Economic assessment of distribution network planning: a practical approach

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Outline of the talk

- Context and challenges in distribution planning
  - Integration of decentralized renewable energy sources and evolution in demand
  - Planning Vs reinforcement
  - Alternatives
- Small-scale examples of constraints in distribution networks
- Approaches to alleviate distribution constraints
  - Reinforcement
  - Technology/Operational practices as alternatives
- Economic assessment of potential solutions
  - Cost/Benefit analysis
  - Business models
- Early conclusions
- Future works
Context and challenges

- **Distribution systems in Europe**
  - A variety of voltage levels
  - Different sizes of feeder lengths
  - Different types of ownership/regulation

- **Challenges in Power distribution**
  - Growth and relocation of demand
  - Massive integration of distributed generation
  - Limited acceptability of overhead infrastructure
  - Growing expectations for power quality and cost-efficiency

- **A wide range of solutions**
  - Technology
  - Operation: Sense/communicate/compute/control
  - Regulation

- **Research goal:** identify best strategies to alleviate distribution network constraints and assess their implications for stakeholders
Research focus

- Focus on Medium Voltage constraints

- Three ways to address changes in local conditions/requirements:
  - **Network planning**
    - (challenging) optimization of the network topology and assets
    - Possibly based on a green-field approach or taking the existing infrastructure as starting point
    - Usually considered for long-term evolutions and/or to check consistency of operators’ practices

  - **Network reinforcement**
    - Exploiting the actual infrastructure without significant change of the topology mainly by re-sizing wires
    - Preferred approach in the case of incremental changes of network users
    - Side-advantages: e.g. reduction of network losses, improvement of power quality, low uncertainty
    - Actual procedure by most DSOs to fit network to usages based on past measurements:
      - when power flows/voltages are out of a specific range, reinforcement is considered

  - **Alternatives to reinforcement**
    - Technologies and operational practices may help solving constraints/keeping system state within the targetted operation range
    - This may help avoiding costly reinforcement, but to what extent?
Small-scale examples of constraints

**High-voltage constraints:**

- **Causes**
  - High active power flow from DG to the substation
  - Long feeders
  - High resistance of MVA cable ($R/X \sim 5$) such that $\Delta V/V \sim R.P + X.Q \sim R.P$

- **Typical conditions of occurrence**
  - Distributed generation concentrated away from the substation
  - Low demand and high generation
  - High-voltage occurs typically during 1-3 hours at lunch time in Spring/Summer (PV) or in the late night (wind)
Small-scale examples of constraints

Low-voltage constraints:

- **Causes**
  - High active power injection from the substation to (remote) loads
  - High resistance of MVA cable \((R/X \sim 5)\) such that \(\Delta V/V \sim R.P + X.Q \sim R.P\)

- **Typical conditions of occurrence**
  - Loads concentrated away from the substation
  - High demand and no/low generation
  - High-voltage occurs typically during 1-2 hours in the evening, in the night (around 1 am) or in the early morning (around 7 am)
Small-scale examples of constraints

**Other constraints:**

- **High current w.r.t. wire characteristics**
  - Same conditions of occurrence as voltage constraints
  - Usually appears after voltage constraints except for short feeders

- **Power quality constraints**
  - Most DSOs are incentivized to minimize loss of load energy
  - A significant part of their investments is motivated by quality and security issues

- **Interface constraints (reactive power exchange with the TSO)**
  - Conditions at the interface TSO/DSO are usually defined by contract/national regulation
  - They may set a range of reactive power at the interface subject to severe penalties for the DSOs
Approaches to alleviate distribution constraints

**General approach: reinforcement**

- **French regulation imposes reinforcement (at a minimum cost) when connecting new users:**
  - DG facilities support the costs associated with reinforcement at the same voltage level
  - The costs associated with the connection of loads are shared between the facility owner and the DSO

- **Different strategies to be selected case by case:**
  - Substituting wires by cables of a wider diameter (typically 150 or 240 mm²): tradeoff between the cost of burying network, the cost of cables, and operation expenditures (e.g. losses)
  - Creating a dedicated feeder/substation (to be shared by several DG facilities for example)
  - Redefinition of the network topology (involves planning)

- **Potential benefits:**
  - Reduction of network losses
  - Improvement in power quality
Approaches to alleviate high-voltage constraints

**Distributed generation reactive power capability**
- The idea is to have DG units absorbing reactive power in case of high voltage
  - It may be a local control

- French regulation imposes reactive power capability for the connection of new DG units:
  - Converters must be slightly over-sized
  - DG units must be able to provide a constant tan phi (constant reactive power could be even more helpful)

- Possible conflict with requirements at the interface:
  - Absorbing significant reactive power by high voltage means that much reactive power will flow at the substation, whereas active power may low (local demand low and high local generation) -> difficult to stay in the tan phi range at the substation
Approaches to alleviate high-voltage constraints

- **Distributed generation shedding**
  - The idea is to have DG units generating less in case of high voltage
    - It may be a local control

  - Nothing in the regulation foresees this solution:
    - DG may require a compensation (maybe by not paying the full cost at the connection)

  - **Order of magnitude of costs:**
    - Variable: mainly the costs of substituting energy

- **Distributed storage**
  - The idea is to have storage units consuming energy locally in case of high voltage and releasing energy later
    - It may be a local control but communication would increase the operational value of storage
Approaches to alleviate high-voltage constraints

- **Load tap changer dynamic setting**
  - The idea is to modulate the load tap changer reference value depending on the voltages across the feeder (and beyond)
    - Needs sensing and communication infrastructure
    - Also needs prediction/anticipation to avoid frequent changes of the setting
  - Feeders may face high-voltage situations while their neighbours (with no DG) have low voltages
    - The room for improvement may be small
  - **Order of magnitude of costs:**
    - High costs to equip substations with appropriate tap changers, when necessary
    - Relatively low cost for sensor/communication infrastructure
Approaches to alleviate low-voltage constraints

- **Reactive power injection**
  - The idea is to have distributed assets injecting reactive power in case of low voltage
    - It may be a local control and may use capabilities of D units for example
  - Less conflict with requirements at the interface:
    - Synchronization of reactive power injection with high power demand
  - Effect on distribution power losses?

- **Dispatchable distributed generation activation**
  - The idea is to have DG units injecting active power in case of low voltage
    - It may be a local control
  - Although micro(co)generation is likely to develop, local capacity may be limited and subject to uncertainty
  - Order of magnitude of costs:
    - Variable: mainly the difference between costs of operating dispatchable DG and the substituted energy
Approaches to alleviate low-voltage constraints

**Demand response**
- The idea is to have demand patterns adapting to constraints
  - Needs accurate local load forecast
  - Needs flexible customers in the constrained area

**Different types of demand response programs**
- Time of use tariffs: high/low retail price depending on the time of every day
- Peak day tariffs: very high retail prices for some days in the year/low retail price for the other days
- Short-term curtailment: not real application by residential customer as of today: mainly postponing usages

**Potential benefits are not only for DSOs but also for the generation portfolio**
- Demand response may improves generation adequacy / flexibility
Economic assessment of potential solutions

- **Perimeter of the cost/benefit analysis**
  - We consider the impact of solutions on the « local power system », including:
    - the local users (generation, storage and demand)
    - the local distribution system
    - the transmission system
    - centralized generation

- We will assess the costs and benefits of each solution
  - Financial transfers from one entity to another are not considered in the CBA

- We analyse only solutions (or combinations of solutions) that solve the constraints
  - Most of the benefit consists of solving the constraints
  - We do not consider regulatory solutions that may prevent the constraint by incentivizing new users to connect in more favorable locations
# Economic assessment of potential solutions

## Examples of assessment
- Costs and benefits for distributed generation shedding

<table>
<thead>
<tr>
<th>Segment impacted</th>
<th>Costs and Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decentralized generation</td>
<td>(- variable generation cost) in €/MWh. Reduction in variable generation costs by the local generation unit, a priori close to 0 for renewable energy sources</td>
</tr>
<tr>
<td>Centralized generation</td>
<td>(+ variable generation cost) in €/MWh. Increase in variable generation costs of centralized generation units depending on the amount of energy curtailed.</td>
</tr>
<tr>
<td>Transmission</td>
<td>(+ Δ transmission costs) in €/MWh. The impact on transmission costs is estimated based on the difference of payment by the DSO to the TSO according to the regulated transmission tariff. We differentiate here when the substation remains with a net consumption and when it injects power into the transmission grid.</td>
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</tbody>
</table>
### Economic assessment of potential solutions

#### Examples of assessment

- **Costs and benefits for peak day tariffs (activated by the DSO)**

<table>
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</tr>
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<tbody>
<tr>
<td>Local demand involved in the program</td>
<td>(+ loss of service cost) in €/MWh. Loss of service associated with the valorization of the response provided by the customer</td>
</tr>
<tr>
<td>Centralized generation</td>
<td>(- variable generation cost) in €/MWh. Decrease in variable generation costs of centralized generation units corresponding to the overall reduction in demand</td>
</tr>
<tr>
<td></td>
<td>(- investment costs in peak power plants) in €/kW/an. Peak day retail tariffs tend to reduce demand on peak days and may allow downscaling the peak generation capacity</td>
</tr>
<tr>
<td>Distribution</td>
<td>(- cost of power losses) in €/MWh. Mainly due to less energy demand</td>
</tr>
<tr>
<td>Transmission</td>
<td>(- Δ transmission costs) in €/MWh. The impact on transmission costs is estimated based on the difference of payment by the DSO to the TSO according to the regulated transmission tariff</td>
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Economic assessment of potential solutions

Impact on business models

- We focus here on:
  - the costs and benefits identified earlier
  - + financial transfers between entities

- Financial transfers strongly depend on the regulatory framework:
  - we consider the actual tariffs and rules
  - We may consider evolutions/alternative frameworks in further works

- The perimeter of analysis includes:
  - All consumers (paying the regulated distribution tariff)
  - Local consumers providing demand response services
  - The retailer/aggregation service provider
  - Centralized generation
  - Local decentralized generation
  - Storage operator
  - Regulated bodies
Economic assessment of potential solutions

Impact on business models

- **Regulated activities:**
  - As of today the costs/benefits supported by the DSOs and the TSOs are covered by the tariff.
  - The tariff is adjusted every year so that any solution (if allowed by the regulator) is assumed to be neutral with respect to the profitability (assumed to be close to zero) of the regulated entities.
  - Stricto sensu, under the current framework a low profitability is possible when the system operators invest in infrastructure.

- **Users:**
  - For most solutions, the users tend to be at the end of the value chain and will support the difference costs/benefits. But it may rely on different users:
    - Average consumer when expenses are supported by the DSO/TSO.
    - Local users (generation/demand) during the connection procedure if stated in the regulatory frameworks.

- **Non-regulated entities:**
  - Some solutions may also involve costs/benefits for the business model of non-regulated entities.
  - An increase/decrease in the activity of non-regulated entities may generate more/less profit.
Early conclusions

- The methodology has been applied to several study cases
  - Rural Vs Urban networks
  - Projection in 10-20 years (consideration of EV + LV PV)
  - Optional integration of renewable energy sources on the feeder

- Simulations performed with Matlab
  - Series of load flows (by step of 10 min over a year: projection of 2011)
  - Empirical modifications of the load curves for solutions involving demand response
  - Optimization tool for reactive power management, storage and generation shedding

- Early results
  - A variety of frequency and depth of the constraints (mainly high-voltage/low-voltage)
  - Reinforcement appears has a powerful way to deal with constraints, but:
    - Some flexible solutions may be of interest, at least to solve the most rare constraints
  - Some solutions may involve decisions/investments by entities that will not be rewarded
  - Some entities may be rewarded for detrimental solutions
    - Attempt to identify regulatory frameworks that allow the deployment of the best combinations of solutions
Future works

**Challenges of scalability**
- What can we deduce from case studies?
- How could we proceed to extend the results to a wider scope (national?)

**Challenges of modelling and decision-making**
- In our simulations, activation is decided with full knowledge of the load curves
- How would it perform if operators had to make decisions under uncertainty
  - Would it result similarly if we consider demand response as emergency tool instead of a preventive tool?
    - activate demand response only when security threshold are reached instead + deciding a reinforcement when demand response is activated too often
    - Vs
  - Activate demand response based on forecasts and keep the same mode of decision for reinforcement (when the threshold is reached, we reinforce)

**Challenges of regulation**
- What kind of regulation would allow the best solutions to be implemented
  - Need to consider the dynamics of entities in terms of investment decisions w.r.t. profitability expectations
  - Need for innovation in terms of innovative tariffs and rules?