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

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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.

The setting

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

$$\begin{cases} \min\limits_{g^i, d_-^i, \gamma_d^i, y^{\varepsilon i}} & \mathrm{C}^i(g^i) - \langle \pi^-, d_-^i \rangle + \langle \pi^d, \gamma_d^i \rangle - \left\langle \pi^e, y^{\varepsilon i} \right\rangle + \mathbb{E}\left[Q_s^i(y^{\varepsilon i}, \gamma_d^i) \right] \\ \text{s.t.} & g_j^i \in \mathcal{G}_j^i, j \in J^i \quad \text{and} \quad d_-^i \in \mathcal{Z}_-^i \\ & 0 \leqslant \gamma_d^i \leqslant \bar{\gamma}_d^i \quad \text{and} \quad 0 \leqslant y^{\varepsilon i} \leqslant \bar{\gamma}_e^i \\ & A^i g^i + d_-^i = \mathbb{D}^i . \end{cases}$$

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:

$$Q_s^i(y^{\varepsilon i}, \gamma_d^i) := \begin{cases} \min\limits_{\Delta g^i, \ell^i} & \mathrm{C}^i(\Delta g^i) + \langle \mathfrak{p}_s, \ell^i \rangle \\ \text{s.t.} & g_j^i + \Delta g_j^i \in [g_j^{i,\min}, g_j^{i,\max}], j \in J^i \\ & A^i \Delta g^i + \ell^i = \mathfrak{d}_s^i - \mathbb{D}^i - \gamma_d^i + y^{\varepsilon i} , \end{cases}$$

where $\mathfrak{p}_s$ is the energy spot price at which eventual exceeding or lack of generation ℓ^i is traded, thus ensuring feasibility.

Generator and DR-market's problem

$$
\begin{cases}
\displaystyle\min_{g^G,\pi^-,\pi^d,\pi^e} & \mathrm{C}^G(g^G) + \left\langle \pi^-, z_-^{\#} \right\rangle - \left\langle \pi^d, z_d^{\#} \right\rangle + \left\langle \pi^e, z_e^{\#} \right\rangle \\
& + \qquad \mathbb{E}\left[Q_s^G(g^G, z_d^{\#}, z_e^{\#}) \right] \\
s.t. & g_j^G \in \mathcal{G}_j^G, j \in J^G \\
& \pi^- \in \Pi_-(z_-^{\#}), \pi^d \in \Pi_d, \pi^e \in \Pi_e \\
& A^G g^G = \mathbb{D}^G - z_-^{\#} .
\end{cases}
$$

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

$$
\begin{cases}
\displaystyle\min_{z^{\#}} & \frac{1}{2}\left\| z_-^{\#} - \sum_i d_-^i \right\|^2 + \frac{1}{2}\left\| z_d^{\#} - \sum_i \gamma_d^i \right\|^2 + \frac{1}{2}\left\| z_e^{\#} - \sum_i y^{\varepsilon i} \right\|^2 \\
s.t. & z_-^{\#} \in \mathcal{Z}_-^{\#} ,
\end{cases}
$$

where the set $\mathcal{Z}_-^{\#}$ determines network feasibility.

QVI reformulation

The quasi-variational reformulation of our problem is described by

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

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

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

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