New approaches of bidding and contract problems: use of non-self Nash games and Radner equilibrium concept

Didier Aussel (Univ. Perpignan)
Olivier Beaude, Wim van Ackooij (EdF R& D, Saclay)
Juan Pablo (Federal University of Rio de Janeiro, Brazil)
Claudia Sagastizabal (University of Campinas, Sao Paulo, Brazil)
The setting

In order to suitably address the challenges brought by the intermittency of renewables, new mechanisms that balance flexibility and reliability need to be put in place.

Demand-response (DR) programs are contracts signed between a generator and a group of prosumers.
In order to suitably address the challenges brought by the intermittency of renewables, new mechanisms that balance flexibility and reliability need to be put in place.

Demand-response (DR) programs are contracts signed between a generator and a group of prosumers.

**Prosumers (like micro- and smart-grid operators):**
- have access to local sources of energy
- can adapt to a certain extent their consumption in exchange of some reward
- operate in a local level
In order to suitably address the challenges brought by the intermittency of renewables, new mechanisms that balance flexibility and reliability need to be put in place.

Demand-response (DR) programs are contracts signed between a generator and a group of prosumers.

**Prosumers (like micro- and smart-grid operators):**
- have access to local sources of energy
- can adapt to a certain extent their consumption in exchange of some reward
- operate in a local level

**The generators:**
- generator has the ability of injecting power in the electrical network, mostly coming from its own utilities
- can shift some consumption from a peak-load time to off-peak times, to avoid congestion or to keep voltage and frequency in a suitable range.
For DR-programs to be of any practical interest, the following elements are crucial:

- the reward should be attractive to the prosumers;
- privacy of each prosumer should be respected;
- the global change in demand, considering the whole set of prosumers, should bring some benefit to the generator;
- the actions of the generator should be compatible with the electrical network.

We consider a model representing the basic interactions in this configuration that allow generators to design DR-contracts satisfying the rules above, while ensuring network balance.
Prosumer problem

\[
\begin{align*}
\min_{g^i, d^i, \gamma_d^i, y^{\varepsilon i}} & \quad c^i(g^i) - \langle \pi^-, d^i \rangle + \langle \pi^d, \gamma_d^i \rangle - \langle \pi^e, y^{\varepsilon i} \rangle + \mathbb{E} \left[ Q_s^i(y^{\varepsilon i}, \gamma_d^i) \right] \\
\text{s.t.} & \quad g^i_j \in G^i_j, j \in J^i \quad \text{and} \quad d^i_\leq \in Z^i_\leq \\
& \quad 0 \leq \gamma_d^i \leq \bar{\gamma}_d^i \quad \text{and} \quad 0 \leq y^{\varepsilon i} \leq \bar{\gamma}_e^i \\
& \quad A^i g^i + d^i_\leq = 0^i.
\end{align*}
\]

Feasibility is ensured by introducing an artificial utility in $J^i$, with very high cost and infinite capacity whose generation represents a positive slack. In the second stage, the exchanges with $G$ determine the recourse and local generation levels are adjusted:

\[
Q_s^i(y^{\varepsilon i}, \gamma_d^i) := \begin{cases} 
\min_{\Delta g^i, \ell^i} & \quad c^i(\Delta g^i) + \langle p_s, \ell^i \rangle \\
\text{s.t.} & \quad g^i_j + \Delta g^i_j \in [g^i_j, \min, g^i_j, \max], j \in J^i \\
& \quad A^i \Delta g^i + \ell^i = v^i_s - 0^i - \gamma_d^i + y^{\varepsilon i},
\end{cases}
\]

where $p_s$ is the energy spot price at which eventual exceeding or lack of generation $\ell^i$ is traded, thus ensuring feasibility.
Generator and DR-market’s problem

\[
\begin{aligned}
\min_{g^G, \pi^-, \pi^d, \pi^e} & \quad C^G(g^G) + \langle \pi^-, z^- \rangle - \langle \pi^d, z_d^\# \rangle + \langle \pi^e, z_e^\# \rangle \\
& + \mathbb{E} \left[ Q_s^G(g^G, z_d^\#, z_e^\#) \right] \\
\text{s.t.} & \quad g_j^G \in G_j^G, j \in J^G \\
& \quad \pi^- \in \Pi^-(z_-^\#), \pi^d \in \Pi_d, \pi^e \in \Pi_e \\
& \quad A^G g^G = D^G - z_-^\#. 
\end{aligned}
\]

In this problem, \(G\)'s recourse function depends on the total exchanges defined by the network manager:

\[
\begin{aligned}
\min_{z^\#} & \quad \frac{1}{2} \| z_-^\# - \sum_i d_i^\# \|^2 + \frac{1}{2} \| z_d^\# - \sum_i \gamma_i^\# \|^2 + \frac{1}{2} \| z_e^\# - \sum_i y^\# \|^2 \\
\text{s.t.} & \quad z_\# \in \mathbb{Z}_-, 
\end{aligned}
\]

where the set \(\mathbb{Z}_-^\#\) determines network feasibility.
The quasi-variational reformulation of our problem is described by

\[
\begin{aligned}
\text{Find } (\bar{z}^\#, \bar{X}) \in P \times K(\bar{z}^\#) \text{ such that } & \exists \mu = (\mu^G, (\mu^i)_{i \in I}) \in H(\bar{X}, \bar{z}^\#) \\
& \text{with } \langle \tau(\bar{X}, \bar{z}^\#), \bar{X} - \bar{X} \rangle + \langle \mu, \bar{X} - \bar{X} \rangle + \langle f^\#(\bar{z}^\#, \bar{X}), \bar{z}^\# - \bar{z}^\# \rangle \geq 0, \\
& \text{for all } (z^\#, X) \in P \times K(\bar{z}^\#).
\end{aligned}
\]

where the set \( P \) and the set-valued map \( K \) are given by \( P = \mathcal{Z}^\# \) and

\[
K(\bar{z}^\#) = \left\{ X = (x^G, x) \in \mathcal{X}^G \times \prod_{i \in I} \mathcal{X}^i : \begin{array}{l}
M^G x^G = \mathbb{D}^G - z^\# \\
M^i x^i = \mathbb{D}^i, \forall, i \in I
\end{array} \right\}
\]

- We showed existence of a Radner equilibrium for this QVI
- During 2021 the work will focus on numerical validation