UNDERSTANDING ACTIVE NETWORK MANAGEMENT IN 40 MINUTES

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INTRODUCTION

Connection of renewable sources of energy to the grid, and in particular to the distribution grid, is **causing many technical problems**.

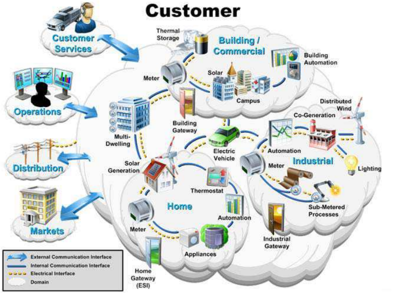
Well-known problems in Wallonia: **(I)** Photovoltaic (PV) installations connected to the low-voltage level (230 V) cause inacceptable voltage rises **(II)** Congestion issues with wind farms connected to distribution networks.

The **BUZZWORDS** for addressing these problems: **Active Network Management (ANM)**.

What is active network management about?

It is about modulating in a smart way production and load (demand side management) so as to operate the electrical network in a safe way, without having to rely on significant investments in infrastructure.

In many talks/research papers, active network management strategies are not well-detailed and their description is often limited to cartoon-like charts.



In this presentation, I take the challenge to sketch in less than 30 minutes and to an audience of mostly non power system engineers, detailed Active Network Management (ANM) solutions.

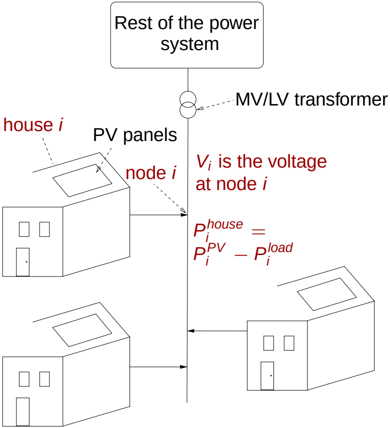
More specifically:

1. I will show through examples how to state mathematically active network management problems.

2. I will discuss computational and technical challenges for implementing solutions to these problems.

3. I will (briefly) discuss the models of interaction between the different actors of the electrical industry that need to be implemented to accommodate the ANM solutions proposed for these examples.

PV PANELS AT THE LOW-VOLTAGE LEVEL



NETWORK ISSUE

Voltages V_is increase with the power injected by the houses into the network (i.e., with the P_i^{house}s). As a consequence, when the PV panels produce a lot of power and the households do not consume much electricity, the V_is may become larger than V^{max}, the upper voltage limit.

ANM PROBLEM I: MODULATION OF THE P_i^{PV}s TO AVOID OVERVOLTAGE PROBLEMS

A MATHEMATICAL FORMULATION OF THIS PROBLEM

Find the values of P_i^{PV} that minimize the amount of power to be curtailed (i.e., that minimize $\sum_i (P_i^{PV,max} - P_i^{PV})$ where $P_i^{PV,max}$ is the maximum power that the PV panels of house i can generate) under the constraint that the V_is stay below V^{max}.

What are the data required for solving this mathematical optimisation problem? A good model of the *Rest of the power system*, detailed model of the low-voltage network, the values of the $P_i^{PV,max}$s and of the P_i^{load}s.

Can this optimisation problem be solved easily on a computer, provided that these data are given? Yes.

At which rate to refresh the solution of this optimisation problem?
It has to be solved every Δt seconds where Δt is smaller than the time after which the data required for solving the problem may change significantly. Δt is called the time discretization step which is in discrete-time control the real time between two discrete instants t and $t+1$.

What are the technical difficulties?
(I) To gather and bring in real-time all these data to the central entity responsible for the modulation of the P_i^{PV}s **(II)** To send the modulation orders to the converters **(III)** To have converters being able to modulate their power output.

What if it is too expensive to build this centralized controller?

There is a possibility to develop much cheaper decentralized controllers, at the price of curtailing more power. For example, such a controller could work by implementing the following logic in the converters:

If voltage V_i greater than V_i^{max}, change (in a smooth way) the current value of P_i^{PV} to $\alpha \times P_i^{PV}$ with $\alpha < 1$. Otherwise, change (in a smooth way) P_i^{PV} to $\min(\beta \times P_i^{PV}, P_i^{max})$ with $\beta > 1$.

What are the additional changes that need to be brought to existing models of interaction to implement this scheme?

1. Choose (or create) the central entity responsible for modulating the P_i^{PV}s. This entity does not necessarily need to be the Distribution Network Operator (DNO).

2. Compensation mechanism for the owners of PV installations who have to curtail their power. If no compensation mechanisms are implemented, fair curtailment strategies need to be developed so as to ensure that it is not always the same PV installations which have to curtail power.

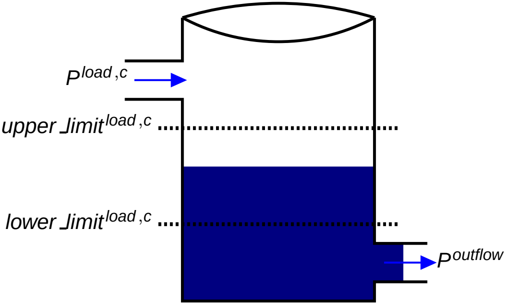
3. Curtailing power will interfere with the role of Access Responsible Party (ARP) of retailers. Mechanisms have to be put in place so as to allow retailers to do their work in fair conditions.

4. This scheme will interfere with the balancing mechanisms of the Transmission System Operator that needs to be informed - as soon as possible - about the curtailment actions.

ANM PROBLEM II: MODULATION OF THE P_i^{PV}s AND THE P_i^{load}s TO AVOID OVERVOLTAGE PROBLEMS

CONTEXT

Loads that have inner storage capabilities (heating/cooling systems, electric cars or fridges) can be modulated/controlled with little to no occupant discomfort. By modulating these loads in a clever way, it is possible to absorb the excess of power (or at least part of it) generated by the PV panels rather than throwing it away.



The **tank model** for representing loads with inner storage capabilities: the power consumption of the load $P^{load,c}$ (inflow of the tank) can be modulated under the constraint the level of the tank stays within its limit. $P^{outflow}$ is the (uncontrollable) outflow of the tank.

ASSUMPTIONS

(I) One controllable load by house i **(II)** The control variables P_i^{PV}, $P_i^{load,c}$ refreshed every Δt seconds **(III)** All the variables remain constant during every time interval Δt **(IV)** No delays for gathering the data, processing the data, sending the control actions and applying these actions.

GENERIC MODULATION SCHEME

At every discrete time-step t:

1. Send the data of the problem to a centralized controller

2. Solve a mathematical optimisation problem

3. Send the solution of this problem (the $P_{i,t}^{PV}$s and the $P_{i,t}^{load,c}$s) to the PV installations and to the controllable loads.

How to state properly the mathematical optimisation problem knowing that you are interested to minimize the sum of the power curtailed over a sequence of T time steps starting from t?

THE MYOPIC FORMULATION

Find the values of $P_{i,t}^{PV}$ and $P_{i,t}^{load}$ that minimize $\sum_i (P_{i,t}^{PV,max} - P_{i,t}^{PV})$ under the constraints:

1. that the V_is stay below V^{max} during the Δt seconds between the two discrete time-steps t and $t+1$.

2. that the level of every tank i stays within its limits the Δt seconds between the two discrete time-steps t and $t+1$.

The main problem with this myopic formulation is that it does not take into account that the values of the variables $P_{i,t}^{load}$s are going to influence the constraint **2.** at the subsequent time steps. These variables indeed modify the levels of the tanks.

As a consequence, the modulation of the loads is done in a suboptimal way which may lead to unnecessary large values of $\sum_t \sum_i (P_{i,t}^{PV,max} - P_{i,t}^{PV})$. A more appropriate formulation would be **...**

...

Find the values of $P^{PV}_{i,t}$, $P^{PV}_{i,t+1}$, $\ldots$, $P^{PV}_{i,t+T-1}$, $P^{load}_{i,t}$, $P^{load}_{i,t+1}$, $\ldots$, $P^{load}_{i,t+T-1}$ that minimize $\sum_{t'=t}^{t+T-1} \sum_i (P^{PV,max}_{i,t'} - P^{PV}_{i,t'})$ under the constraints:

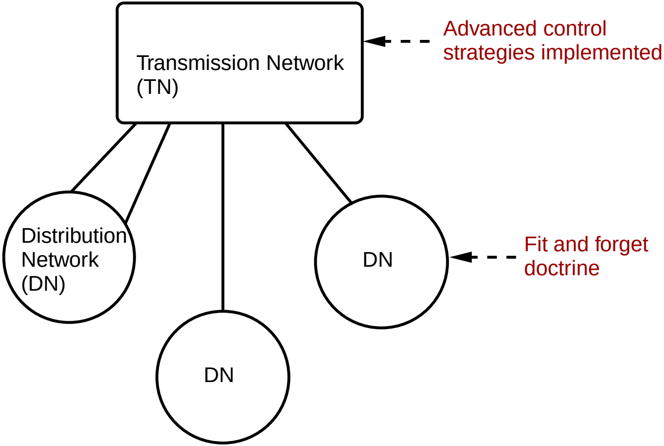
1. that the V_is stay below V^{max} during the $T \times \Delta t$ seconds following instant t.

2. that the level of every tank i stays with its limits the $T \times \Delta t$ seconds following instant t.

WARNING

Solving this optimisation problem requires accurate predictions of the $P_i^{PV,max}$s and of the load behavior (in particular the $P_i^{outflow}$s). If these accurate predictions are not available, probabilistic scenarios for modelling uncertainty have to be used. In such a context, the problem becomes of stochastic optimal sequential decision making problem where the expected amount of power to be curtailed under probabilistic constraints is minimized. The complexity of these problems may become rapidly out of reach of today's computers when the number of optimisation variables starts growing.

PREVIOUSLY



Transmission Network (TN)

Advanced control strategies implemented

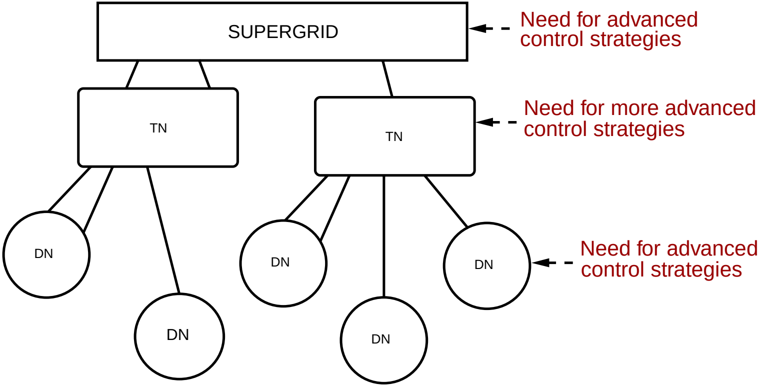
Distribution Network (DN)

DN

DN

Fit and forget doctrine

NOWADAYS



Need for advanced control strategies

Need for more advanced control strategies

Need for advanced control strategies

Challenges for designing well-performing control strategies and make them work together are immense.