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From fit and forget to active network management

Distribution networks traditionnally operated according to the **fit and forget doctrine**.

Fit and forget. Network planning is made with respect to a set of critical scenarios so as to assure that sufficient operational margins are always ensured (i.e., no over/under voltage problems, overloads) without any control over the loads or the generation sources.

Shortcomings. With rapid growth of distributed generation resources, the preservation of such conservative margins comes at continuously increasing network reinforcement costs.

The buzzwords for avoiding prohibitively reinforcement costs: **active network management**.

Active network management. Smart modulation of generation sources and loads (demand side management) so as to operate the electrical network in a safe way, without having to rely on significant investments in infrastructure.

GREDOR project. Redesigning in an integrated way the **whole decision chain** used for managing distribution networks so as to do active network management in an optimal way (i.e., maximisation of social welfare).

Decision chain

The four stages of the decision chain for managing distribution networks:

1. Models of interaction
2. Investments
3. Operational planning
4. Real-time control

1. Models of interaction

A model of interaction defines the flows of information, services and money between the different actors.
Defined (at least partially) in the regulation.

2. Investments

Decisions to build new cables, investing in telemeasurements, etc.

3. Operational planning

Decisions taken few minutes to a few days before real-time. Decisions that may interfere with energy markets. Example: decision to buy the day-ahead load flexibility to solve overload problems. Important: new investments may significantly affect the cost of operational strategies.

4. Real-time control

Almost real-time decisions. Typical examples of such decisions: modifying the reactive power injected by wind farms into the network, changing the tap setting of transformers. In the normal mode (no emergency situation caused by "unfortunate event"), these decisions should not modify production/consumption over a market period.

GREDOR as an optimisation problem

$\mathcal{M}$: set of possible **m**odels of interaction
$\mathcal{I}$: set of possible **i**nvestment strategies
$\mathcal{O}$: set of possible **o**perational planning strategies
$\mathcal{R}$: set of possible **r**eal-time control strategies

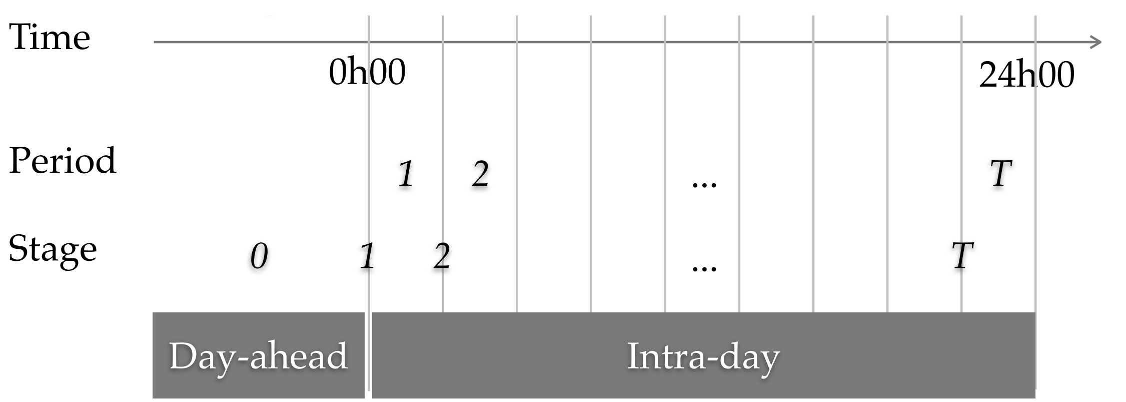
Solve:

$$\underset{(m,i,o,r)\in\mathcal{M}\times\mathcal{I}\times\mathcal{O}\times\mathcal{R}}{\arg\max} \quad social\_welfare(m,i,o,r)$$

A simple example

$\mathcal{M}$: reduced to one single element.

Model of interaction mainly defined by these two components:
1. Distribution Network Operator (DNO) can buy the day-ahead load flexibility service.
2. Between the beginning of every market period, it can decide to curtail generation for the next market period or activate the load flexibility service. Curtailment decisions have a cost. *Note:* No uncertainty when taking these curtailment decisions.



More about the load modulation service

- Any load offering a flexibility service must follow a baseline demand profile unless otherwise instructed by the DNO.
- The loads specify upward and downward demand modification limits per market period.
- Any modulation instructions by the DNO should not modify the net energy volume consumed by a flexible load over the market day, with respect to the baseline profile.
- In the day-ahead, the DNO analyzes the different offers and selects the flexible loads it will use for the next market day.

$\mathcal{I}$: made of two elements. Either to invest in an asset A or not to invest in it.

$\mathcal{O}$: the set of operational strategies is the set of all algorithms that (i)in the day-ahead process information available to the DNO to decide which flexible loads to buy (ii) process before every market period this information to decide (a) how to modulate the flexible loads (b) how to curtail generation.

$\mathcal{R}$: empty set. No real-time control implemented.

$social\_welfare(m, i, o, r)$: the (expected) costs for the DNO.

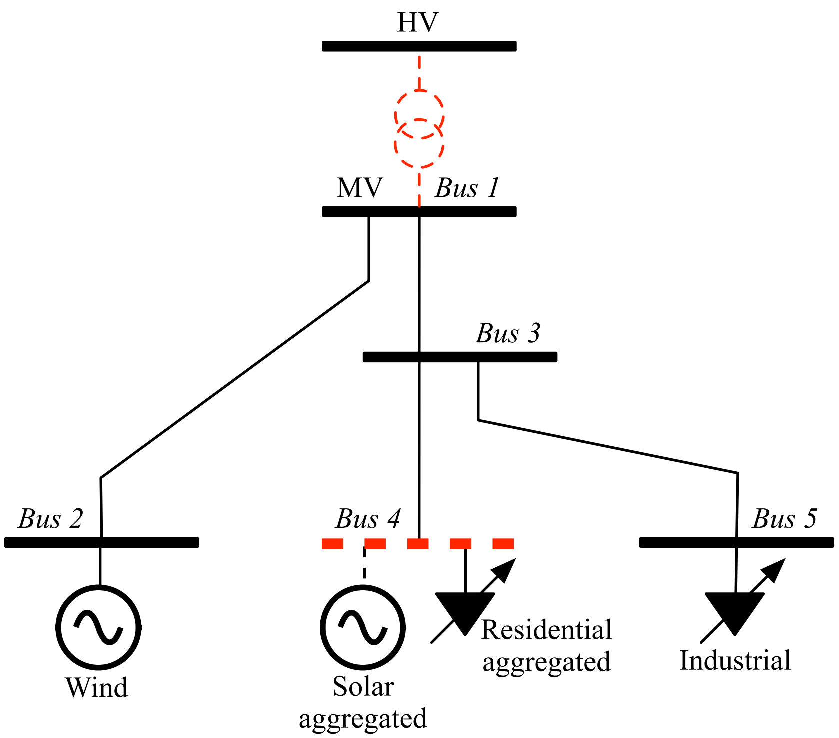
The optimal operational strategy

Let o^* be an optimal operational strategy. Such a strategy has the following characteristics:
1. for every market period, it leads to a safe operating point of the network (no overloads, no voltage problems).
2. there are no strategies in O leading to a safe operating point of the network and a smaller(expected) total cost than o^*. The total expected cost is defined as the cost of buying flexiblity plus the costs for curtailing generation.

It can be shown that the optimal operation strategy can be written as a stochastic sequential optimisation problem.

Solving this problem is challenging. Getting even a good suboptimal solution may be particularly difficult for large distribution networks and/or when there are the day-ahead strong uncertainty on the power injected/withdrawn at the different nodes of the distribution network.

The benchmark problem

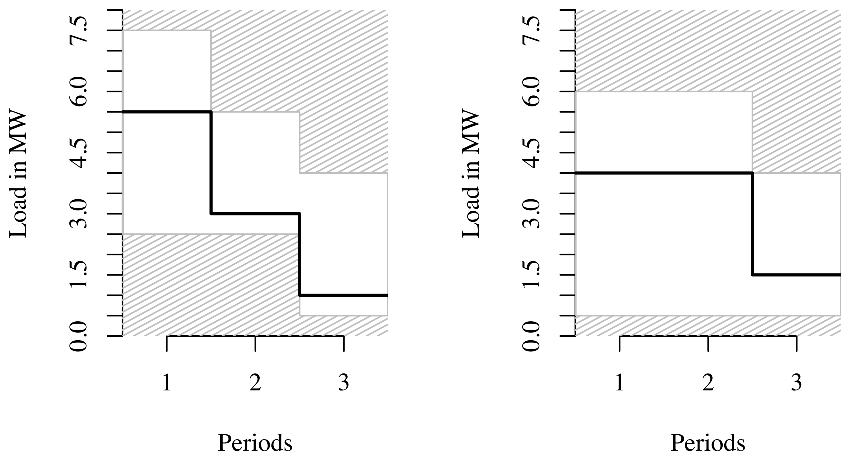


When Distributed Generation (DG) sources produce a lot of power: (I) overvoltage problem at *Bus 4* (II) overload problem on the *MV/HV* transformer.

Two flexible loads; only three market periods; possibility to curtail the two DG sources before every market period (at a cost).

Information available to the DNO on the day-ahead

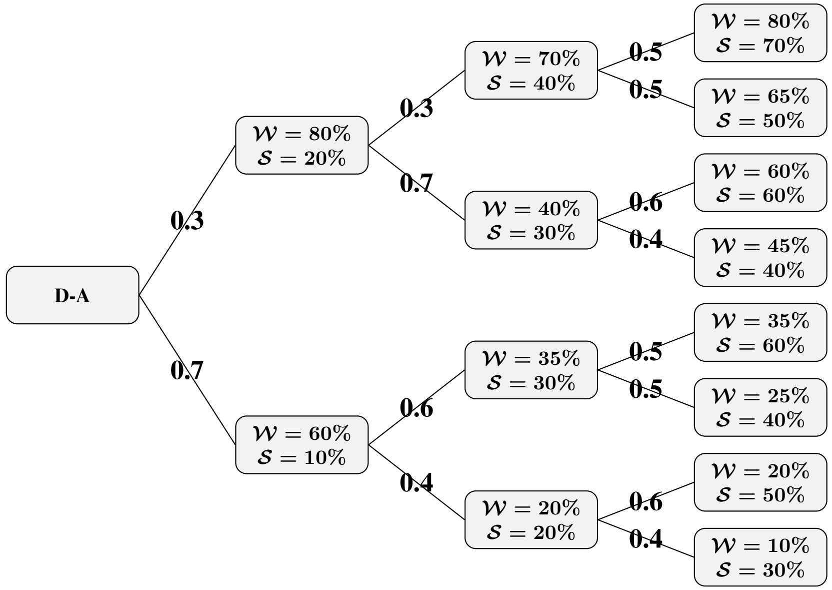
The flexible load offers:



Left: residential aggregated. Price p_r.

Right: Industrial. Price p_i.

Scenario tree for representing uncertainty:



$\mathcal{W}$ = Wind; $\mathcal{S}$ = Sun.

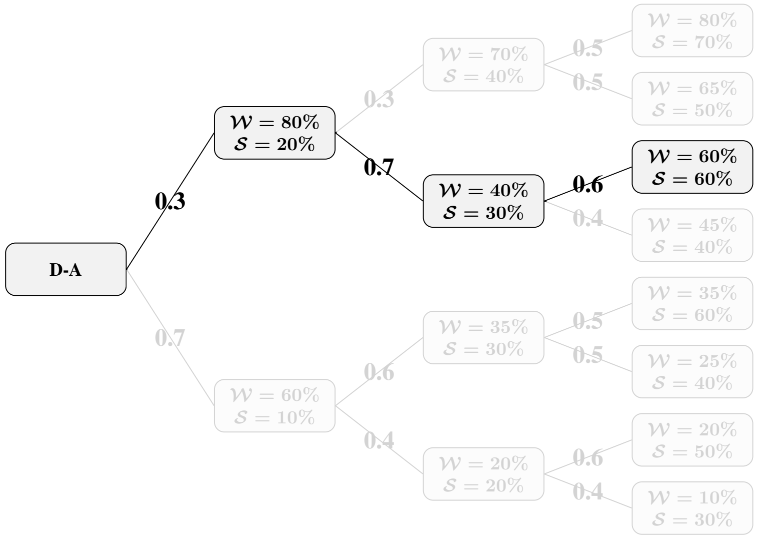
Additional information: a load-flow model of the network; the price (per MWh) for curtailing generation.

Decisions output by o^*

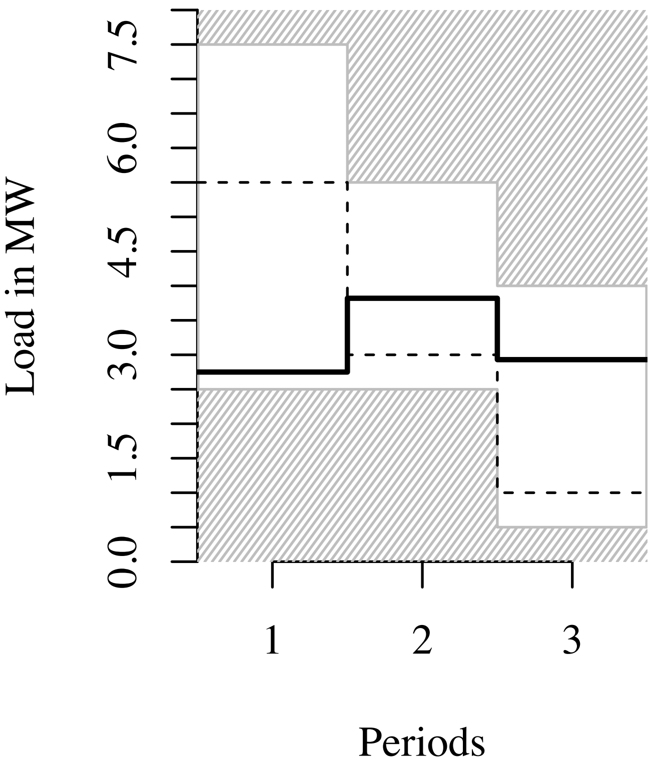
The day-ahead: To buy flexibility offer from the *residential aggregated load*.

Before every market period:

We report results when generation follows this scenario:



Results: Generation never curtailed. Load modulated as follows:



On the importance of managing well uncertainty

	$E\{cost\}$	max_cost	min_cost	$std\_dev.$
o^*	46$	379$	30$	72$
MSA	73$	770$	0$	174$

where MSA stands for Mean Scenario Strategy.

Observations: Managing well uncertainty leads to smaller expected costs than working along a mean scenario.

More results in:

"Active network management: planning under uncertainty for exploiting load modulation" Q. Gemine, E. Karangelos, D. Ernst and B. Cornélusse. Proceedings of the 2013 IREP Symposium-Bulk Power System Dynamics and Control -IX (IREP), August 25-30, 2013, Rethymnon, Greece, 9 pages.

The optimal investment strategy

Remember that we had to choose between doing investment A or not. Let AP be the amortization period and $cost\_A$ the cost of investment A. The optimal investment strategy can be defined as follows:

1. Simulate using operational strategy o^* the distribution network with element A several times over a period of AP years. Extract from the simulations the expected cost of using o^* during AP years. Let $cost\_o^*\_with\_A$ be this cost.

2. Simulate using operational strategy o^* the distribution network without element A several times over a period of AP years. Extract from the simulations the expected cost of using o^* during AP years. Let $cost\_o^*\_without\_A$ be this cost.

3. If $cost\_A + cost\_o^*\_with\_A \leq cost\_o^*\_without\_A$, do investment A. Otherwise not.

GREDOR project: four main challenges

Data: Difficulties for DNOs to gather the right data for building the decision models (especially for real-time control).

Computational challenges: Many of the optimisation problems in GREDOR are out of reach of state-of-the-art techniques.

Definition of $social\_welfare(\cdot,\cdot,\cdot,\cdot)$ function: Difficulties to reach a consensus on what is social welfare, especially given that actors in the electrical sector have conflicting interests.

Human factor: Engineers from distribution companies have to break away from their traditional practices. They need incentives for changing their working habits.

Acknowledgements

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Website: www.gredor.be