Optimization issues for new electrical systems

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New context…

Evolution of the electrical system supporting the ecological transition

- Distributed / intermittent generation: PV, wind…
  ⇒ new (uncontrollable) randomness on generation-side
- Smart technologies: smart meters, demand side management
  ⇒ new controllable flexibilities on consumer-side
- New storage devices: batteries, electric vehicles…
- New local actors emerge with potentially conflicting objectives and constraints
  ⇒ self consumption, emissions constraints, …

Local issues

- New renewable generation and flexibilities (storage, consumption) are mainly connected to the Distribution Grid (DG)
  ⇒ new constraints on the DG
- New local actors require the development of specific local energy management systems
  ⇒ self consumption, emissions constraints, …

Global issues

- Joint generation / consumption design & control
- High dimensional storage management problems
- Comprehensive view of the whole system

New issues for (new) actors requiring optimization tools

- Regulator [Reg] Design interactions rules between the different actors ensuring the global efficiency of the system
- Distribution System Operator [DSO] Alleviate DG-constraints, arising with massive integration of renewable energies, using all available flexibilities
  $\Rightarrow$ Operational, investment and organizational issues: e.g. connecting rules, incentives, market design
- Transmission System Operator [TSO] Integrate distributed flexibilities to provide (ancillary) services
- Producer/Provider [PP] Jointly optimize the whole portfolio including generation, storage and (flexible and non-flexible) consumption taking into account uncertainties
  $\Rightarrow$ Operational and investment issues: e.g. control a large number of flexibilities, design customer contract/tariff, incentives for flexible electric consumption
- Aggregator [Agg] Control an aggregate of distributed generation or storage and demand flexibilities, while preserving both privacy and potentially conflicting objectives of participating agents: efficient/fair equilibrium
- Prosumer, Consumers [Pros], [Cons] Energy Management Systems (EMS) (intermittent gen. + cons. + storage) taking into account local uncertainties and local objectives (e.g. self-consumption), at different levels: house, district,...

Outline

Global control of demand flexibilities

Local control

- Local control of flexibilities (without uncertainties)
- Local control of flexibilities under uncertainties

Handling with Distribution Grid constraints

Construction of tariffs, contract design

Global control of demand flexibilities

Motivations Control demand flexibilities to contribute to global equilibrium [TSO,PP]

Problem Control the consumption of a very large population of devices in order to follow a (possibly random) target profile Y_t s.t.

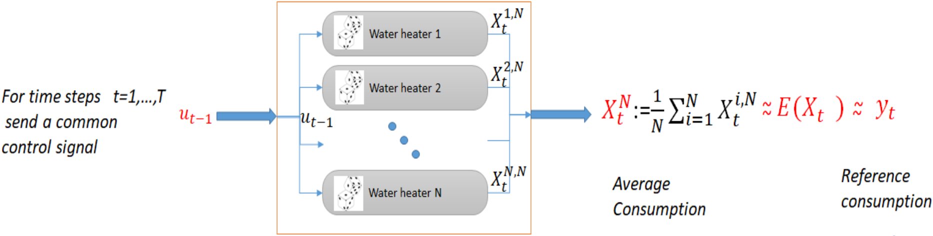
- minimizing communications (latency)
- preserving each appliance Quality of Service

$$
\begin{cases}
dX_t^{i,u} = b\big(t, X_t^{i,u}, u(t, X_t^{i,u})\big)dt + \sigma(t, X_t^{i,u})dW_t^i \\
\min_{u \in \mathcal{U}} J(u) \ , \quad \text{where} \\
J(u) := \int_0^T \Big(\underbrace{\mathbb{E}\big[d(\frac{1}{N}\sum_{j=1}^{N} X_t^{j,u}, Y_t)\big]}_{\text{Deviation cost}} + \underbrace{\frac{1}{N}\sum_{i=1}^{N} \mathbb{E}\big[f_t\big(u_t(t, X_t^{i,u}), X_t^{i,u}\big)\big]}_{\text{Local cost}} \Big) dt
\end{cases}
$$

Mean-field approximation

[Busic&Meyn, 2016][Tindemans etal. 2015][Kizilkale&Malhame,2016]

$$\begin{cases} dX_t^u = b\big(t, X_t^u, u(t, X_t^u)\big)dt + \sigma(t, X_t^u)dW_t \\[2ex] \min\limits_{u \in \mathcal{U}} J(u)\ , \quad \text{where} \\ J(u) := \displaystyle\int_0^T \Big(\underbrace{\mathbb{E}\big[d(\mathbb{E}[X_t^u], Y_t)\big]}_{\text{Deviation cost}} + \underbrace{\mathbb{E}\big[f_t\big(u_t(t, X_t^u), X_t^u\big)\big]}_{\text{Local cost}} \Big)\, dt \end{cases}$$



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Outline

Following a global objective in a distributed way

Motivations Coordinate consumptions flexibilities in order (for instance) to follow a reference signal while preserving privacy
EX: collective self-consumption
[Agg,Pros]

Problem Control the consumption of a relatively small population in order to follow a deterministic target profile y_t

$$\min_{u_i \in U_i} \sum_{t=0}^{T} \Big[\underbrace{d(y_t, \sum_{i=1}^{N} u_{i,t})}_{\text{Deviation cost}} + \underbrace{\sum_{i=1}^{N} f_{i,t}(u_{i,t})}_{\text{Local cost}} \Big]$$

The admissible sets, U_i, may be non-convex

Distributed optimization approaches

- Lagrangian decomposition
- Block minimization
- Alternate Direction Method of Multipliers (ADMM),...

Following a global objective in a decentralized way

Motivations Coordinate consumptions flexibilities to conciliate a global objective with local objectives while preserving privacy [Agg]

Problem Provide efficient decentralized algorithms to compute the equilibrium where each consumer $i \in \{1, \cdots, N\}$ wants to

$$\min_{u_i \in U_i} \sum_{t=0}^{T} \Big[\underbrace{a(u_{i,t}, \sum_{j \neq i}^{N} u_{j,t})}_{\text{Coupling cost}} + \underbrace{f_{i,t}(u_{i,t})}_{\text{Individual cost}} \Big]$$

- Analyse the equilibrium in terms of efficiency and fairness
- efficient algorithms for a large number of flexible consumers
- in a hierarchical case with aggregate groups of consumers

Approach Approaches based on game theory and *best response algorithms* [Jacquot etal. 2018]

Outline

Local control of flexibilities under uncertainties

- A new issue
  - Increasing uncertainties (market, generation, ...)
  - Local entities (Districts, towns, self-consumption collectivity) may manage intermittent generation consumption flexibilities with interconnected batteries
- One promising approach to circumvent the curse of dimension
  - Recent progress in stochastic control in the community of mathematical finance
  - Link between stochastic control and PDEs (Partial differential Equations)
  - Probabilistic representations of *forward* PDEs => Develop efficient Monte Carlo methods

Stochastic control: technical issues

- Consider a *state process* $(X_s^{t_0,x,\alpha})_{t_0 \le s \le T}$ on $\mathbb{R}^d$ solution of the controlled SDE

$$\begin{cases} dX_s^{t_0,x,\alpha} & = & b\big(s, X_s^{t_0,x,\alpha}, \alpha(s, X_s^{t_0,x,\alpha})\big)ds + \sigma\big(s, X_s^{t_0,x,\alpha}, \alpha(s, X_s^{t_0,x,\alpha})\big)dW_s \\ X_{t_0}^{t_0,x,\alpha} & = & x \ , \end{cases} \quad (1)$$

  - W being the Brownian motion on $\mathbb{R}^d$,
  - α a *feedback* control

$$\alpha \in \mathcal{A}_{t_0,T} := \Big\{\alpha \ : (t,x) \in [t_0,T] \times \mathbb{R}^d \ \mapsto \ \alpha(t,x) \in A \subset \mathbb{R}^k\Big\}$$

- The goal is to maximize the criteria J, for a given initial time and state $(t_0, x) \in [0,T] \times \mathbb{R}^d$, over the *feedback* controls, $\alpha \in \mathcal{A}_{t_0,T}$

$$J(t_0,x,\alpha) := \mathbb{E}\left[\underbrace{g(X_T^{t_0,x,\alpha})}_{\text{Terminal gain}} + \int_{t_0}^T \underbrace{f\big(s, X_s^{t_0,x,\alpha}, \alpha(s, X_s^{t_0,x,\alpha})\big)}_{\text{Running gain}} ds\right] . \quad (2)$$

Hamilton Jacobi Bellman equation (HJB)

- Introduce the value (or *Bellman*) function v : $[t_0, T] \times \mathbb{R}^d \to \mathbb{R}$

$$\begin{cases} v(T,x) & := & g(x) \\ v(t,x) & := & \sup_{\alpha \in \mathcal{A}_{t,T}} J(t,x,\alpha) \ , \quad \text{for } t \in [t_0, T) \ , \end{cases} \tag{3}$$

- v is solution of the non linear Partial Differential Equation (PDE):

$$\frac{\partial v}{\partial t}(t,x) + H(t,x,Dv,D^2 v) = 0 \ . \tag{4}$$

- Probabilistic representation of PDEs
  - Nonlinear SDEs in the sense of Mckean [McKean67]
  - Forward Backward Stochastic Differential Equations [PardouxEtPeng92]
  - Feynman-Kac branching processes [McKean75],

Outline

Handling with Distribution Grid (DG) constraints

Motivations: New renewables are mainly connected to the DG inducing critical voltage constraints
=> Flexibilities could contribute to alleviate DG constraints [DSO,Agg]

Problem: Satisfy DG power flow constraints with renewables injections using

- modifications of grid topology and storage devices (batteries, EV) to alleviate voltage constraints on the DG
- heat potential to alleviate DG constraints

Issues

- Provide optimization tool in a deterministic setting
- Integrate uncertainties related to renewable production, electricity and heat demand...

Local flexibilities serving the local or global level ?

Motivations Decide whether to use local flexibilities to alleviate local constraints on the DG or to contribute to the global equilibrium at the TG level.
[Reg, TSO, DSO]

Approach

- Local Marginal prices related to the DG constraints are added to the spot market prices and allow to decide whether to activate the flexibility or not.
- ???

Outline

Designing contract or tariffs

Motivations

- Design contracts distinguishing different types of consumers w.r.t. a given cost function
- Design contract for a flexible consumer such as to give proper incentives to modify the consumption

[Agg,PP]

Principal *Multi-level optim*, *Stackelberg game*, *Principal-Agent*,

- Parametric & deterministic with detailed constraints [Brotcorne etal. 2018]
- Nonparametric & deterministic [Alasseur etal. 2017]
- Nonparametric & stochastic [Aïd etal. 2017]

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