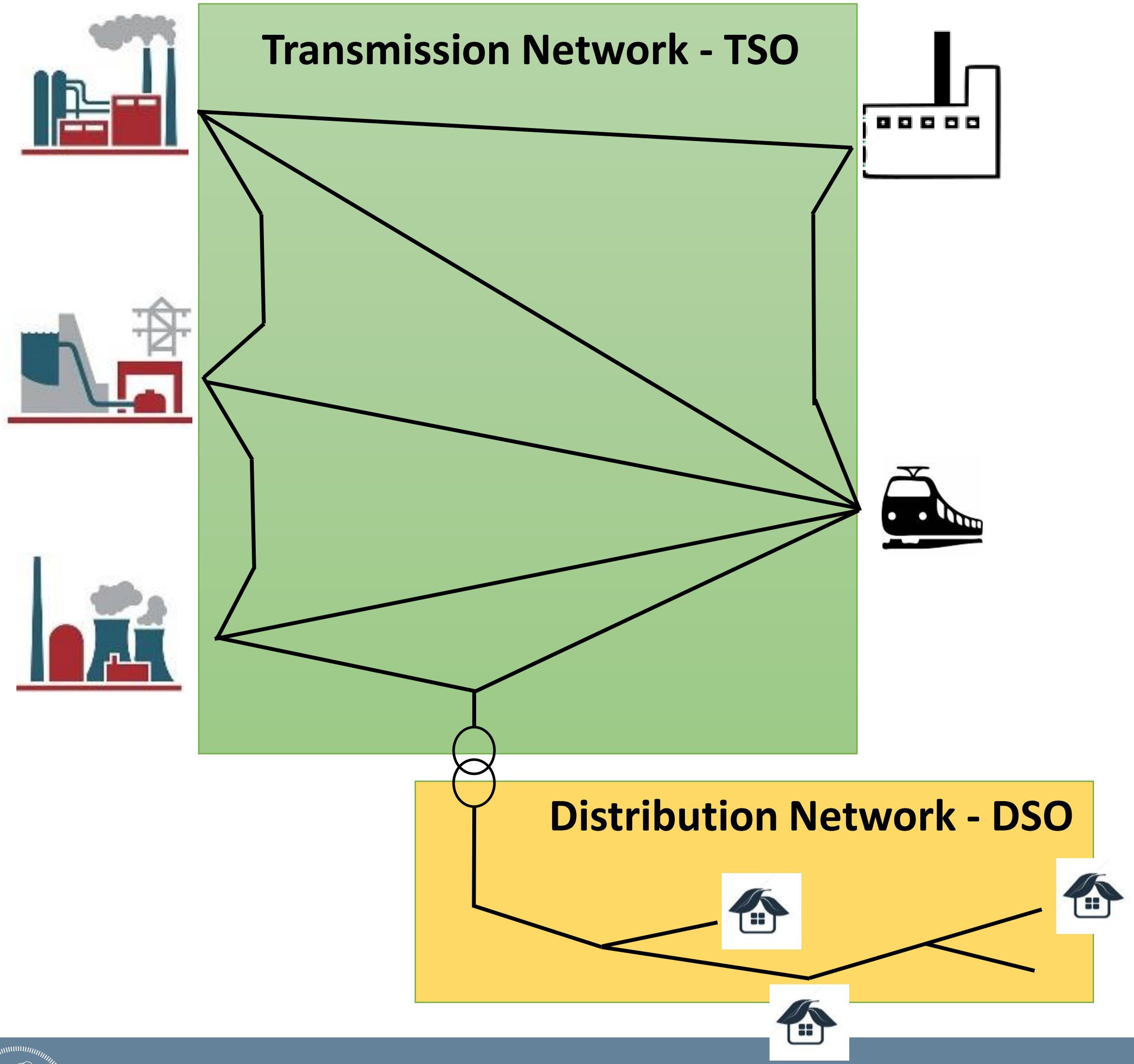
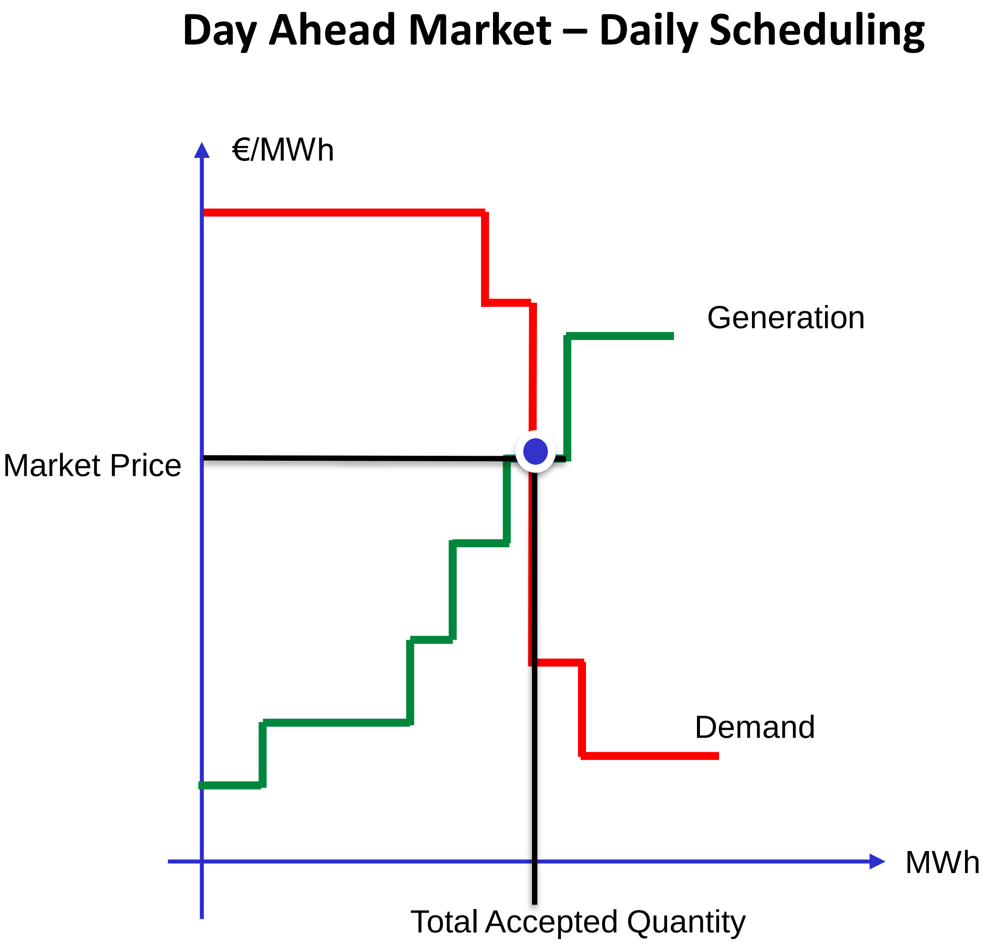
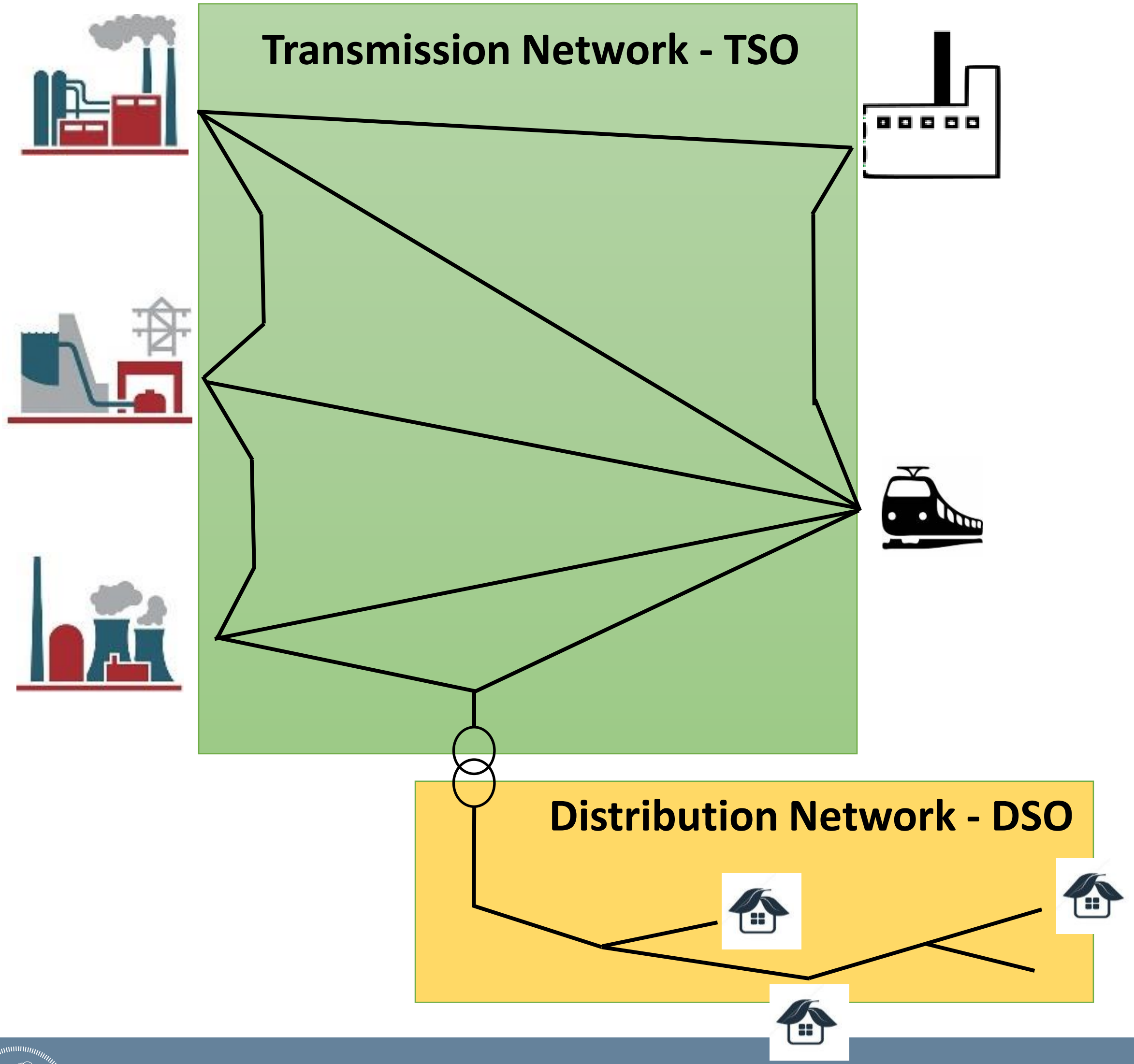
Department of Energy

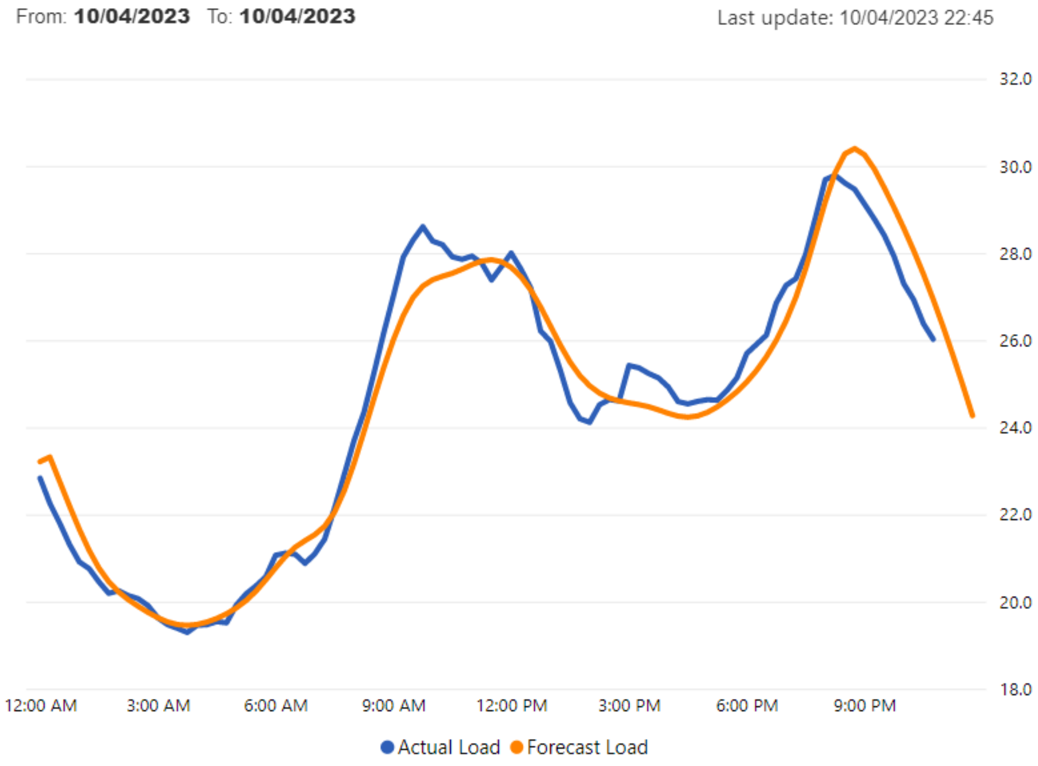
Electricity Markets as of today







Ancillary Service Market (ASM) –generation and load balancing



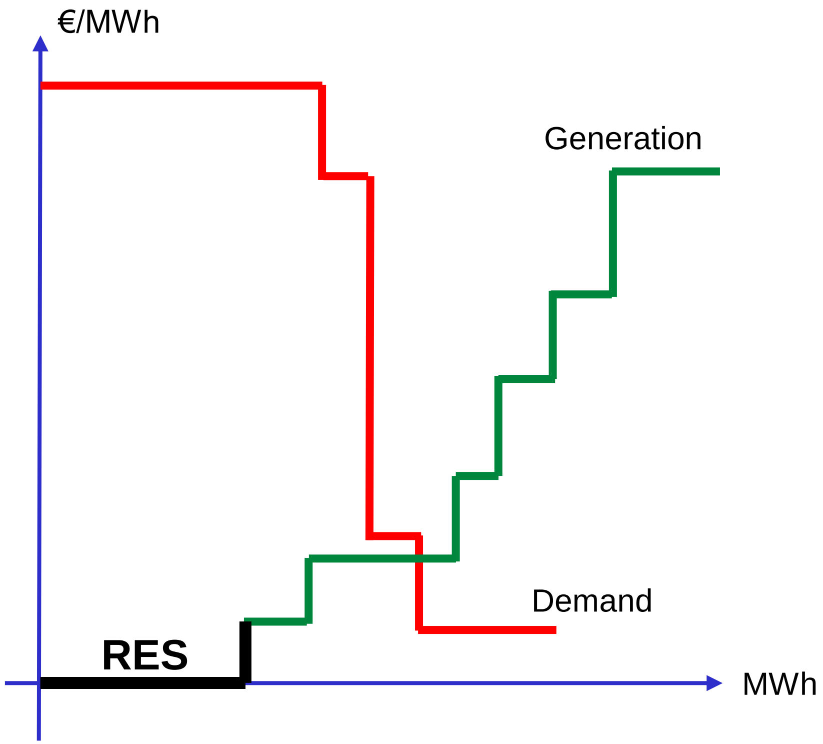
Tomorrow ?

EU decarbonization targets:

- 32% of total demand covered by Renewable Energy Sources (RES) by 2030
- the share of clean vehicles in the total procured at least 35% by 2025

Impact:

- *Day-Ahead Market*: cheaper prices but fewer programmable generation available



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- 32% of total demand covered by Renewable Energy Sources (RES) by 2030
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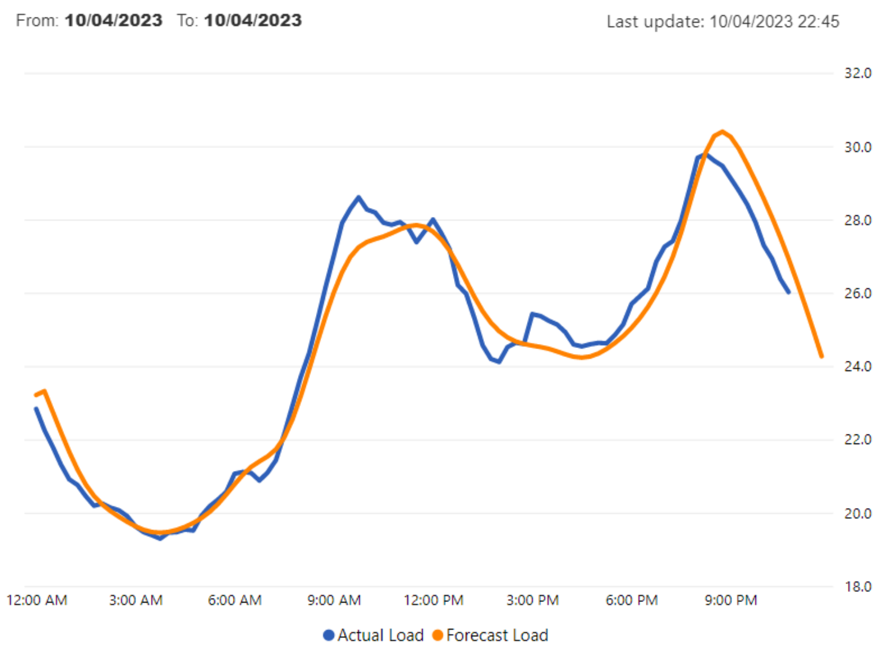
Impact:

- *Day-Ahead Market*: cheaper prices but fewer programmable generation available

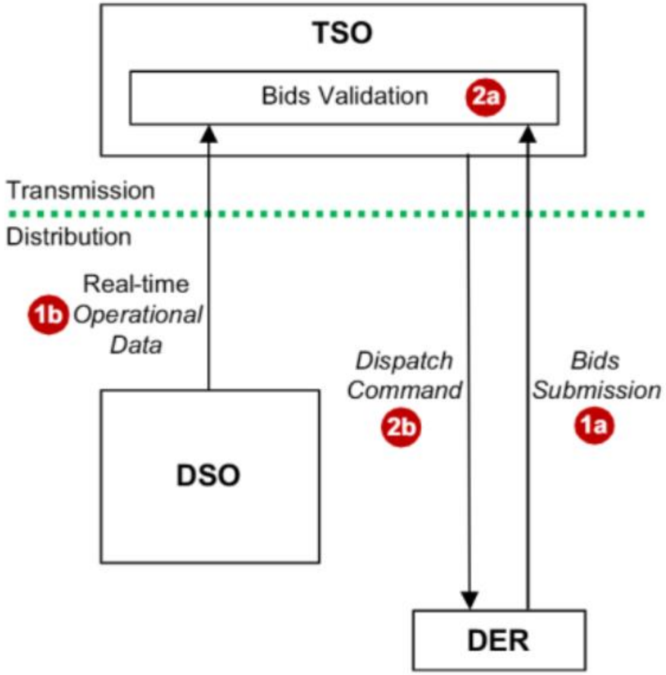
- *ASM Market*: imbalance increase due to RES intermittence and lack of flexible programmable generation available

- *In general*: RES et all are spread across the distribution grid (let's call them DERs)

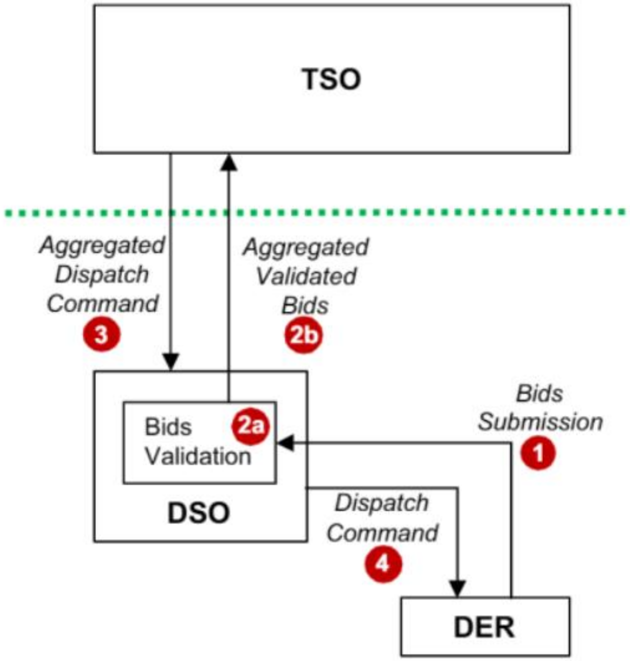


DER Flexibility management

TSO Centralized Model

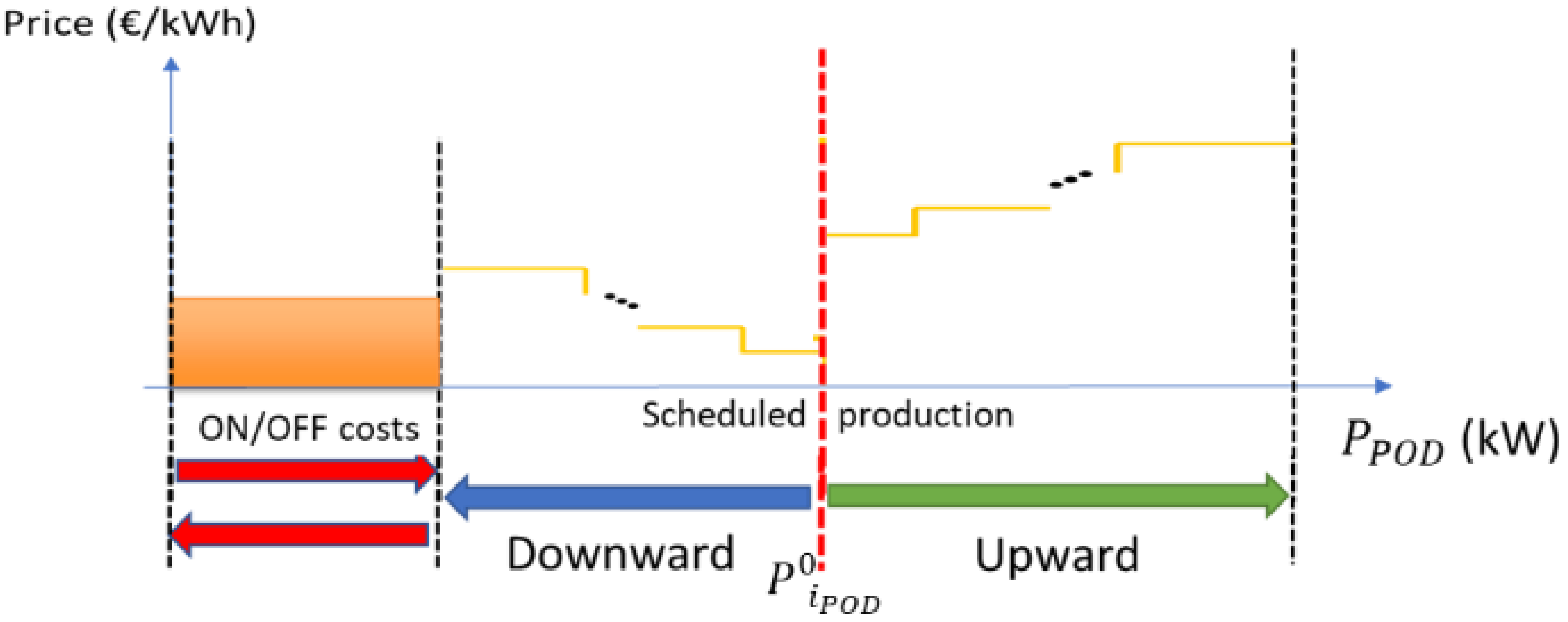


DSO managed Model



A. G. Givisiez, K. Petrou, and L. F. Ochoa, "A review on TSO-DSO coordination models and solution techniques," *Electr. Power Syst. Res.*, vol. 189, 2020.

First step: aggregation of flexibility under a POD in a single economic flexibility offer



Second step: Optimization of flexibility

Optimization Function: minimize total cost of flexibility OR maximize flexibility reserve made available to TSO

Constraints:

- satisfy the power balance in each node of the network, at each time window considered
- avoid thermal current limit violation for the cables of the grid
- avoid voltage bounds violation in the nodes of the grid
- make sure the network's load is balanced at least at PCC with the TSO

Constraints:

satisfy the technical & physical constraints of various technologies if already not aggregated

- for example, a BESS:

$$SoE_t = SoE_{t-1} + \frac{\tilde{\Delta} t}{\tilde{\overline{E}}}\left(P_t^{chg}\tilde{\eta}^{chg} + \frac{P_t^{dis}}{\tilde{\eta}^{dis}}\right)$$

$$\underline{\tilde{SoE}} \leq SoE_t \leq \overline{\tilde{SoE}}$$

$$0 \leq P_t^{chg} \leq \overline{\tilde{P}}^{chg} Z_t^{chg}$$

$$\underline{\tilde{P}}^{dis} Z_t^{dis} \leq P_t^{dis} \leq 0$$

$$Z_t^{chg} + Z_t^{dis} \leq 1$$

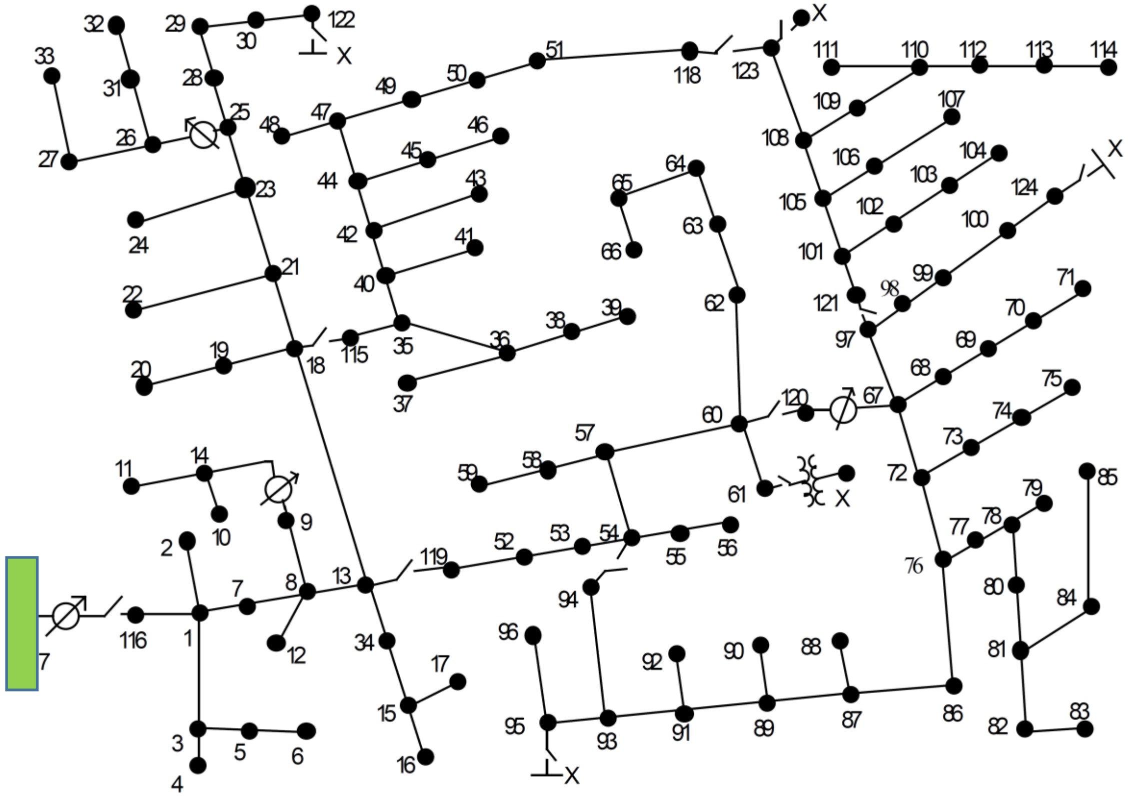
$$BRL_t = \tilde{\alpha} e^{-\tilde{\beta} d_t} + (1 - \tilde{\alpha}) e^{-d_t}$$

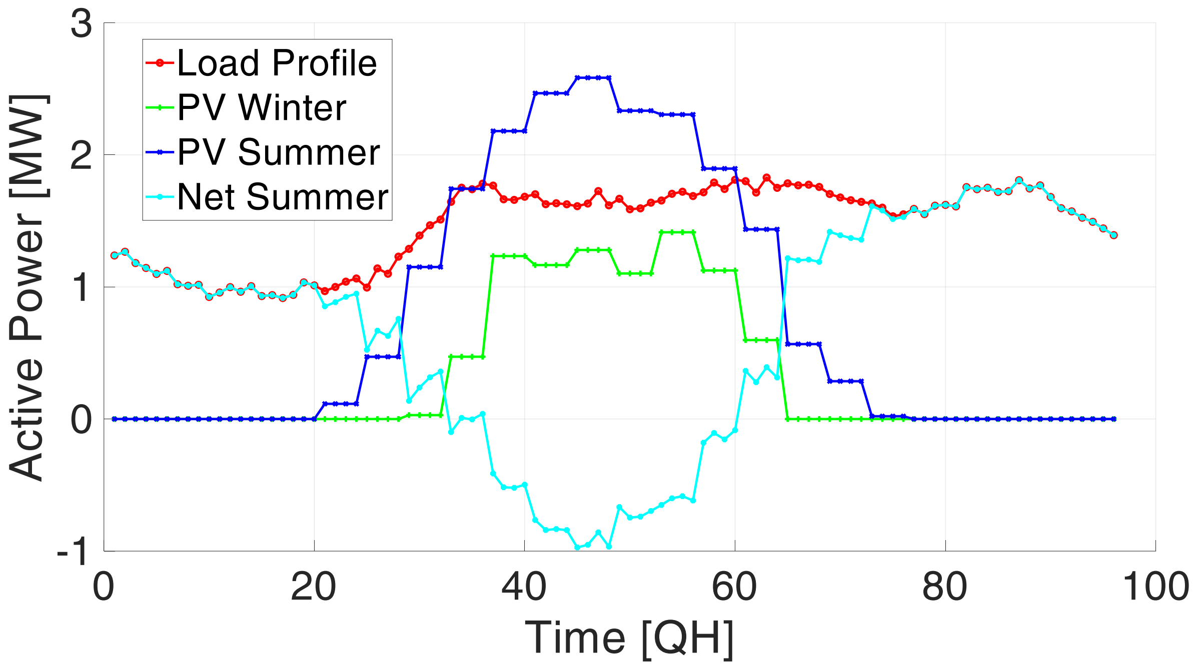
$$d_t = d_t^{op} + d_t^{id}$$

$$d_t^{op} = d_t^{time} + d_t^{CR} d_t^{DoD} d_t^{SoE} d_t^{Temp}$$

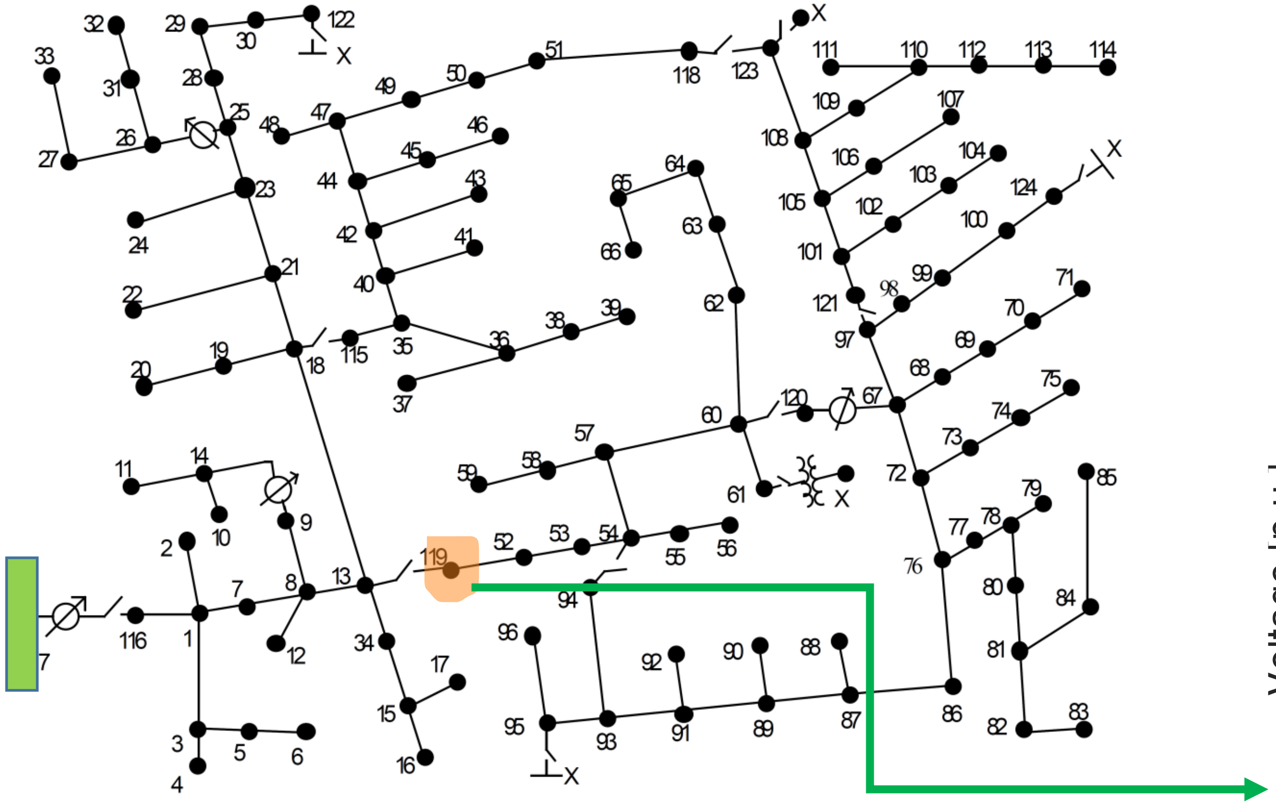
$$d_t^{id} = d_t^{time} d_t^{SoE} d_t^{Temp}$$

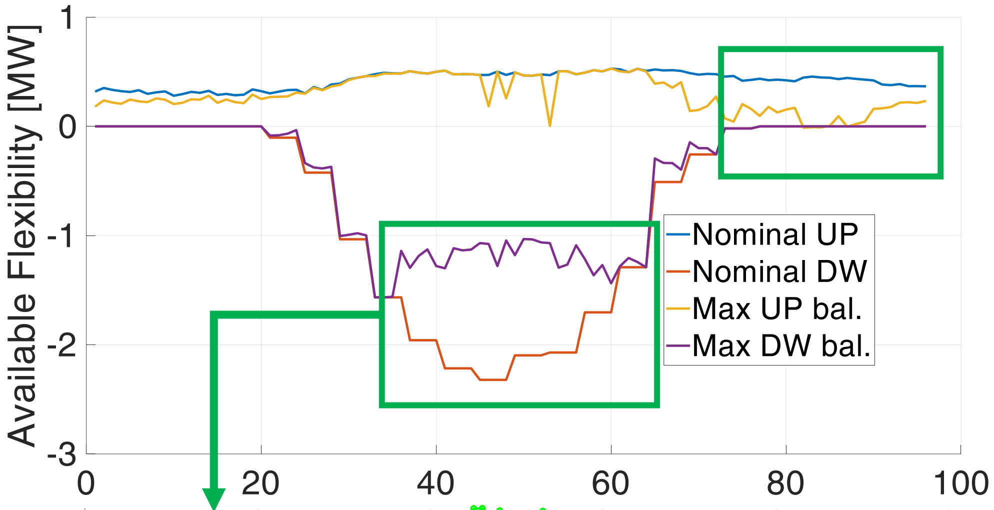
Results

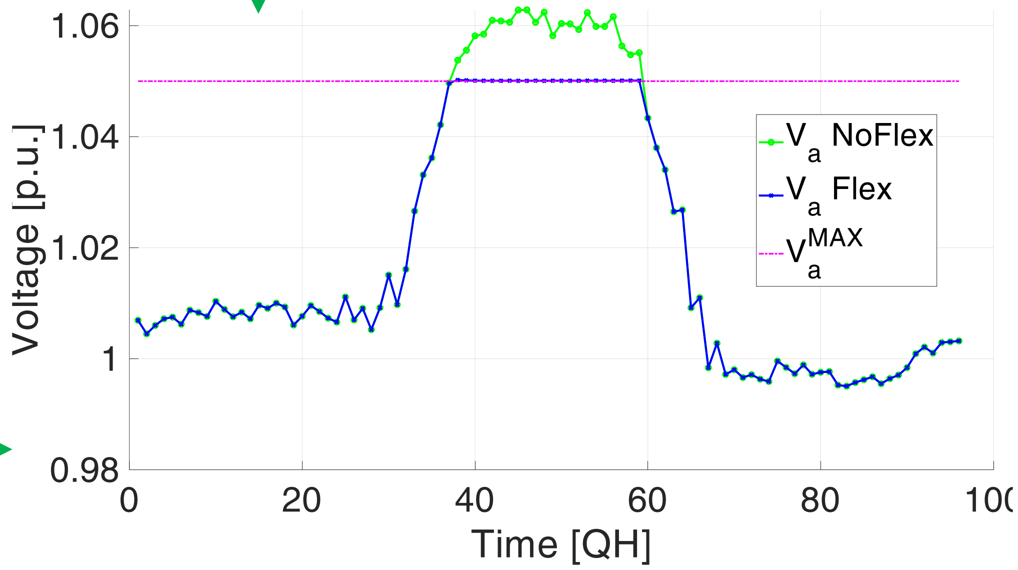



Load Profile
PV Winter
PV Summer
Net Summer
Active Power [MW]
Time [QH]
3
2
1
0
-1
0
20
40
60
80
100

Results




Available Flexibility [MW]
Nominal UP
Nominal DW
Max UP bal.
Max DW bal.


Voltage [p.u.]
Time [QH]
V_a NoFlex
V_a Flex
V_a^{MAX}

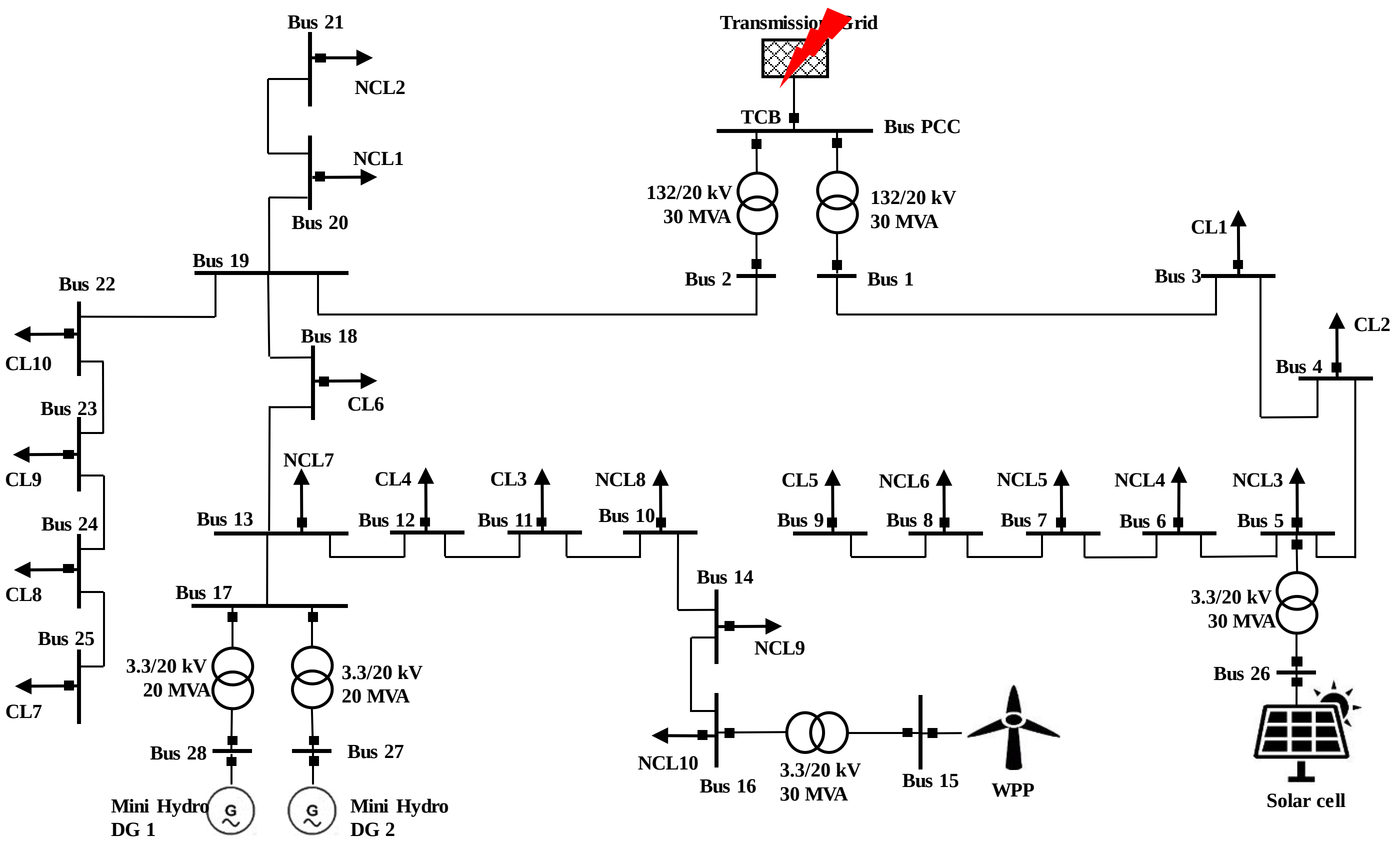
Network resilience

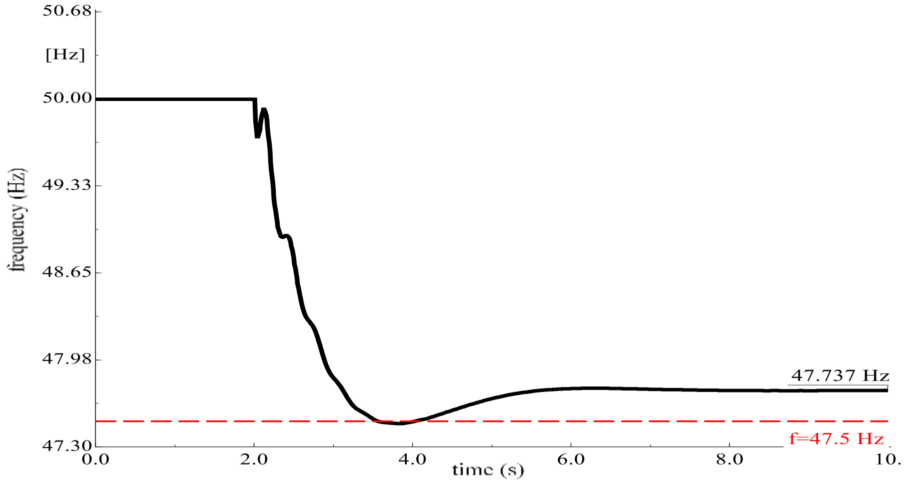
Unfortunately, future urban distribution grids face various security threats that can lead to the blackout of the grid (or a part of it):

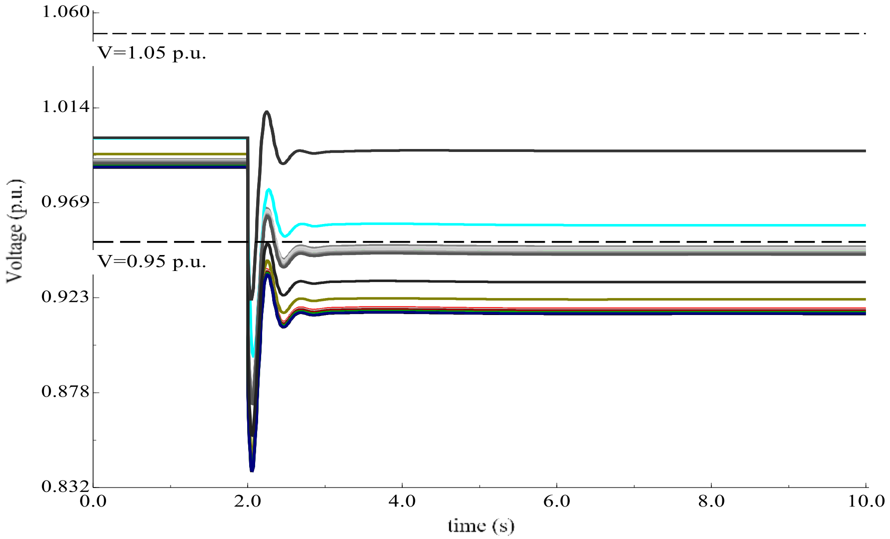
- climate changes (e.g. heatwaves);
- cyberattacks;
- natural disasters.

Developing appropriate **resiliency strategies** is crucial as the electrical infrastructure failure affects numerous other critical infrastructures (such as fire and medical facilities, communications, and mobility).

Resilience strategy: Robust island operation







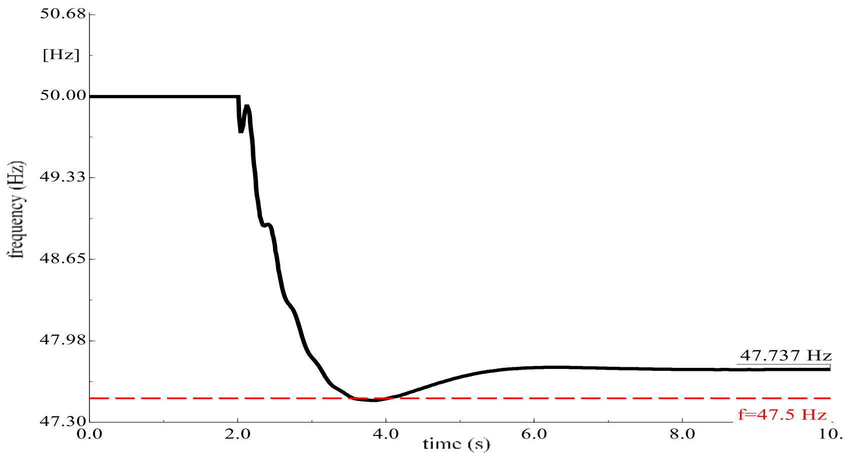
Resilience strategy: Robust island operation

Load and generation are considered curtailable (continuous or discrete) and the curtailment a paid service to the grid.

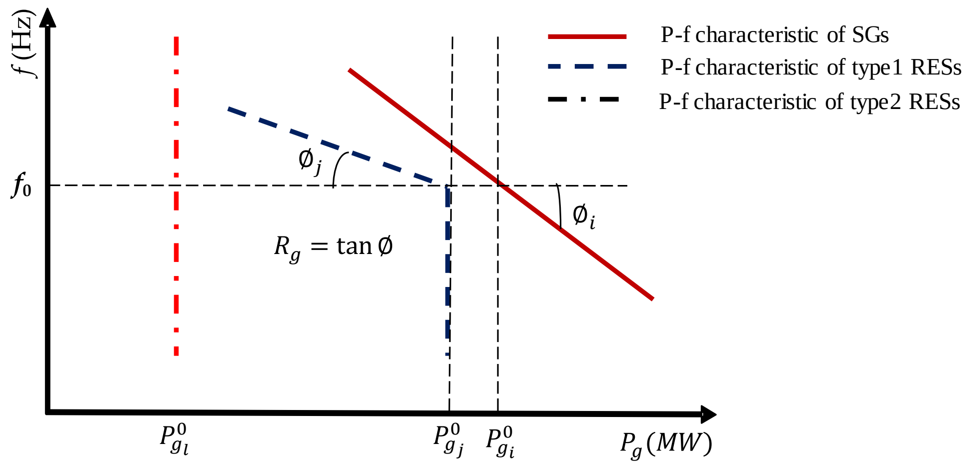
Optimization Function: minimize the total cost of curtailment.

Constraints:

Guarantee frequency security of the grid



Generation *f* response



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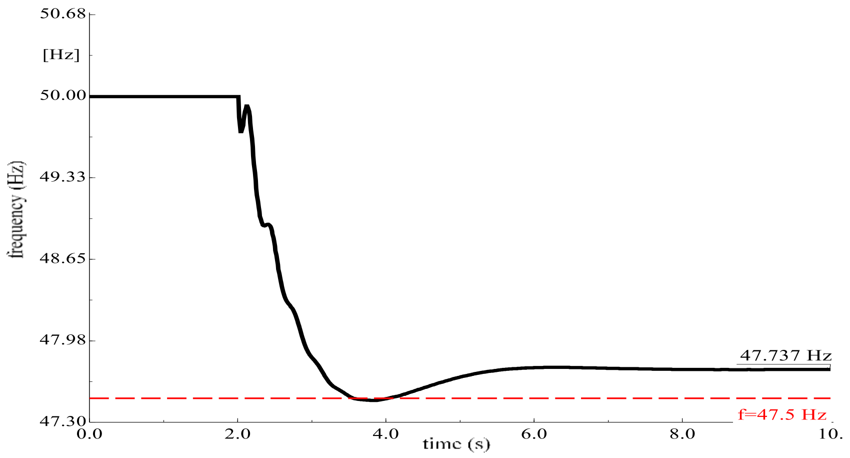
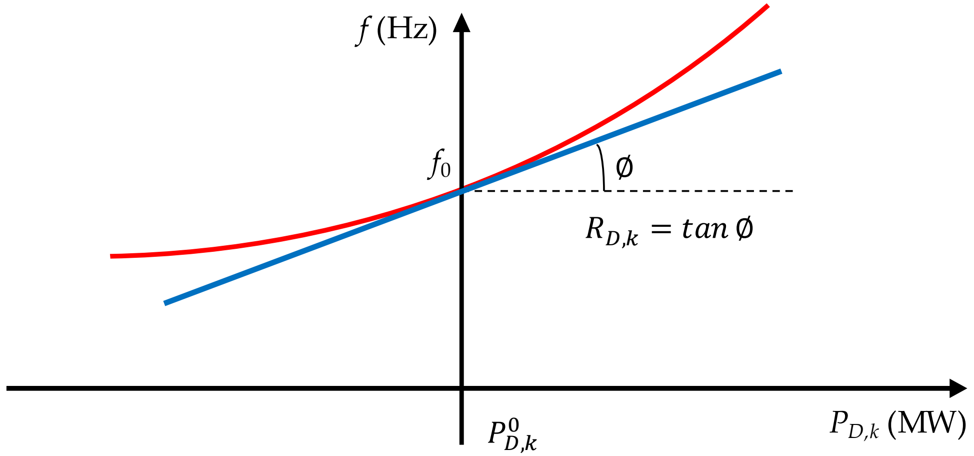


Demand *f* response



Resilience strategy: Robust island operation

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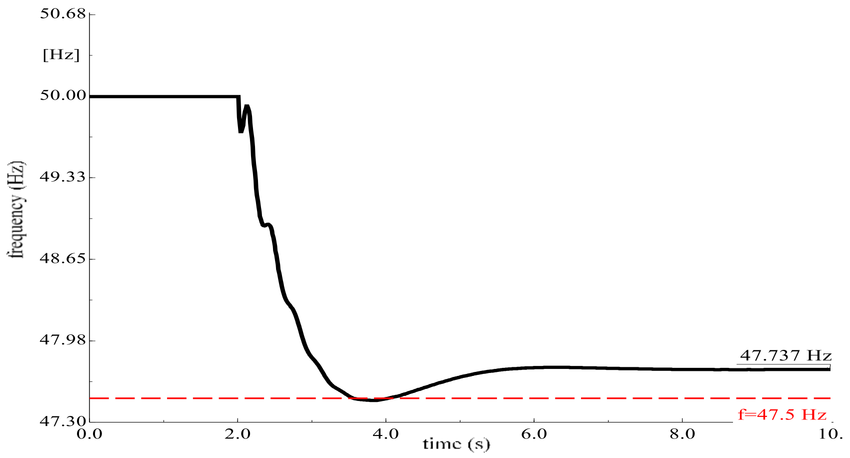


$$\Delta f^{min} \leq \Delta f \leq \Delta f^{max}$$

$$P_{g,d}^{new} = P_{g,d}^{ini} + f(\Delta f)$$

Resilience strategy: Robust island operation

Load and generation are considered curtailable (continuous or discrete) and the curtailment a paid service to the grid.

Optimization Function: minimize the total cost of curtailment.

Constraints:

satisfy the power balance in each node of the network, at each time window considered

secure minimum power reserves for future events

represent correctly the shedding model

avoid thermal current limit violation for the cables of the grid

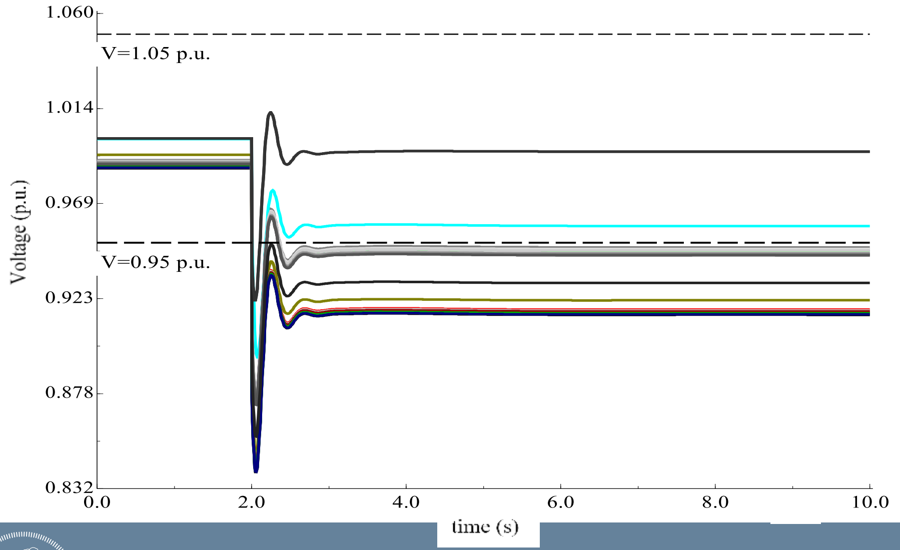
Resilience strategy: Robust island operation

Load and generation are considered curtailable (continuous or discrete) and the curtailment a paid service to the grid.

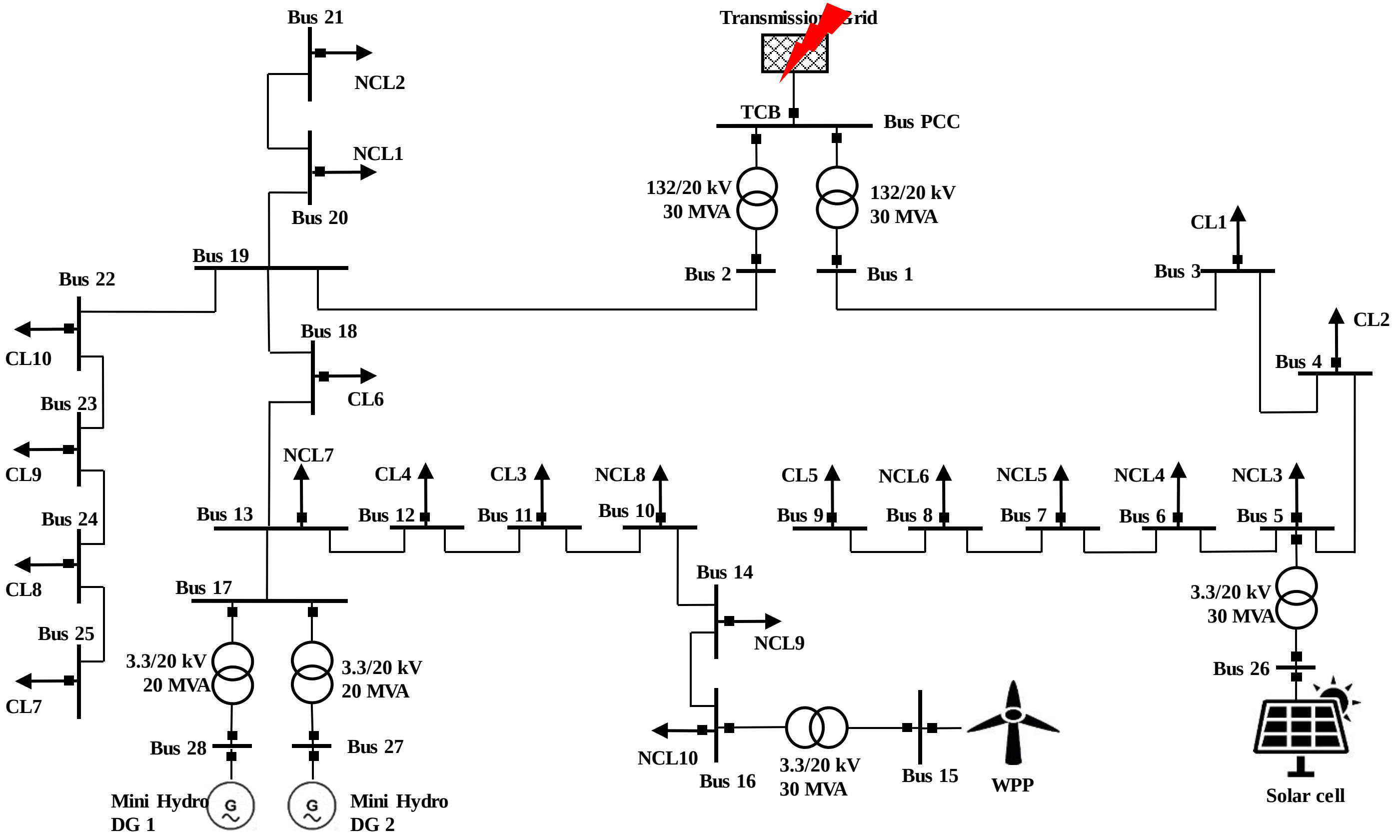
Optimization Function: minimize the total cost of curtailment.

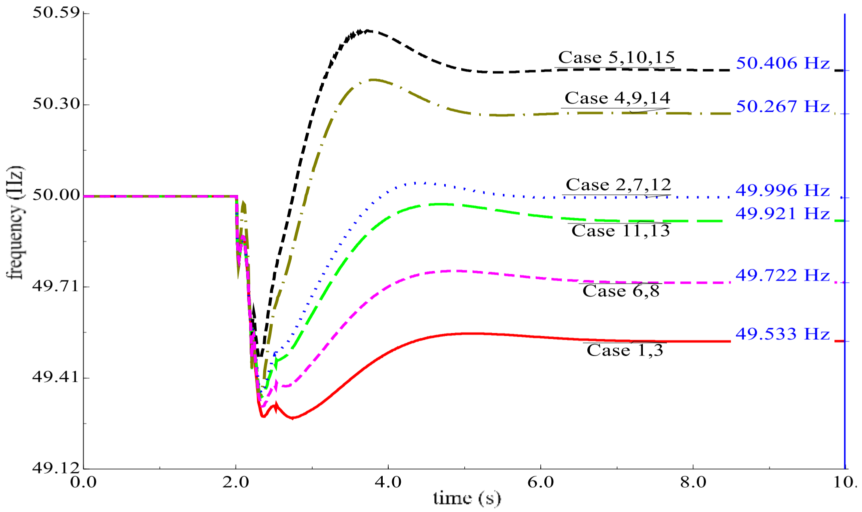
Constraints:

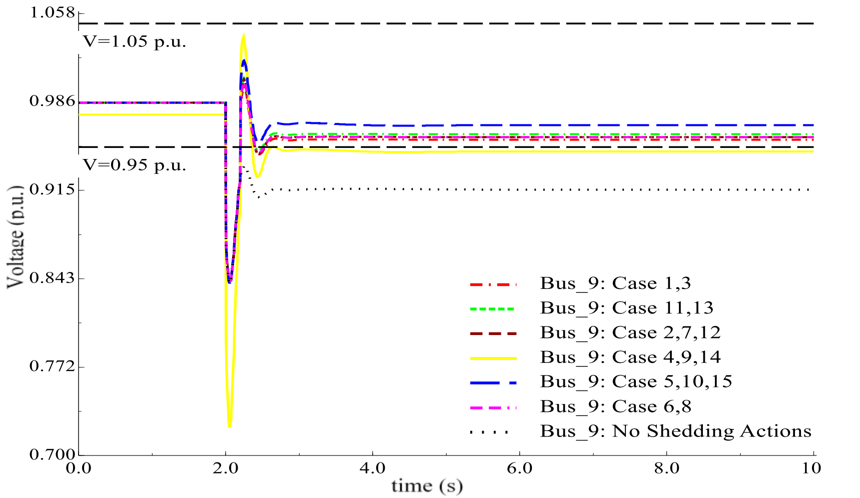
avoid voltage bounds violation in the nodes of the grid

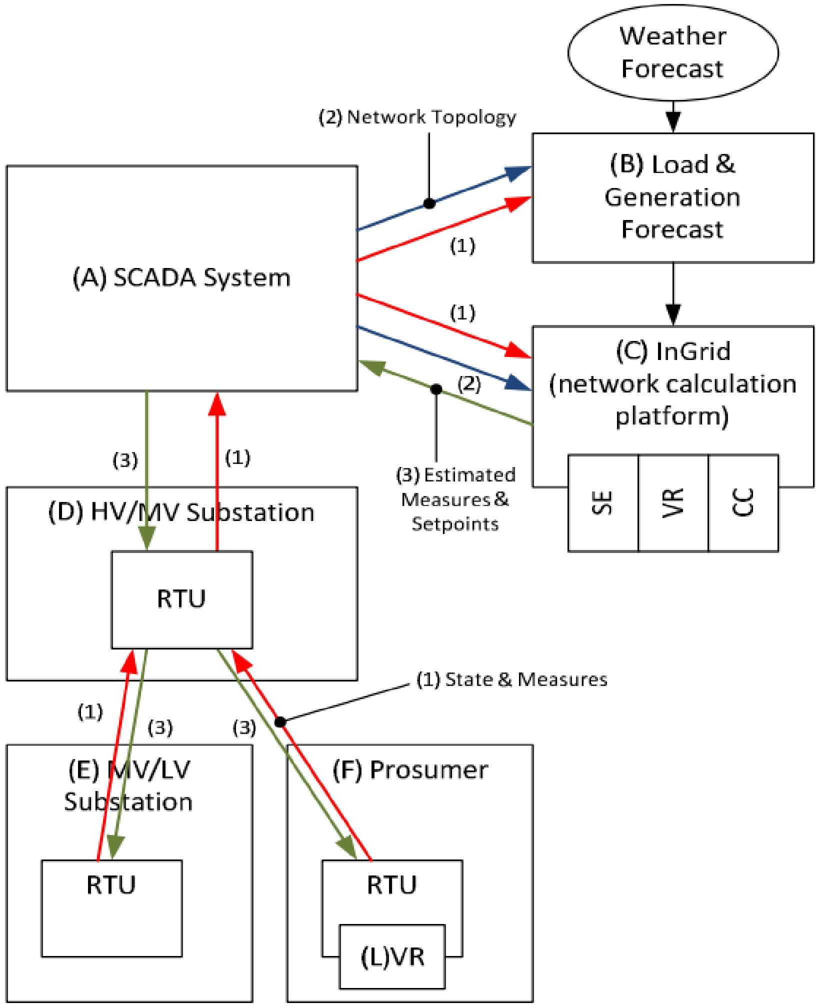


Results


Transmission Grid
TCB
Bus PCC
132/20 kV
30 MVA
132/20 kV
30 MVA
Bus 2
Bus 1
Bus 21
NCL2
NCL1
Bus 20
Bus 19
Bus 22
CL10
Bus 18
CL6
Bus 23
CL9
Bus 24
CL8
Bus 25
CL7
CL1
Bus 3
CL2
Bus 4
NCL7
Bus 13
CL4
Bus 12
CL3
Bus 11
NCL8
Bus 10
CL5
Bus 9
NCL6
Bus 8
NCL5
Bus 7
NCL4
Bus 6
NCL3
Bus 5
Bus 17
3.3/20 kV
20 MVA
3.3/20 kV
20 MVA
Bus 28
Bus 27
Mini Hydro
DG 1
Mini Hydro
DG 2
Bus 14
NCL9
NCL10
Bus 16
3.3/20 kV
30 MVA
Bus 15
WPP
3.3/20 kV
30 MVA
Bus 26
Solar cell


frequency (Hz)
time (s)
50.59
50.30
50.00
49.71
49.41
49.12
0.0
2.0
4.0
6.0
8.0
10.
Case 5,10,15
50.406 Hz
Case 4,9,14
50.267 Hz
Case 2,7,12
49.996 Hz
49.921 Hz
Case 11,13
49.722 Hz
Case 6,8
49.533 Hz
Case 1,3


Voltage (p.u.)
time (s)
1.058
0.986
0.915
0.843
0.772
0.700
0.0
2.0
4.0
6.0
8.0
10
V=1.05 p.u.
V=0.95 p.u.
Bus_9: Case 1,3
Bus_9: Case 11,13
Bus_9: Case 2,7,12
Bus_9: Case 4,9,14
Bus_9: Case 5,10,15
Bus_9: Case 6,8
Bus_9: No Shedding Actions



Shown functionalities require:

- the network be continuously monitored through RTUs;
- production and consumption be constantly forecasted;
- fast communication systems for data collection and command transmission;
- data centralization by SCADA systems.

Thank you for attention