Congestion Avoidance in Low-Voltage Networks

Using Smart Meters

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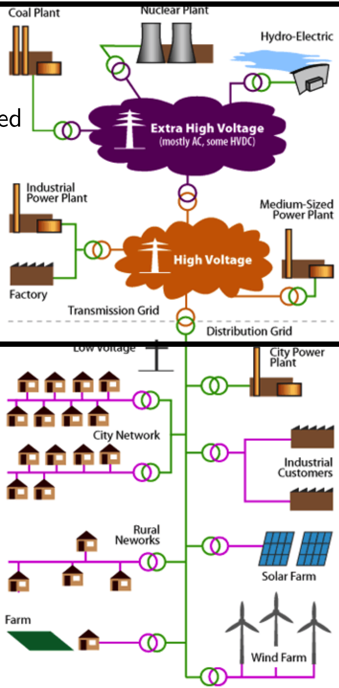
Control problems in electricity networks:

- Production / consumption balance
- Voltage/current control

Well instrumented

Controlled



Control problems in electricity networks:

- Production / consumption balance
- Voltage/current control

New usages

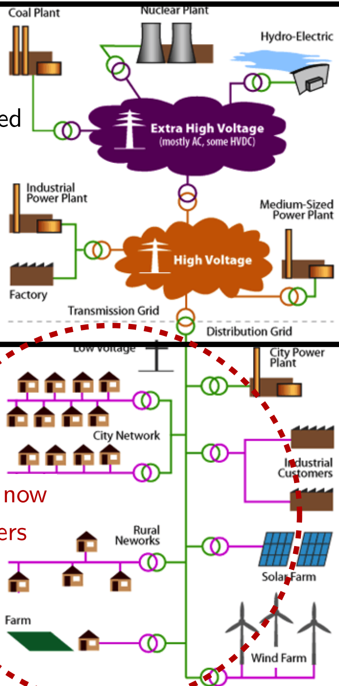
- Decentralized production
- Electric vehicles

New technologies

- In France: Linky

Well instrumented

Controlled



Few control up to now

Linky: 35M meters

Some challenges

- (Distributed) optimization : how to (can we?) use smart meters for control.
  - Online optimization, limited computation resources.
  - Network tomography, learning aspects
- Communication issues
  - Linky uses CPL-G3.
    - Network throughput is low (at the very best 35kbps)
- Experimentation

How "bad" can the communication network be?

Linky:

- 35 millions meters deployed before 2021
- Communication: PLC-G3 standard
- Used for metering only (one indicator per day)
  - 35kbps max, RTT=1s or more (can be 5 sec)

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CPL is essentially a wireless network

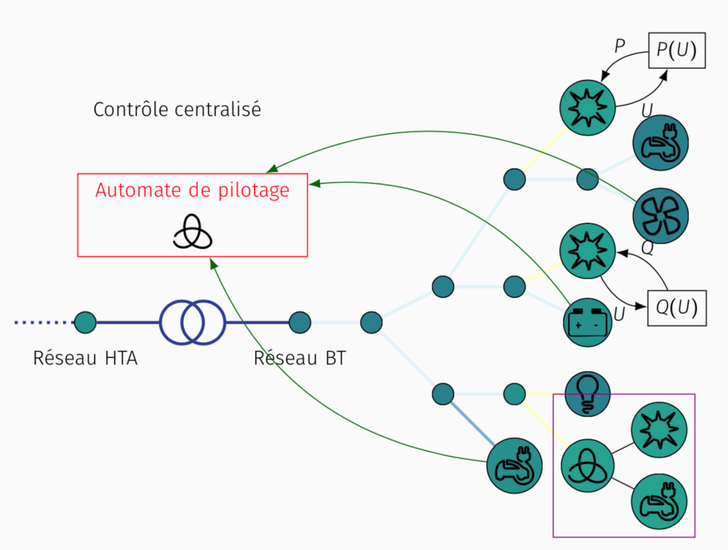
Wireless	Wired
Electro-magnetic perturbations	Isolated
Attenuation/path loss	Negligible losses
Shared channel (need for collision detection)	Private channel

- If we plan to use CPL, we cannot rely on complex message exchanges.
- We choose a maximum of 1 message per meter per 15min.

Outline

1. Mathematical Formulation of the Idealized Problem
2. What Design for a good Control Policy?
3. Numerical exploration
4. Conclusion and Future Work

Conception of a control automata



- How much flexibility does a network has?
- Which control methods should I choose to attain this optimum?

Electric Network model

Problem setting:

- 3-phased distribution network
- Controllable PV panels.
- Objective: Respect voltage and power constraints.

What makes our problem specific is:

The only data available are the one provided by the smart meters.

- Network geometry is unknown (impedance / phases of buses,...)
- No load or production forecasts available.
- We can send to each node one control signal every 15min.

Idealized problem: goal = minimize energy production

$$\max \sum_{g \in \text{Generators}} p_g(t)$$
$$\text{such that } \forall g : p_g(t) \in [0, p_g^{\max}(t)]$$
$$\mathbf{p}(t) = \mathbf{p}_g(t) + \mathbf{p}_\ell(t)$$
$$\forall b : U_b(\mathbf{p}) = 230V \pm 8.5\%$$
$$T(\mathbf{p}) \in [0, \text{Transformer capacity}].$$

where

- $\mathbf{p}_\ell(t)$ = consumption of loads (uncontrolled)
- $U(\mathbf{p})$ and $T(\mathbf{p})$ are non-linear functions that comes from the three-phased load-flow equations.
  - $U_b(\mathbf{p})$ = voltage at bus b
  - $T(\mathbf{p})$ = power at transformer.

Reminder: $U(.)$, $T(.)$, $p_\ell(t)$ and $p_g^{\max}(t)$ **are unknown**.

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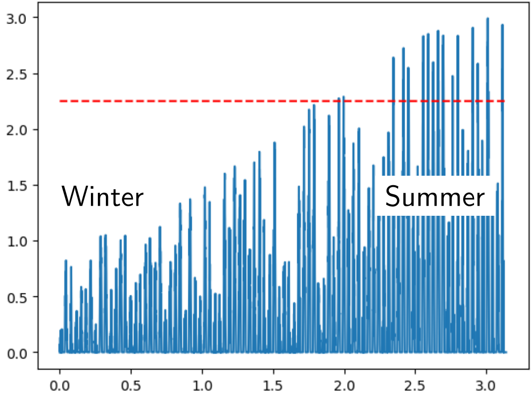
Design Choices

- Open-loop: set a constant maximum output
- Pure feedback policies: local $P(U)$ and $Q(U)$ policies.
- Feed-forward policy: learn a model and adjust it online.

The **Open Loop** policy: why does it make sense?

Open-loop 75%: the PV panel is allowed to produce at most 75% of its nominal power.

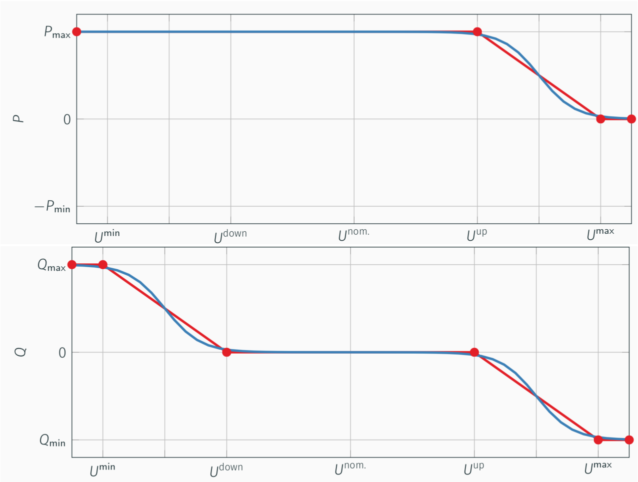


PV rarely produce their maximum output.

- Capping at 75% looses less than 5% of the energy in practice.

Pure-feedback $P(U)$ and $Q(U)$

Idea: more production of active/reactive power leads to higher voltage.



Feedforward policy

Main ideas:

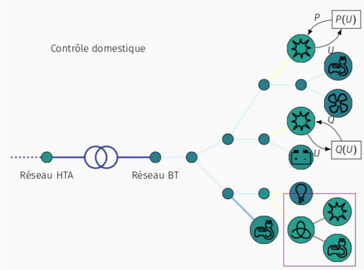
- Replace the non-linear functions $T(.)$ and $U(.)$ by linear constraints with parameters estimated using past data.
- Use a forecast to estimate $p_g^{\max}(t)$ and $p_\ell(t)$ using $p_g(t-1)$ and $p_\ell(t-1)$.

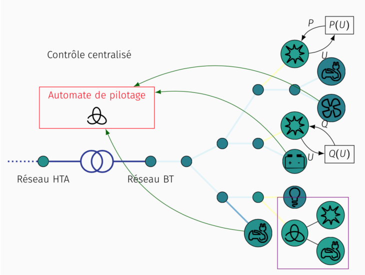
The problem then becomes:

$$
\begin{aligned}
\max \sum_{g\in\text{Generators}} & p_g(t) \\
\text{such that } & \forall g : p_g(t) \in [0, \tilde{p}_g^{\max}(t)] \\
& \mathbf{p} = \mathbf{p}_g(t) + \mathbf{p}_\ell(t-1) \\
& \forall b : A\mathbf{p} + b = 230V \pm 8.5\% \\
& C\mathbf{p} + d \in [0, \text{Transformer capacity}],
\end{aligned}
$$

Summary of the different policies

Open-loop / feedback v.s. Control automata





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PV case study

Data extracted from the "Low Carbon Network Fund Tier 1" leads by Electricity North West Limited and Manchester University.

- Network data (21 feeders)
- Curves of productions and consumption.

We develop a simulator that:

- Performs the electric simulation by solving the load-flow equations.
- Simulate smart homes and PV.
- Implement the various control and learning mechanisms.

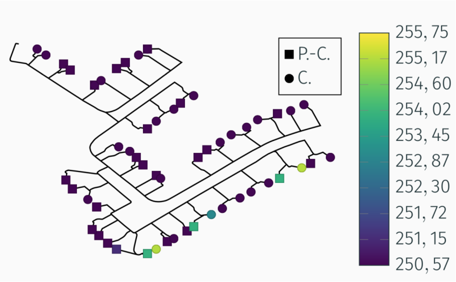
Numerical comparison of the various policies

Open loop policies

- 0% = no production
- 25,50,75
- 100% = no constraints

Feedback P(U) and Q(U)

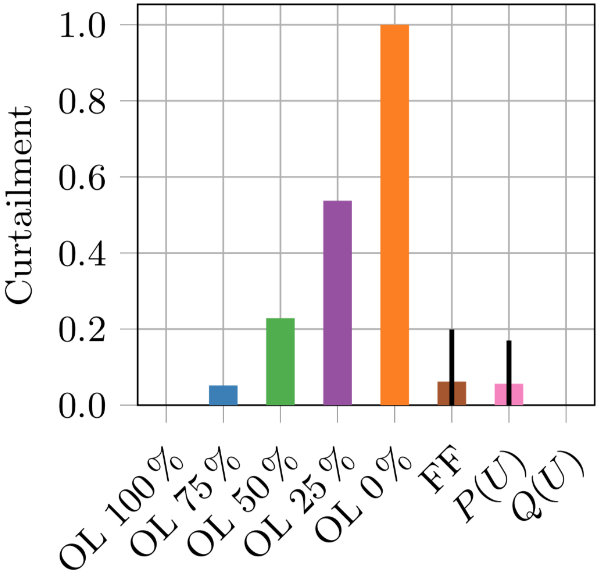
Feed-foward.



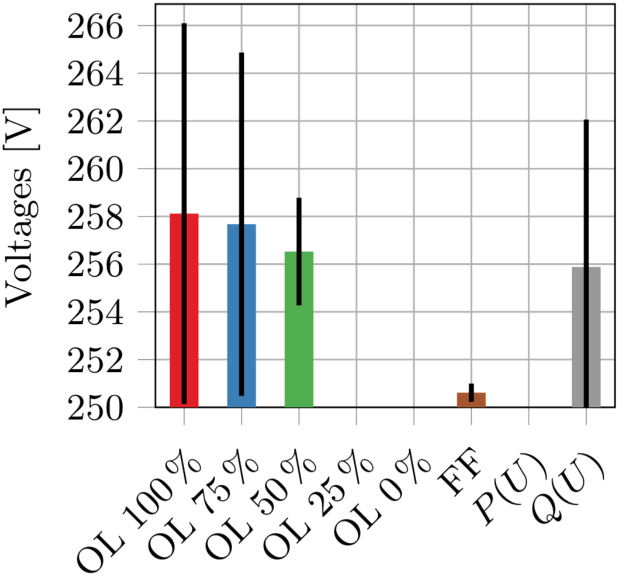
We compare:

- Energy curtailed
- Respects of over-voltage constraints
- Over-powers at the transformer

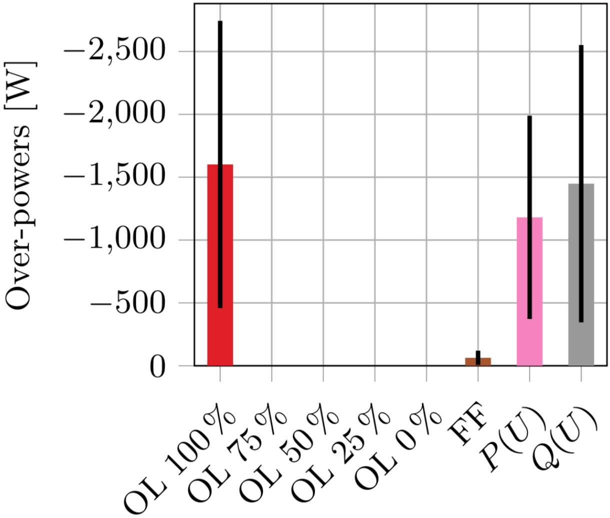
Performance metrics 1: Energy curtailed



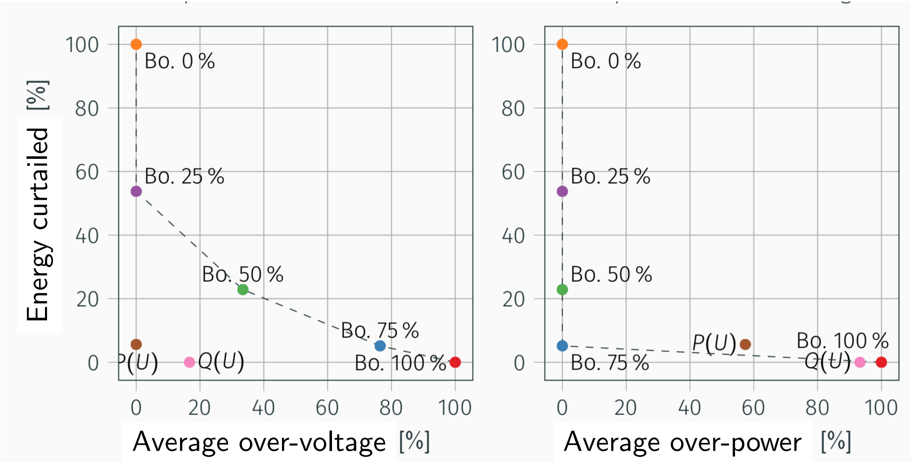
Performance metrics 2: Respect of over-voltage constraints



Performance metrics 3: Over-powers at the transformer



Best compromise: Pareto curve



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Recap and conclusion

- It is possible to build an efficient control based mostly on smart meter.
- It provides better compromise than P(U) or open-loop while requiring limited communication.
- Linear model provide already good results.

Open question:

- Compare to an "optimal" controller.
- Quantify where we loose (learning / forecasting)

Future work

Current and Future work

- Performance of PLC (model and experience).
- Co-simulation (electric & telecom, real and simulated environment)

Collaborations

- Enedis (ex-ERDF)
- Roseau technologie (start-up)
- Schneider Electric (bourse de thèse)