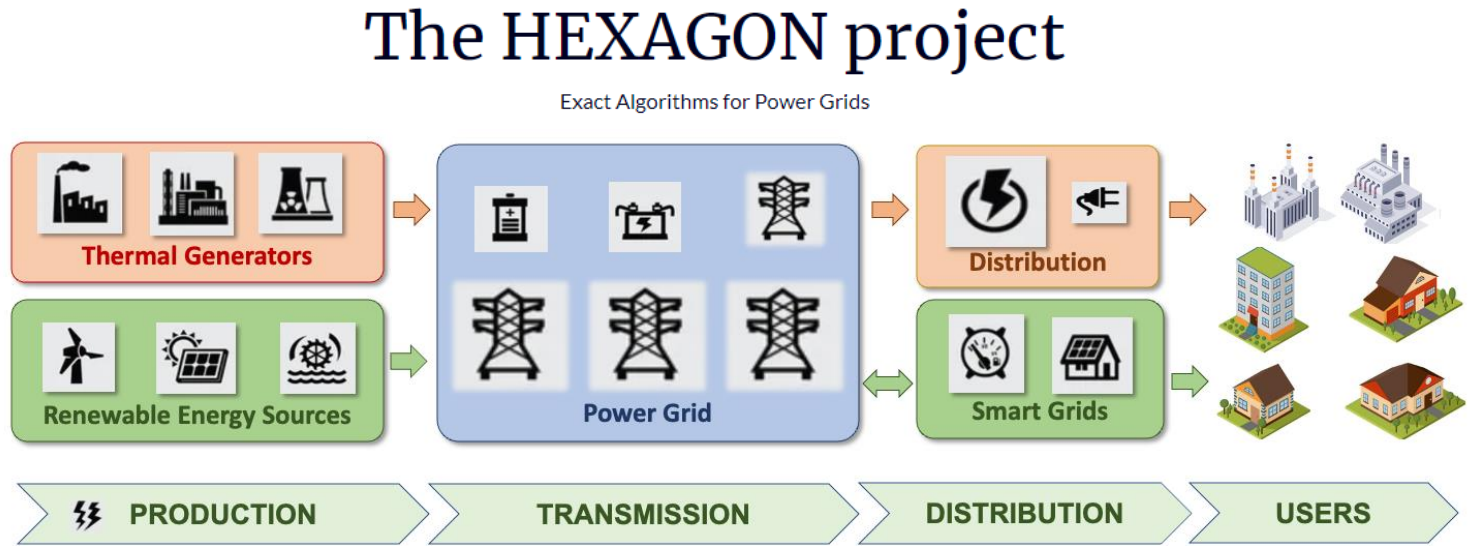
Coordinated planning of transmission and distribution networks based on optimization

Marco Rossi

June 18th, 2024



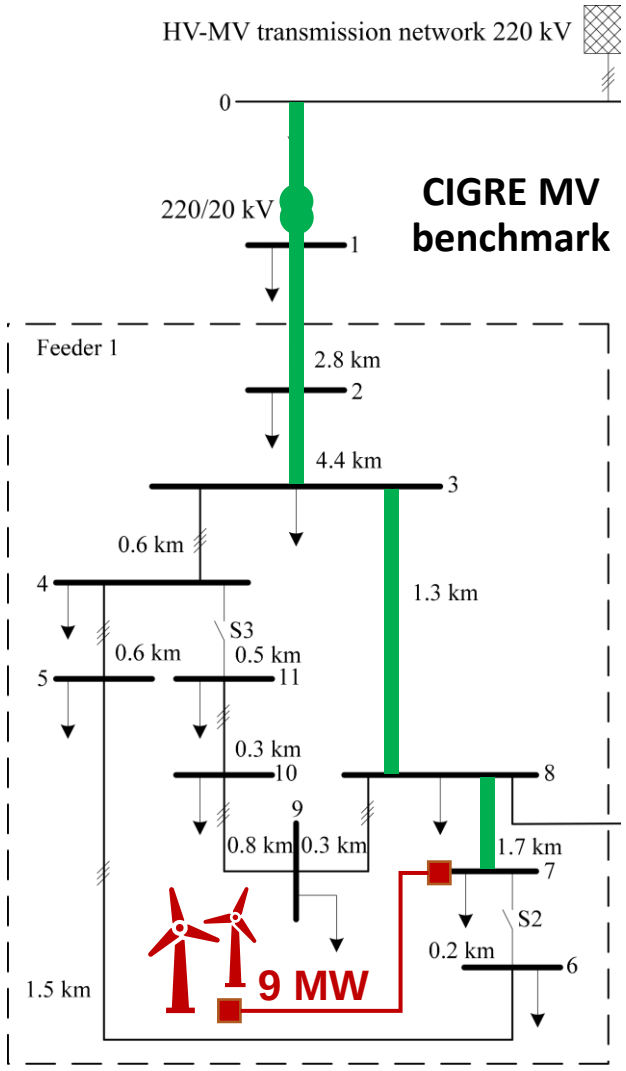
Planning of distribution network

Flexible demand/generation/storage can provide a multitude of services and distribution system operators could exploit them as **alternative planning option** with respect to conventional grid reinforcement:

min ***Reinforcement Costs***

such that

- distribution grid constraints are respected



Planning of distribution network

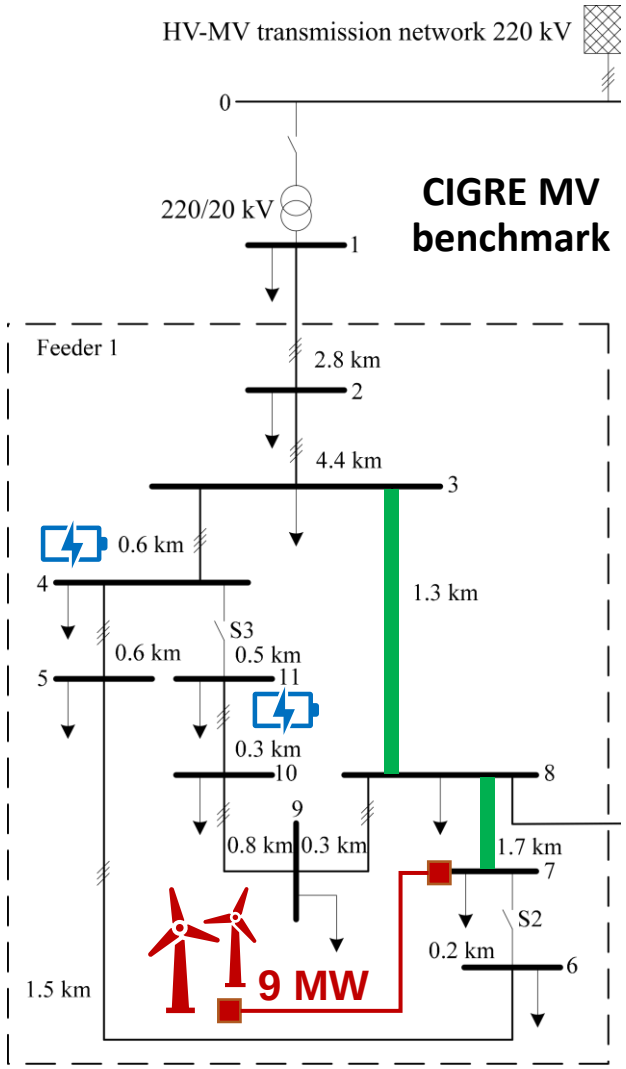
Flexible demand/generation/storage can provide a multitude of services and distribution system operators could exploit them as **alternative planning option** with respect to conventional grid reinforcement:

$$\min \textit{Reinforcement Costs} + \textit{Flexibility Costs}$$

such that

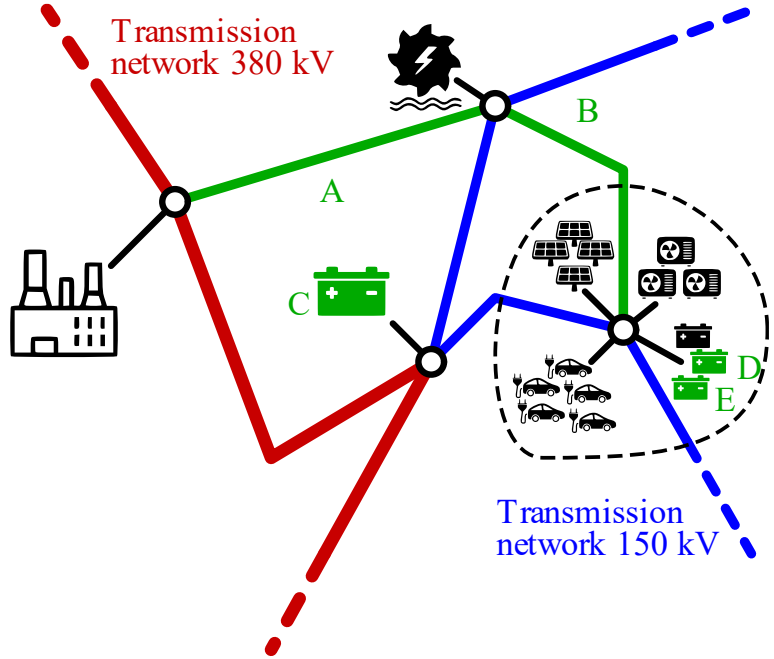
- distribution grid constraints are respected

The engagement of existing/new **flexible resources** and the related **costs** can be competitive with respect to the reinforcement of grid sections.



Planning of transmission network

Flexible demand/generation/storage can provide a multitude of services and transmission system operators could exploit them as **alternative planning option** with respect to conventional grid reinforcement.



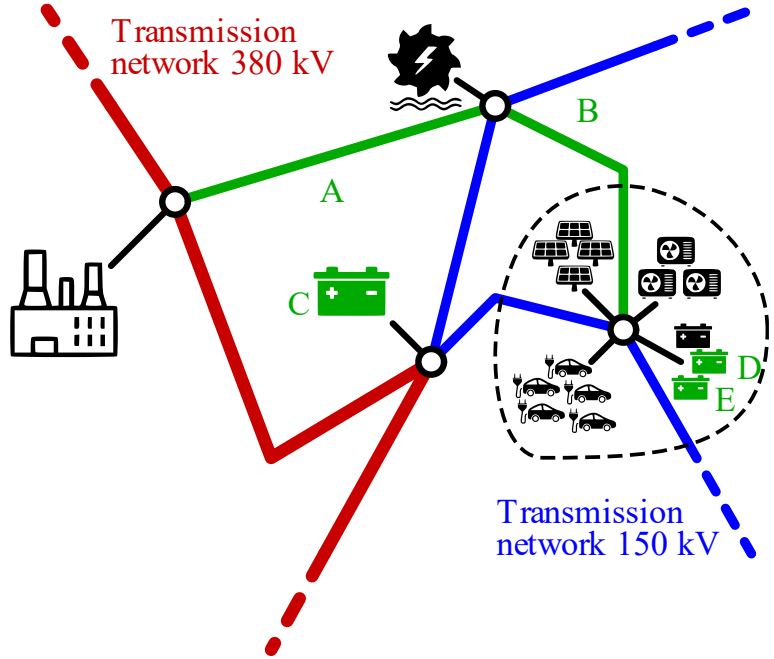
min ***Reinforcement Costs*** + ***Flexibility Costs***

such that

- transmission grid constraints are respected

Joint transmission & distribution planning

Flexible demand/generation/storage can provide a multitude of services and transmission system operators could exploit them as **alternative planning option** with respect to conventional grid reinforcement.

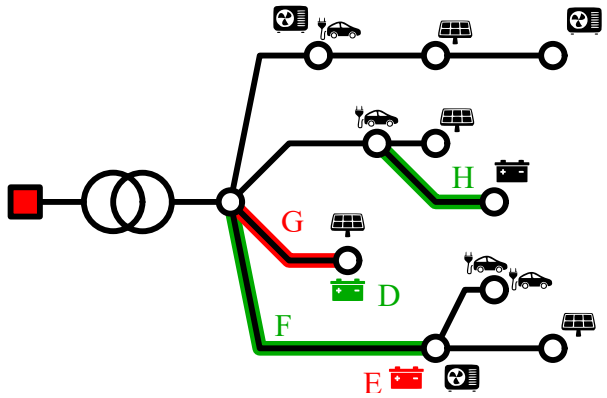


min ***Reinforcement Costs*** + ***Flexibility Costs***

such that

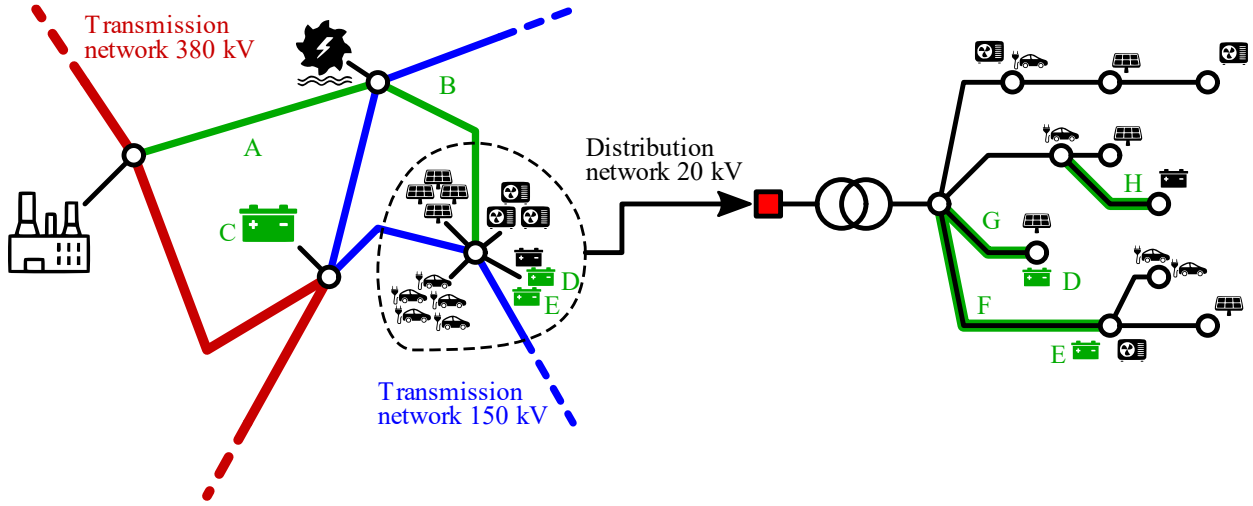
- transmission grid constraints are respected
- distribution grid constraints are respected

A large portion of the **available flexibility** is expected to be located at **distribution level**, and its exploitation for transmission services needs to consider also lower voltage systems.



Joint transmission & distribution planning

Optimal planning (for the entire system) needs the simultaneous consideration of both distribution and transmission requirements



⚠ Unbearable optimization problem for state-of-the-art of mathematical solvers

- Model complexity (DC+AC OPF)
- Dimension of the problem (number of variables and long-time horizons)

⚠ Lack of transparency and standards to exchange information among transmission and distribution system operators

Decoupled and collaborative T&D Planning

Transmission and distribution **separation in planning routines** is still a requirement, but procedures can be updated in order to consider the potential of power/energy flexibility outside of the planning perimeter.

For what concerns **distribution network**, there is a **planning conflict**

Minimization of the distribution planning cost

min ***Reinforcement Costs*** + ***Flexibility Costs***

such that

- distribution grid constraints are respected

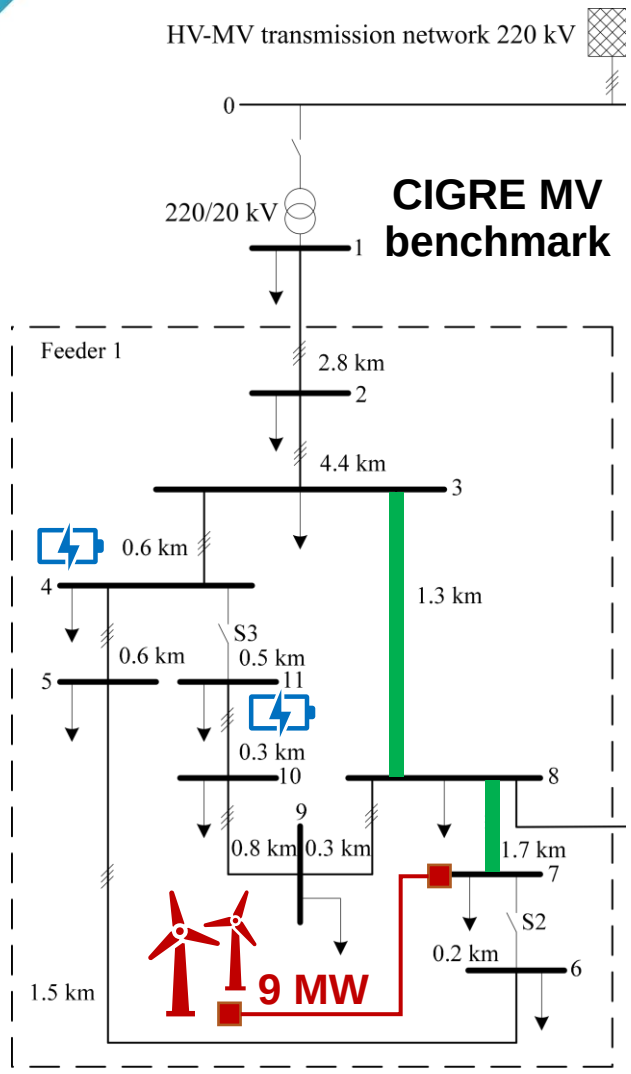
Maximization of local flexibility for transmission services

max ***flexible power exchange btw. T&D***

such that

- distribution grid constraints are respected
- Reinforcement and flexibility costs are disregarded

Distribution planning options

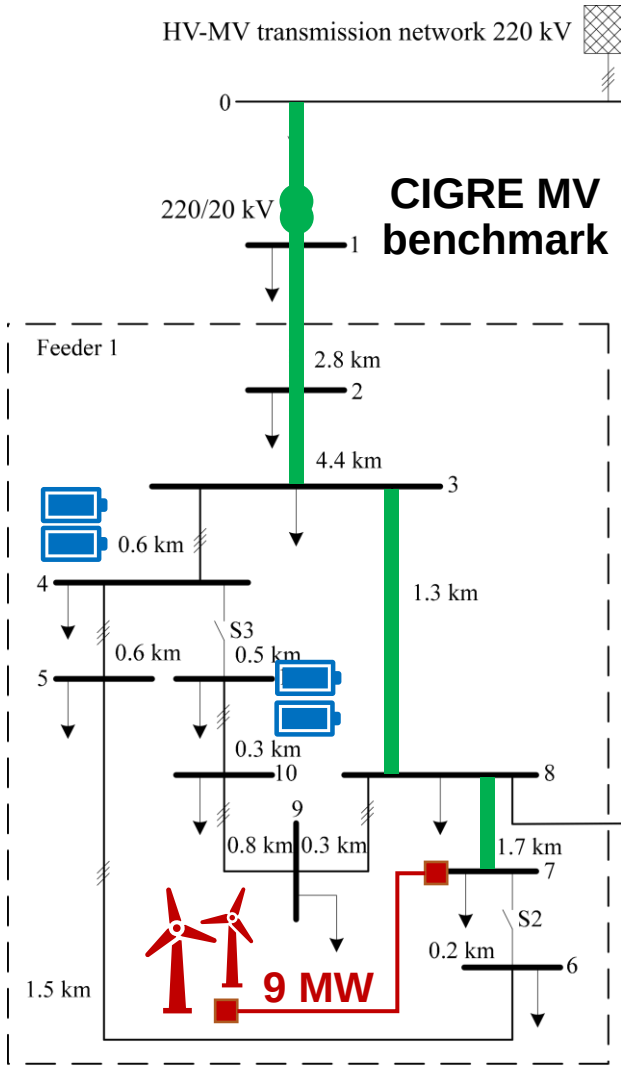


Minimization of the distribution planning cost

- 3 km reinforced lines
- Storage units provide local congestion management services
- **Reinforcement** + **flexibility use** = **691 k€**

Maximization of local flexibility for transmission services

- 10.2 km reinforced lines and substituted distribution transformer
- Local storage units **enhanced** and available for transmission services
- **Reinforcement** + **flexibility investments** = **2,792 k€**
  (*local use of flexibility* = 0)



More distribution planning options

More options can be explored to determine **trade-offs** between minimum planning costs and maximum flexibility for transmission services

	Investment costs (on local network) [k€]	flexibility use (distribution services) [k€]	Equivalent storage flexibility for transmission services
✓	446	245	1.0 MW / 2.0 MWh
✓	1,006	245	2.0 MW / 4.0 MWh
✗	1,566	245	2.0 MW / 4.0 MWh
✗	1,706	245	2.0 MW / 4.0 MWh
✓	2,792	0	3.6 MW / 7.2 MWh

intermediate options

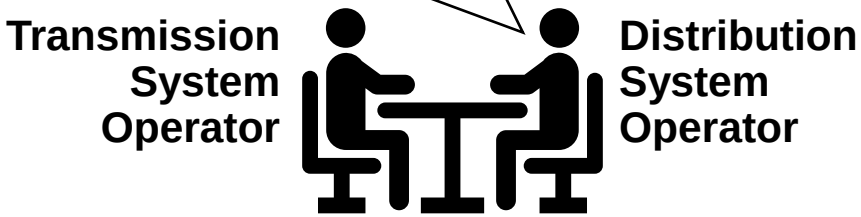
max ***flexible power exchange btw. T&D***

such that

- distribution grid constraints are respected
- limited reinforcement costs

Coordinated T&D Planning

Investment costs (on distrib. network) [k€]	Equivalent storage flexibility for transmission services
446	1.0 MW / 2.0 MWh
1,006	2.0 MW / 4.0 MWh
2,792	3.6 MW / 7.2 MWh



Simple and efficient cooperation between system operators:

- The identified distribution planning options can be negotiated with a limited exchange of standard and non-sensitive information

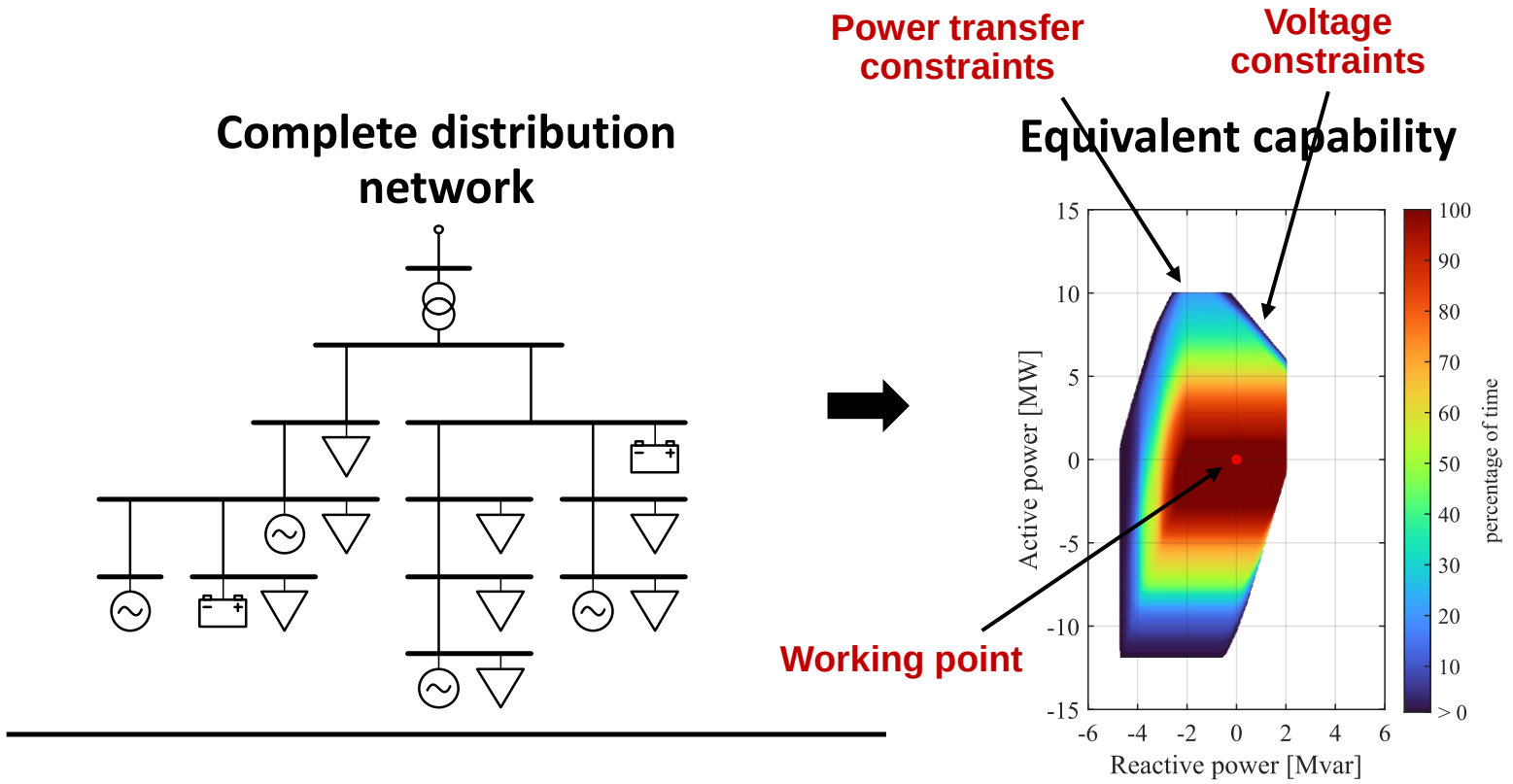
Transmission system operator can run its own planning routines (separately) by considering the proposed options and related costs.

min ***Reinforcement Costs*** + ***Flexibility Costs***

such that

- transmission grid constraints are respected
- distribution grid planning options are considered

Modelling of distribution flexibility



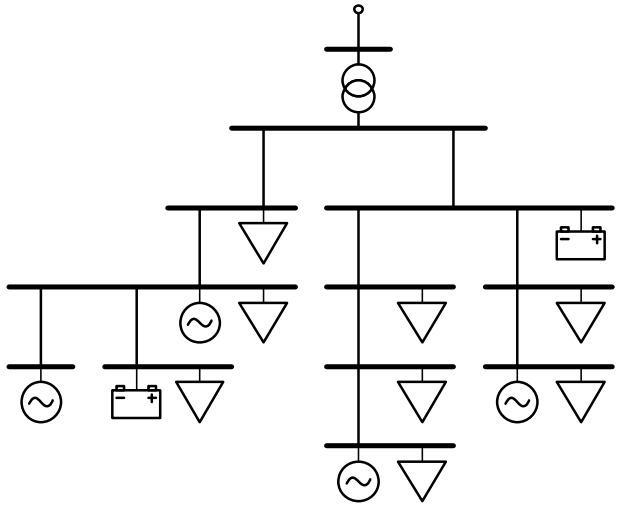
The entire distribution network can be seen as a unique flexible **Virtual Unit**.

Each point of the **equivalent capability** corresponds to the optimal dispatch of distribution resources when transmission system requires a variation with respect to the **working point**.

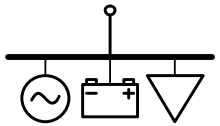
Conventional Optimal Power Flow algorithms **do not include a standard model** for units characterized by complex power capabilities.

Modelling of distribution flexibility

Complete distribution network



Surrogate model



The entire distribution network is approximated by means of a **Surrogate Model**.

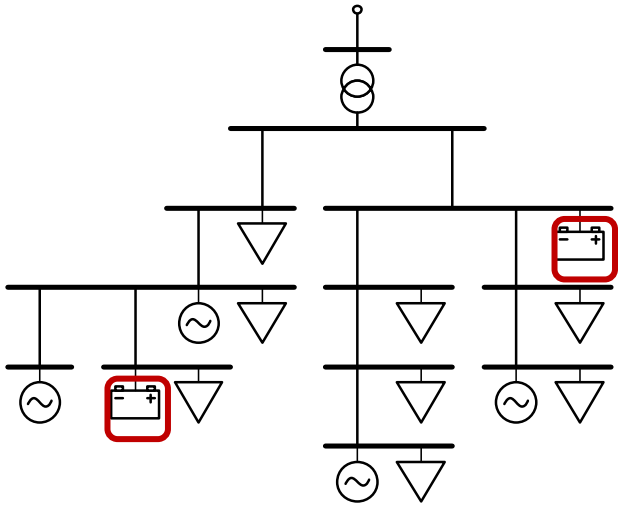
The surrogate model approximates the network flexibility behavior around the current working point by using **standard Power Flow elements**.

The adoption of a surrogate model introduces approximations:

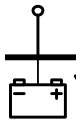
- It represents a **sub-set of the possible flexibility margins**
- The costs of flexibility associated to the possible working points might be **non-optimal**

Surrogate model construction (storage)

Complete distribution network

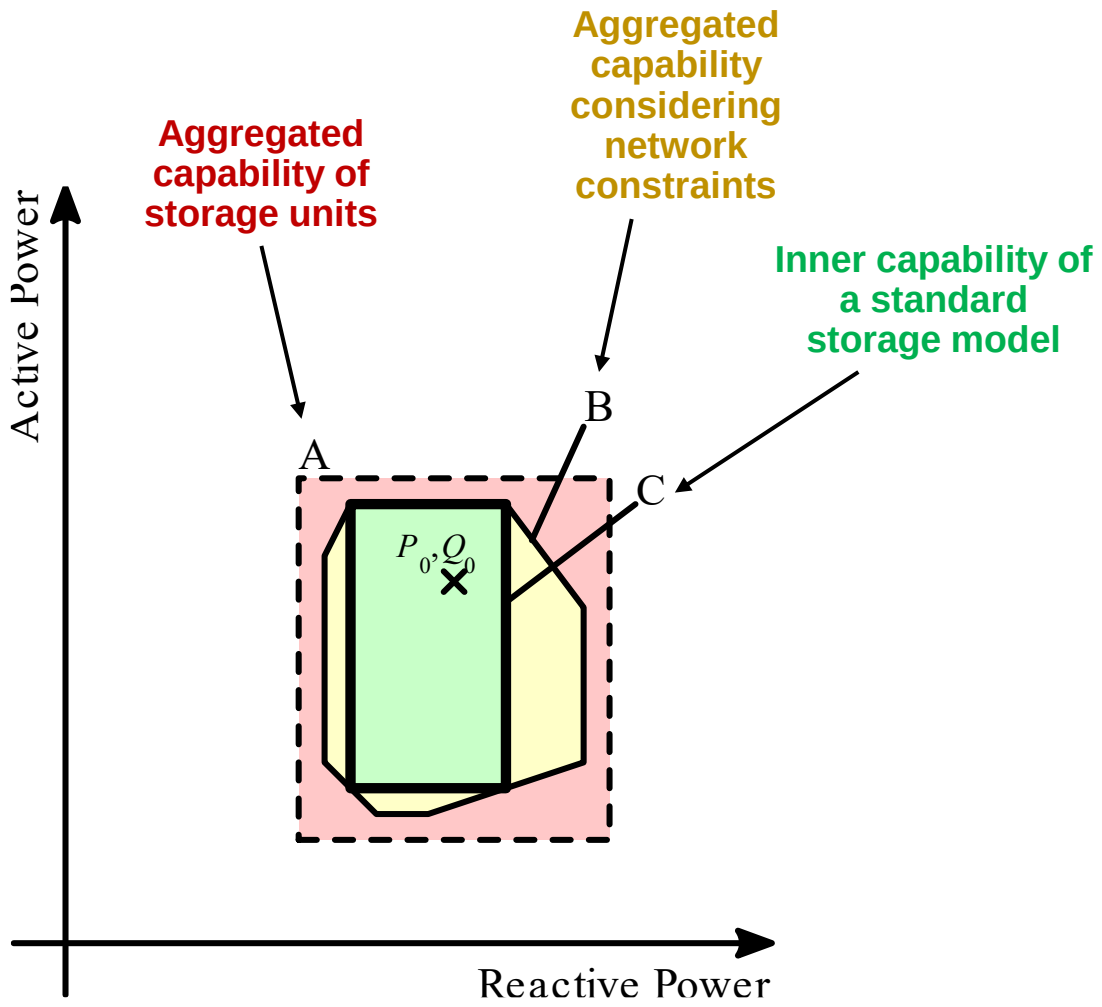


Surrogate model



All the other elements (generators and loads) are temporarily considered as non-dispatchable units.

Surrogate model construction (storage)



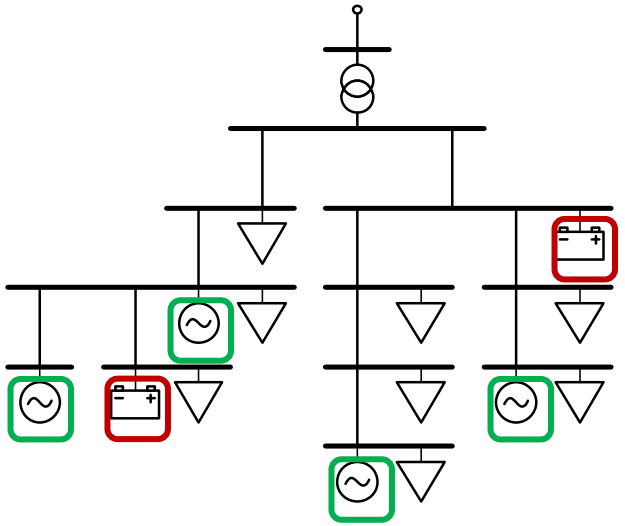
Network limits reduce the amount of flexibility of local storage units that can be exploited by transmission network.

To model the residual flexibility, one of the inscribed rectangles of the **limited aggregated capability** is extracted and assigned to the **surrogate storage model**.

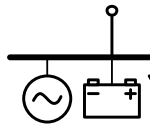
(storage units are assumed to feature a rectangular power capability)

Surrogate model construction (generation)

Complete distribution network

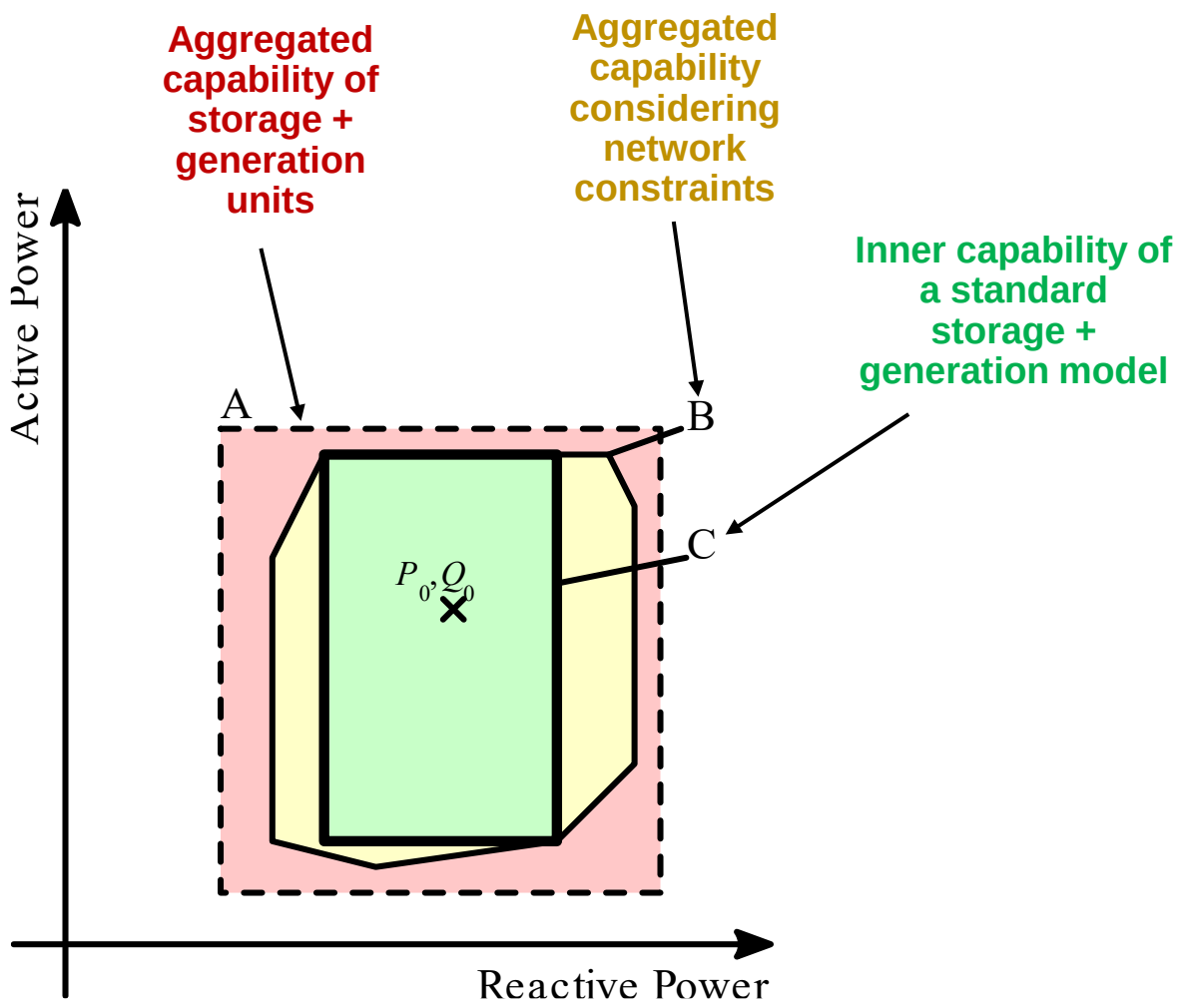


Surrogate model

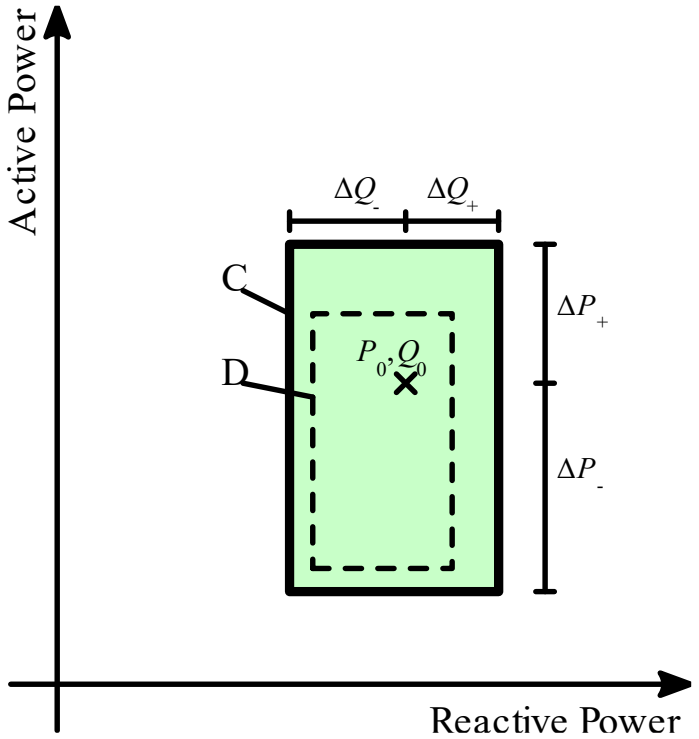


Only flexibility from storage (from previous step) and generators is considered.

Surrogate model construction (generation)

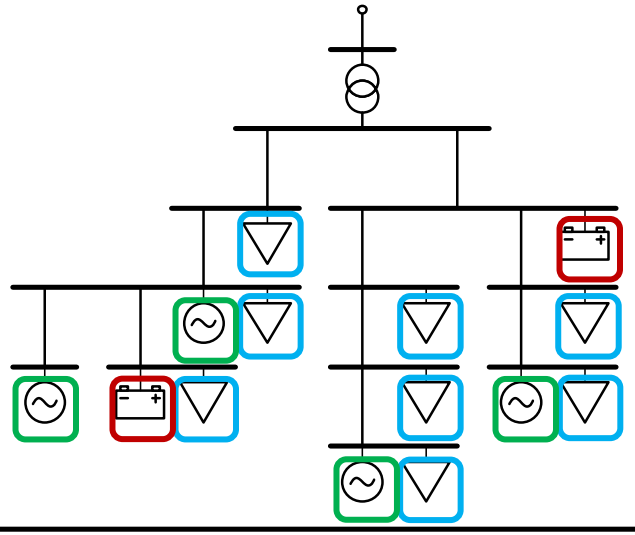


The **surrogate generator model** is deduced by the shape of the inner capability, from which the storage capability (D) needs to be subtracted.

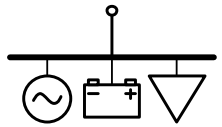


Surrogate model construction (load)

Complete distribution network

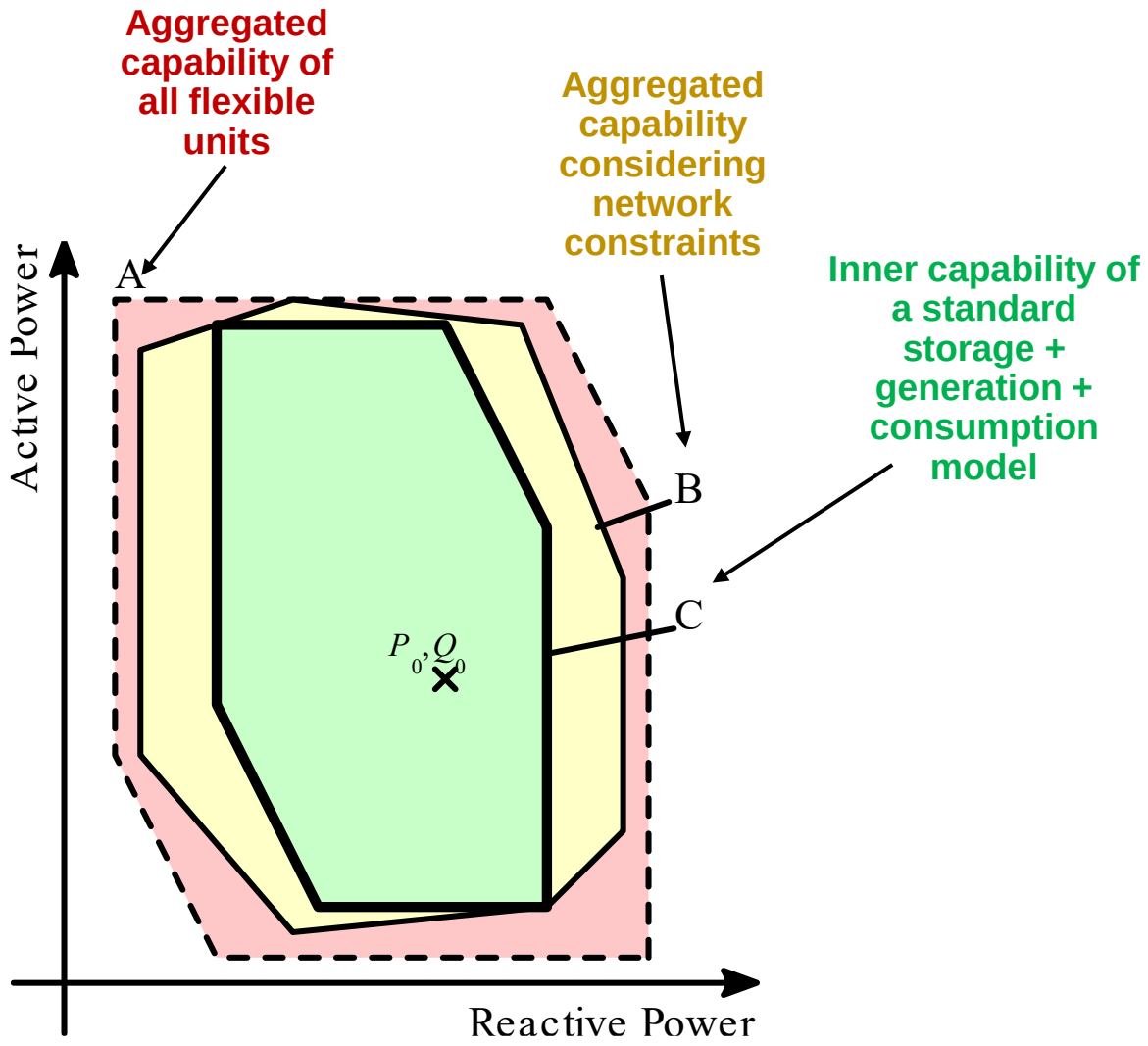


Surrogate model

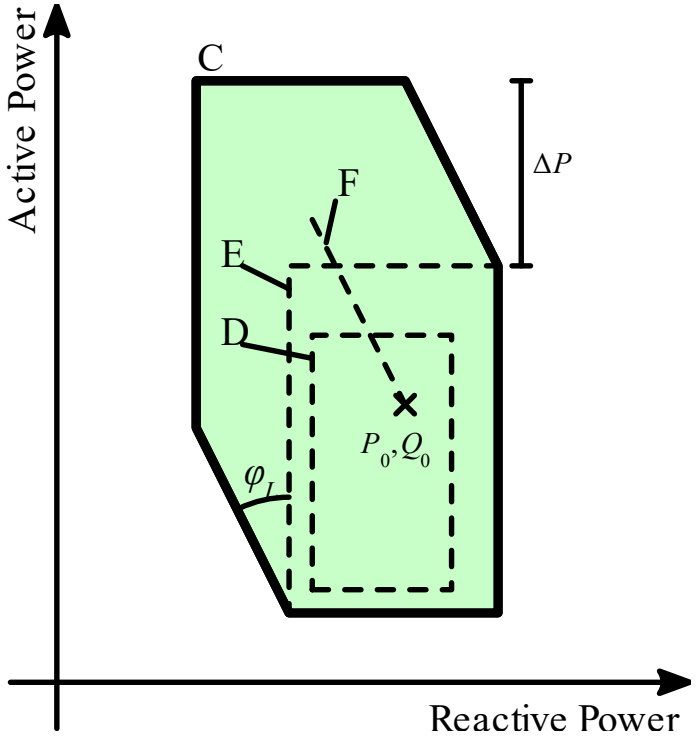


The flexibility of all network elements is considered.

Surrogate model construction (load)



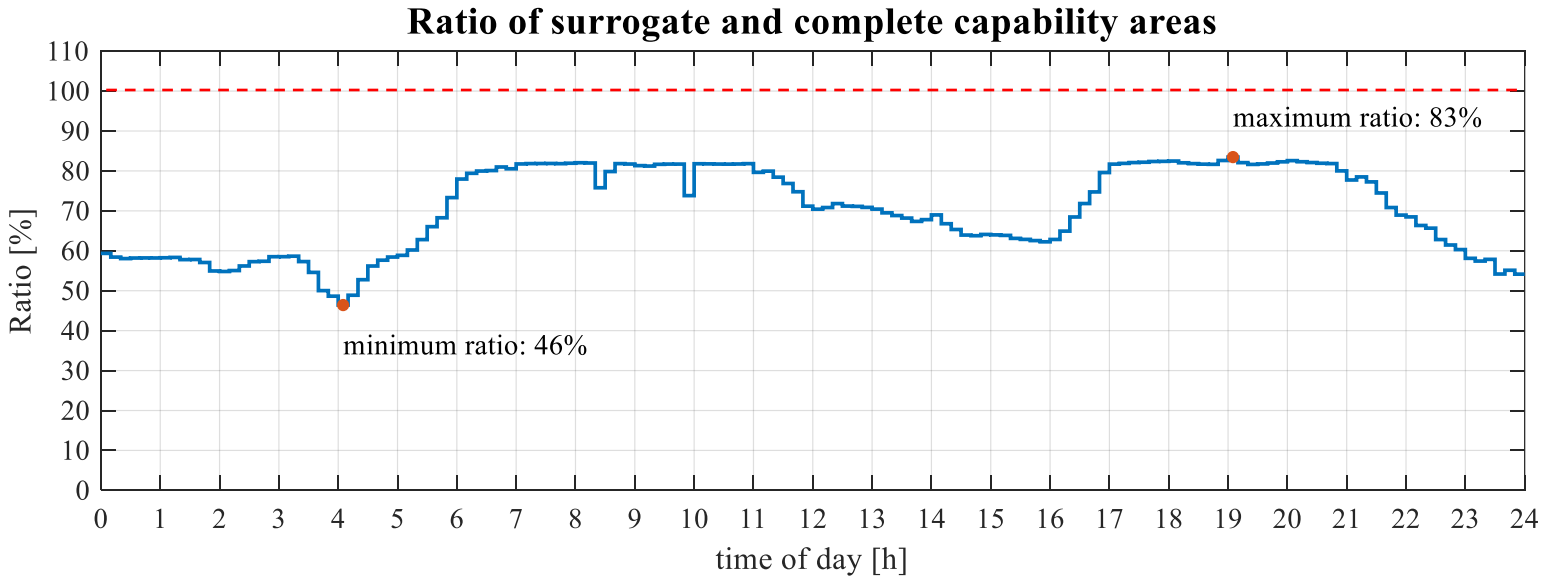
The **surrogate load model** (F) is deduced by the shape of the inner capability, from which the storage capability (D) and the generator capability (E) needs to be subtracted.

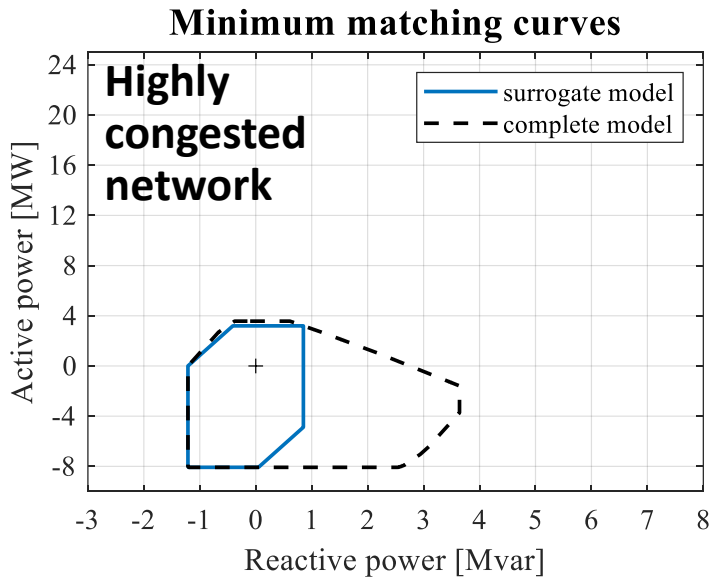


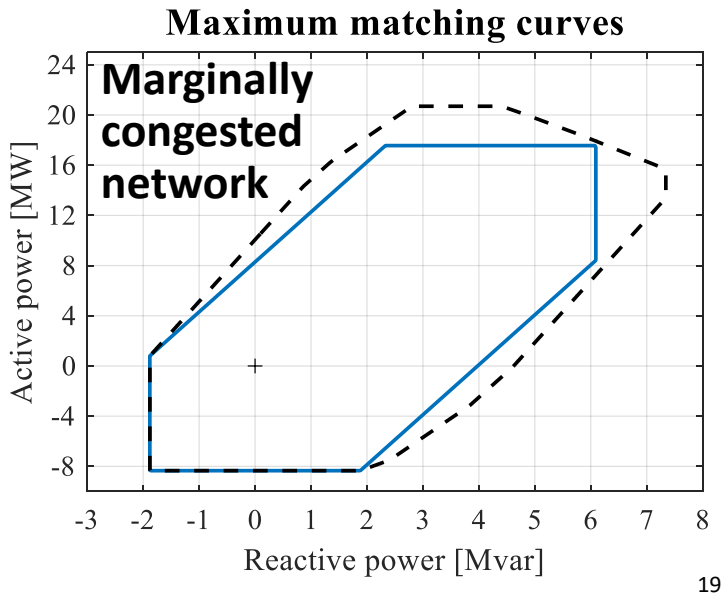
Surrogate model sub-optimality

Surrogate model includes a **sub-set of the possible working points** of a distribution network.

Because of **distribution network constraints**, the capability of the lumped standard elements does not generally match the actual one.

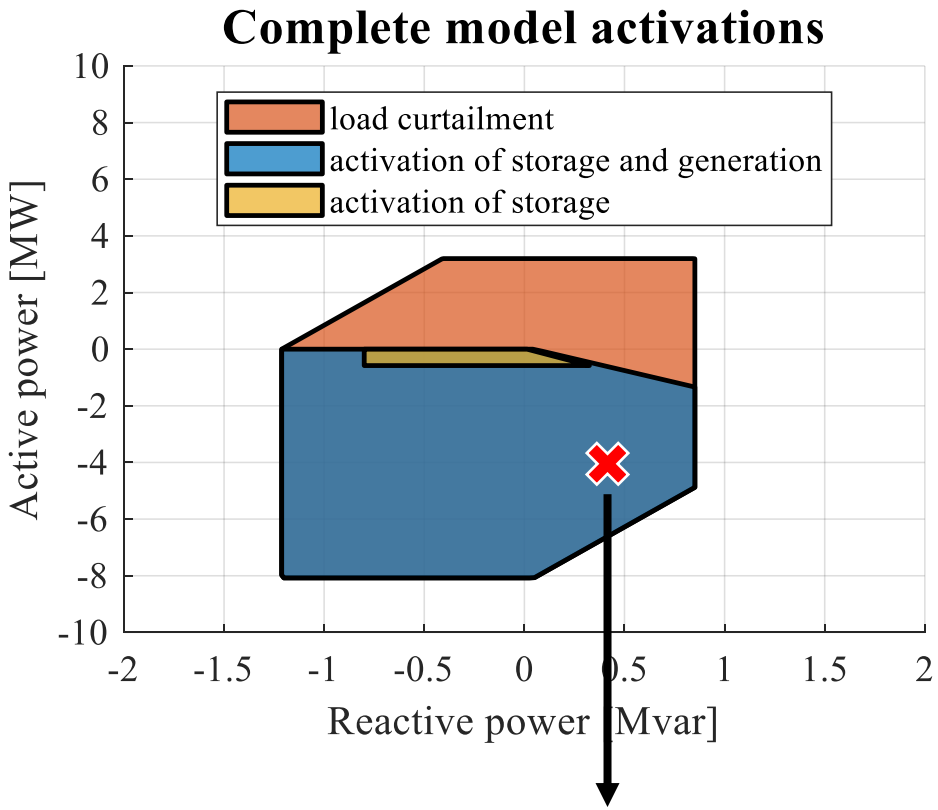






Surrogate model sub-optimality

Activation on the surrogate model **does not generally coincide** with the one resulting from the optimal dispatch for the selected working point ✖



Redispatch of storage, and generators

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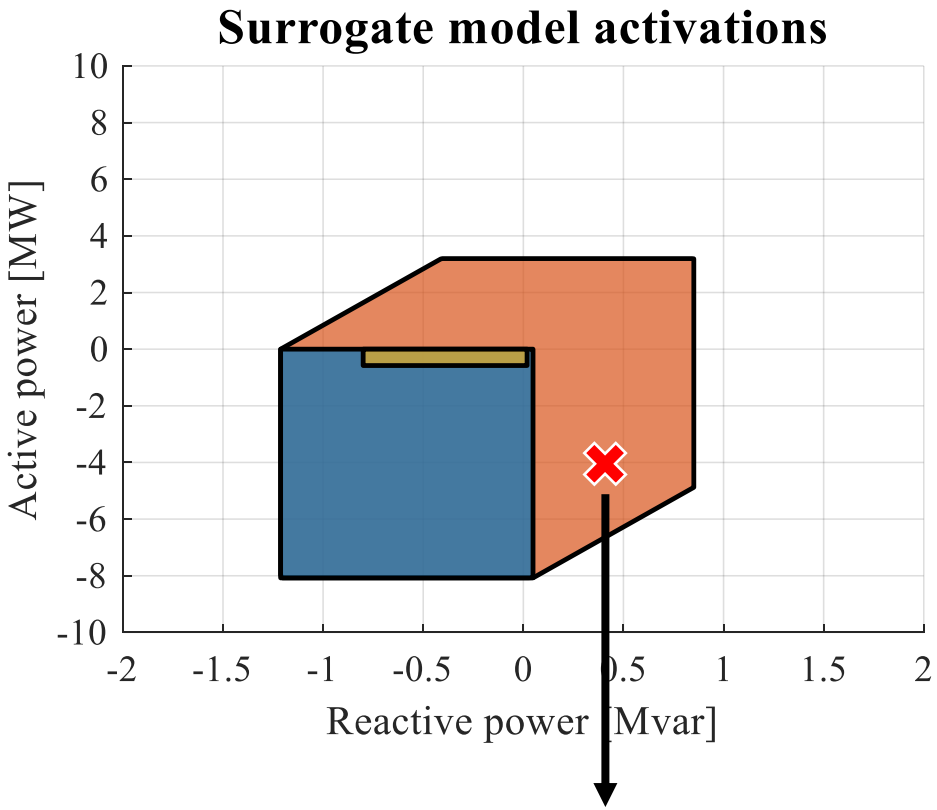

Redispatch of storage, generators and loads

Surrogate model sub-optimality

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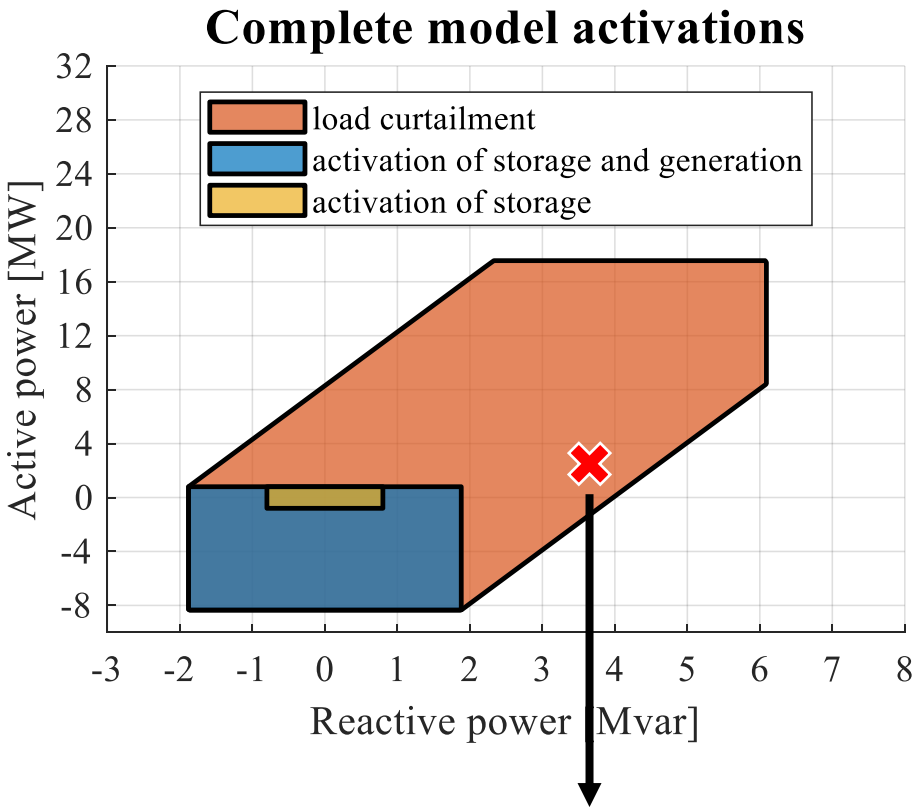

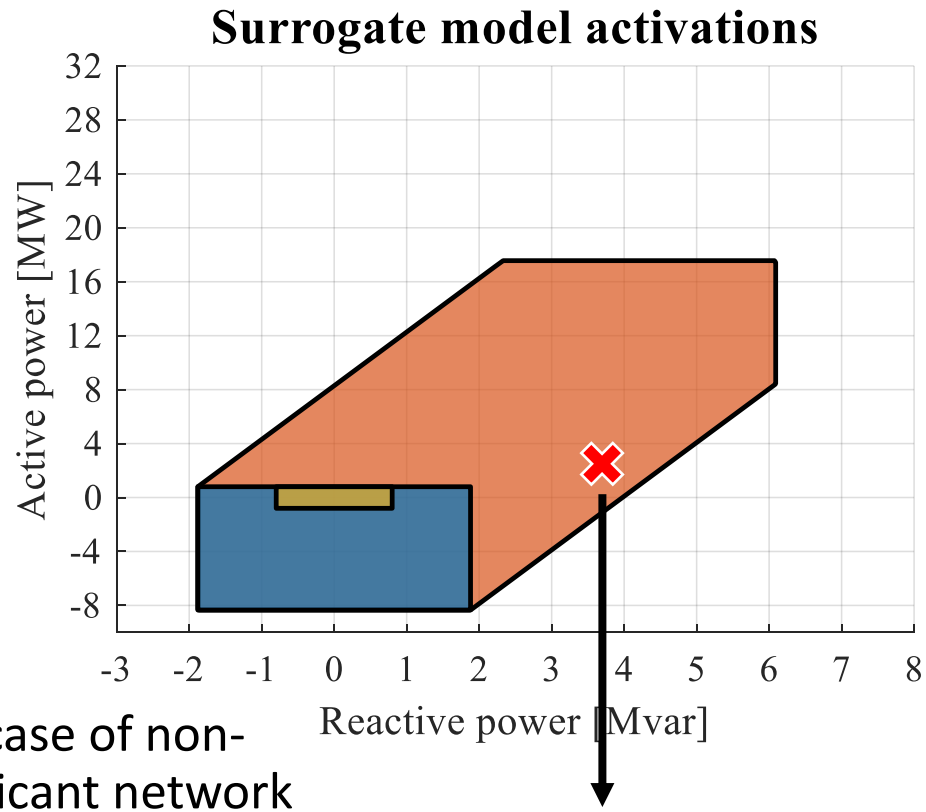

Redispatch of storage, generators and loads

In case of non-significant network constraints

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Redispatch of storage, generators and loads

Conclusions

A novel paradigm (still in the early development phases) for the planning of distribution networks has been presented, which consider a fundamental aspect:

- **Local resources can be exploited for both local and global flexibility services**

Although the procedure is characterized by a non-negligible complexity, it introduces **significant advantages** for a **global optimization** of distribution and transmission systems. It guarantees:

- **Separated management** of the transmission and distribution planning problem
- Simple and efficient **cooperation between system operators**

References

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M. Rossini *et al*., "A surrogate model of distribution networks to support transmission network planning," *27th International Conference on Electricity Distribution (CIRED 2023)*, Rome, Italy, 2023, pp. 2567-2571

Thank you for your kind attention

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