L'électrification intelligente au service de la transition énergétique

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An ADMM-based Coordination Strategy for the Control of Distributed Storage at the Household Level – Impact of the End-User Settings

Rémy Rigo-Mariani, Vincent Debucsshere

ELECTRIMACS 2022
14th International Conference of TC-Electrimacs Commitee
16-19 May, Nancy, France

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Simulated Use Case

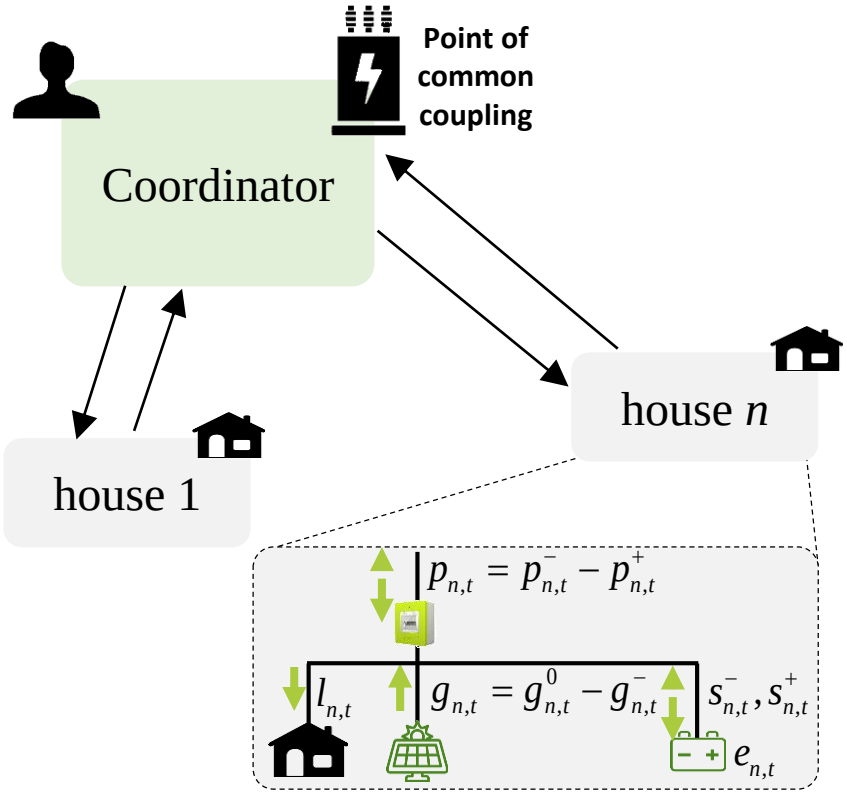
Coordinated Management of Distributed Storage

- **System :**
  - A pool of N users with solar + storage systems.
  - A coordinator at the PCC level with no direct control of end-users' assets.
- **Application :**

  Optimal scheduling (operational planning), arbitrage between system and individual objectives.
- **Assumptions :** .

  Grid not represented, active power management only, deterministic forecast profiles.
- **Implemented Solution :** .

  Coordination/decentralized strategy based on exchanged « price/quantity » information.



Data:

Load - REFIT load measurements - London

Solar - Radiation/Temperature from NASA

$f_n(x_n) = \sum_{t \in T} \left(p^+_{n,t} \times \pi^+_t - p^+_{n,t} \times \pi^- \right) \times dt$

Model Equations

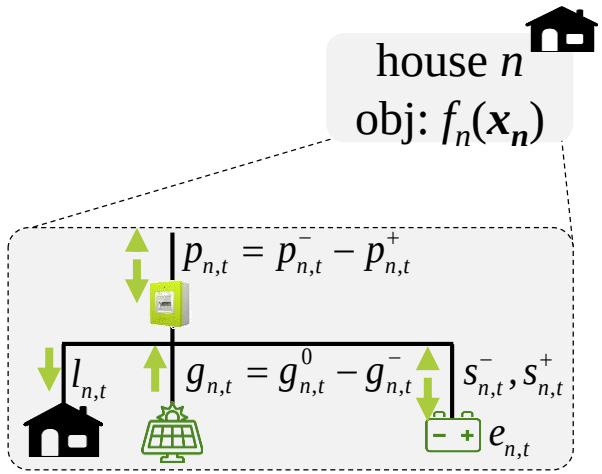
Models and Objectives

- **End Users :**
  - **Controls :** storage charge/discharge, curtailed solar.
  - **State variables :** stored energy, grid power.
  - **Objective :** minimize the electricity bill, subject to operating constraints (linear).

$$\text{obj} : \min_{x_n} f_n(x_n) \quad \text{s.t} \quad g_n(x_n) \leq 0$$

$$f_n(x_n) = \sum_{t \in T} \left(\underbrace{p^+_{n,t} \times \pi^+_t}_{\text{purchase}} - \underbrace{p^+_{n,t} \times \pi^-}_{\text{sell}} \right) \times dt$$

- **Billing scenarios :**
  - **S1 :** purchase + selling.
  - **S2 :** purchase + selling + ability to curtail solar.
  - **S3 :** purchase + ability to curtail solar.



$$x_n = \{s^-_{n,t}, s^+_{n,t}, e_{n,t}, g^-_{n,t}, p^-_{n,t}, p^+_{n,t}\}$$

$$p^+_{n,t} + g_{n,t} + s^-_{n,t} = l_{n,t} + s^+_{n,t} + p^-_{n,t} \quad \forall t \in T \qquad \text{balance}$$

storage:

$$0 \leq s^-_{n,t}, s^+_{n,t} \leq \overline{s_n} \quad \forall t \in T$$

$$0 \leq e_{n,t} \leq \overline{e_n} \quad \forall t \in T$$

$$e_{t=1} = e_{t=T}$$

$$e_{n,t} = e_{n,t-1} + s^+_{n,t} \times \eta - s^-_{n,t} / \eta \quad \forall t \in T - \{1\}$$

curtail:

$$0 \leq g^-_{n,t} \leq g^0_{n,t} \quad \forall t \in T$$

$$g_{n,t} = g^0_{n,t} - g^-_{n,t} \quad \forall t \in T$$

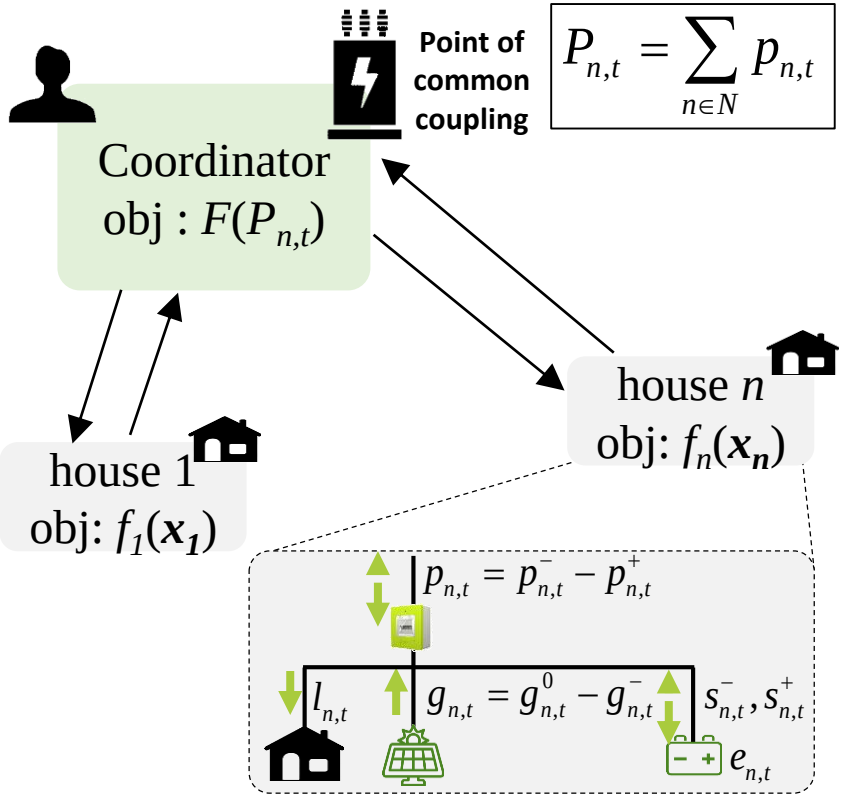
Model Equations

Models and Objectives

- **Coordinator :**
  - **Controls :** No asset control, compute the global power based on users' decisions.
  - **Objective :** minimize energy import/export and peak values.

$$\text{obj} : \min_{\substack{X=\{x_1,..,x_n\} \\ \text{from users}}} F(X) = \sum_{t\in T} \left(P_t\right)^2 \times dt = \sum_{t\in T} \left(\sum_{n\in N} p_{n,t} \right)^2 \times dt$$

- **Motivations :**
  - **Technical :** penalize both import/export flows, implicitly embeds grid losses.
  - **Mathematical :** convex, continuous function.
  - **Economical :** increasing marginal cost of generation.

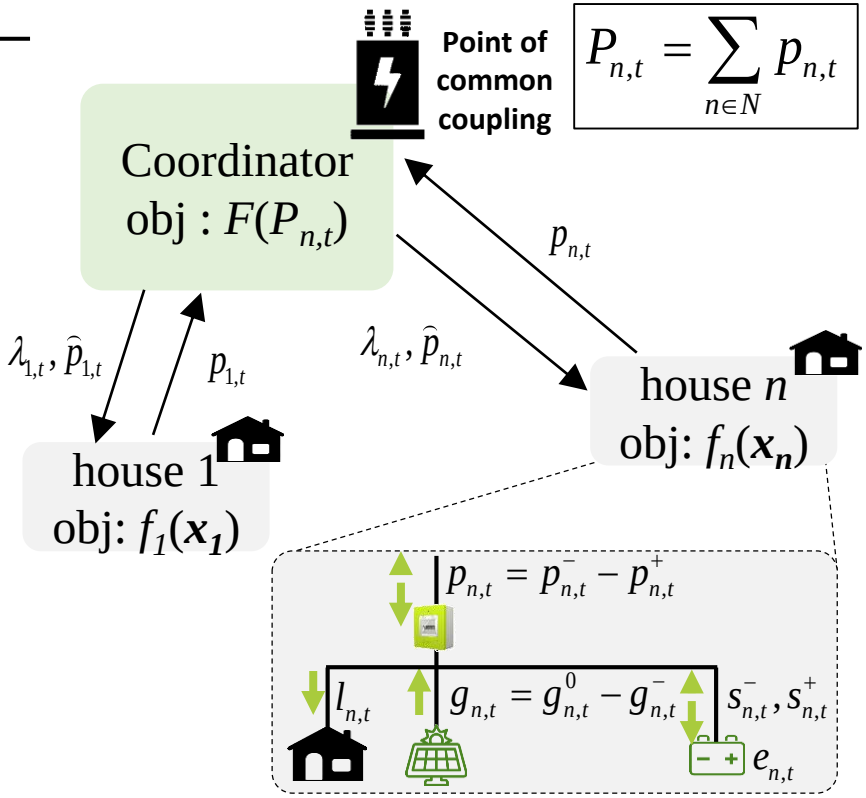


$$x_n = \{s^-_{n,t}, s^+_{n,t}, e_{n,t}, g^-_{n,t}, p^-_{n,t}, p^+_{n,t}\}$$

Coordination Strategy

Coordination Strategy

- **Alternating Direction Method of Multipliers - ADMM:**
  - Iterative process with exchange of "price/quantity" information.
  - **Quantity :** predicted grid power from the users $p_{n,t}$, reference power computed by the coordinator $\widehat{p}_{n,t}$.
  - **Price :** penalty coefficient, dual variables, lagrangian multipliers $\lambda_{n,t}$.



- **User Preference Settings :**

Willingness to deviate from individual optimum in case of uncoordinated control – additional constraint with response coefficient α.

$$\left| f_n(\boldsymbol{x_n}) - f_n^{\,0}(\boldsymbol{x_n}) \right| \leq \alpha \times f_n^{\,0}(\boldsymbol{x_n})$$

individual optimum

$$\boldsymbol{x_n} = \{s^-_{n,t}, s^+_{n,t}, e_{n,t}, g^-_{n,t}, p^-_{n,t}, p^+_{n,t}\}$$

Coordination Strategy

Coordination Strategy C-ADMM

- **Iterative Process :** successive updates of individual $f_n^{(k)}$ and global objectives $F^{(k)}$.

1. User optimization : returns predicted grid power $p_{n,t}$.

$$\text{obj: } \min_{x_n} f_n(x_n) + \lambda_n^T \left(p_{n,t} - \hat{p}_{n,t} \right) + \frac{\rho}{2} \left\| p_{n,t} - \hat{p}_{n,t} \right\|_2^2$$

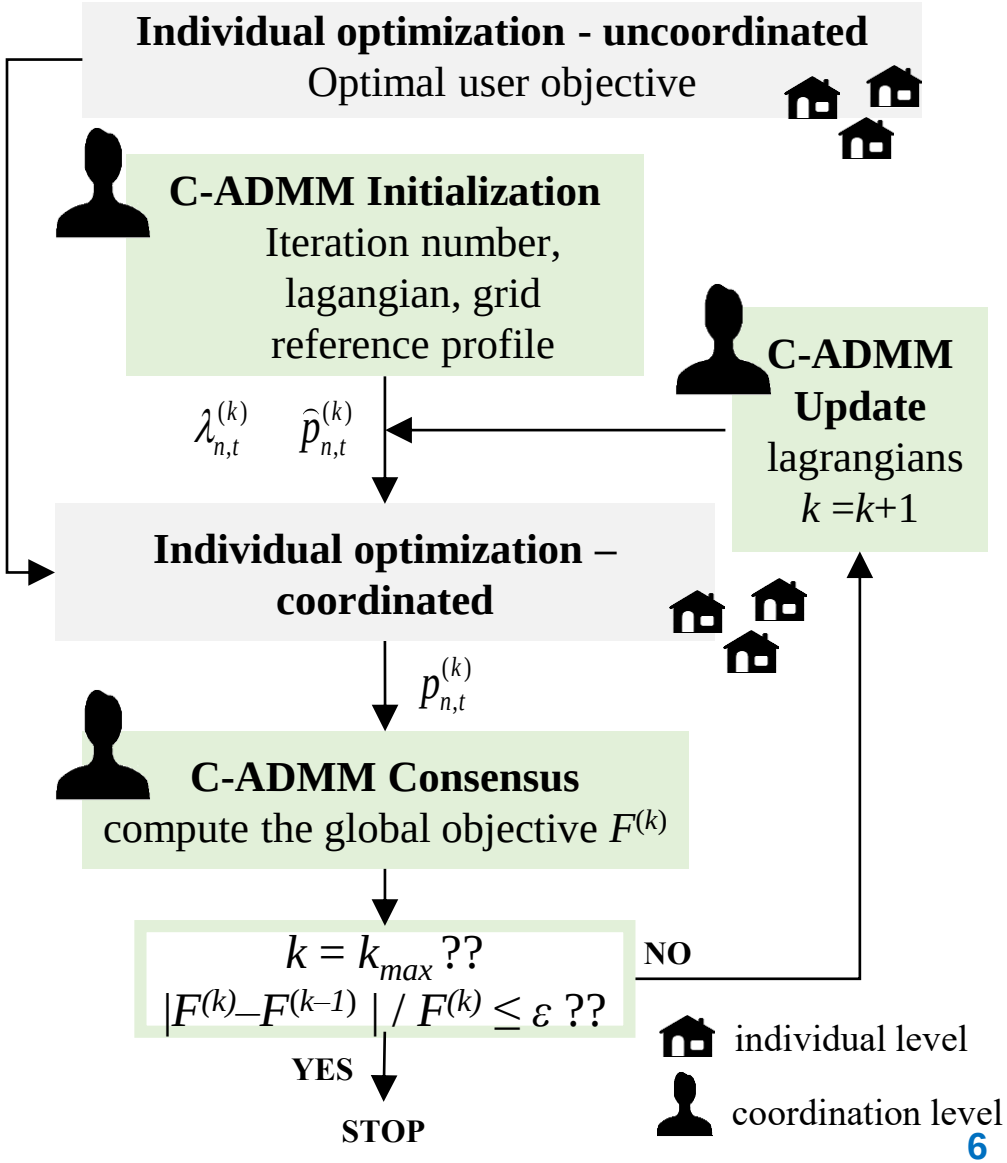
2. Coordination optimization : returns the best reference grid powers power $\widehat{p_{n,t}}$.

$$\text{obj: } \min_{\substack{\hat{p}_{n,t} \\ \forall \{n,t\} \\ \in (N,T)}} F(X) + \sum_{t \in T} \sum_{n \in N} \lambda_{n,t}^T \left(p_{n,t} - \hat{p}_{n,t} \right) + \frac{\rho}{2} \left\| p_{n,t} - \hat{p}_{n,t} \right\|_2^2$$

convergence rate

3. Lagragians update :

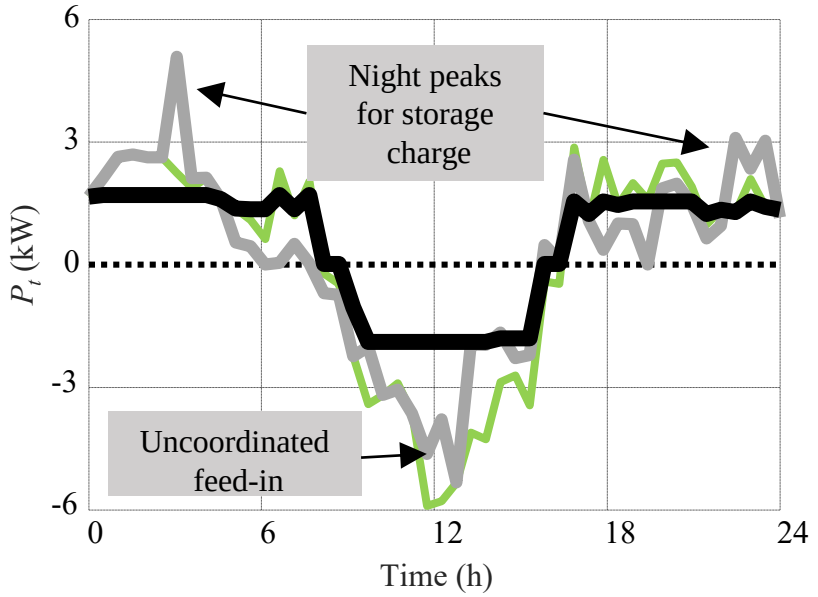
$$\lambda_{n,t}^{(k+1)} = \lambda_{n,t}^{(k+1)} + \rho / 2 \left(p_{n,t}^{(k+1)} - \hat{p}_{n,t}^{(k+1)} \right)$$

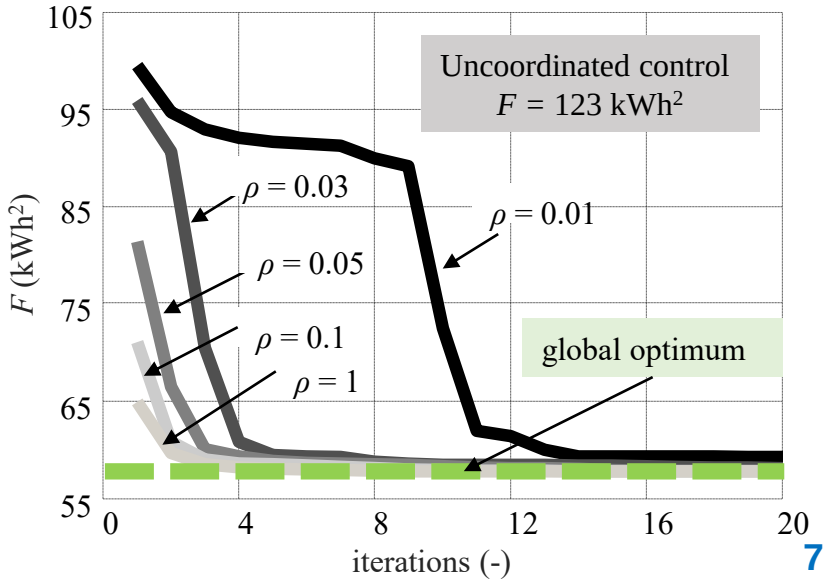


Obtained Results

Preliminary Tests with 3 Houses

- Global objective optimum value can be computed with all the assets centrally controlled.
- Need for coordination – global objective F value:
  - No storage control – F = 163 kWh^2
  - Uncoordinated control – F = 123 kWh^2
  - Global optimum – F = 58 kWh^2
- Coordination reaches the global system optimum with over 99 % accuracy.
- Impact of convergence-rate.
- Convergence in 4 iterations in the best case scenario.



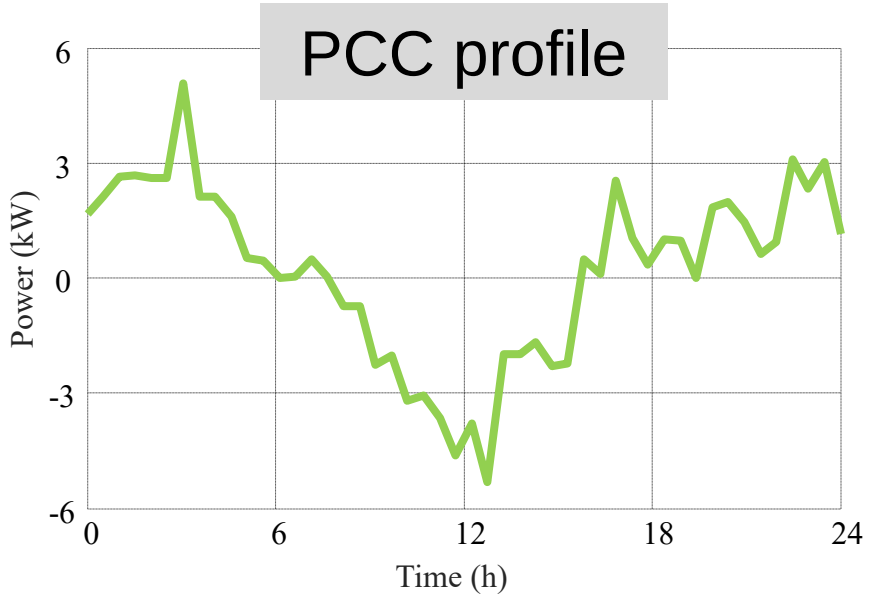


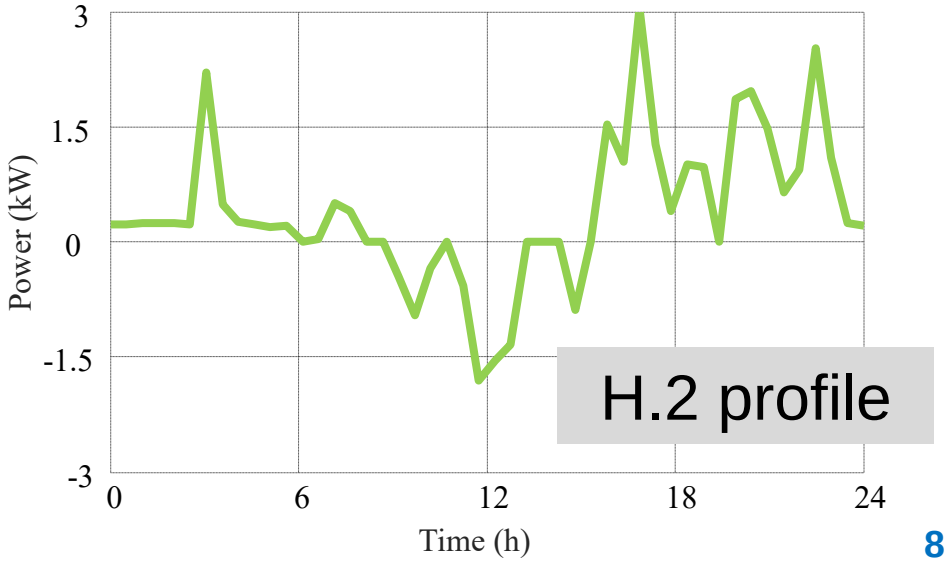
Obtained Results

Preliminary Tests with 3 Houses

- Aggregated power and house 3 power along the iterations
- Global and user objectives along the iterations.
- From uncoordinated control to global optimum.

	F (kWh^2)	f_1 (€)	f_2(€)	f_3(€)
Uncoord.	123.72	-0.34	0.35	1.73
Iter. 1				
Iter. 2				
Iter. 3				
Iter. 4				





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Iter. 2				
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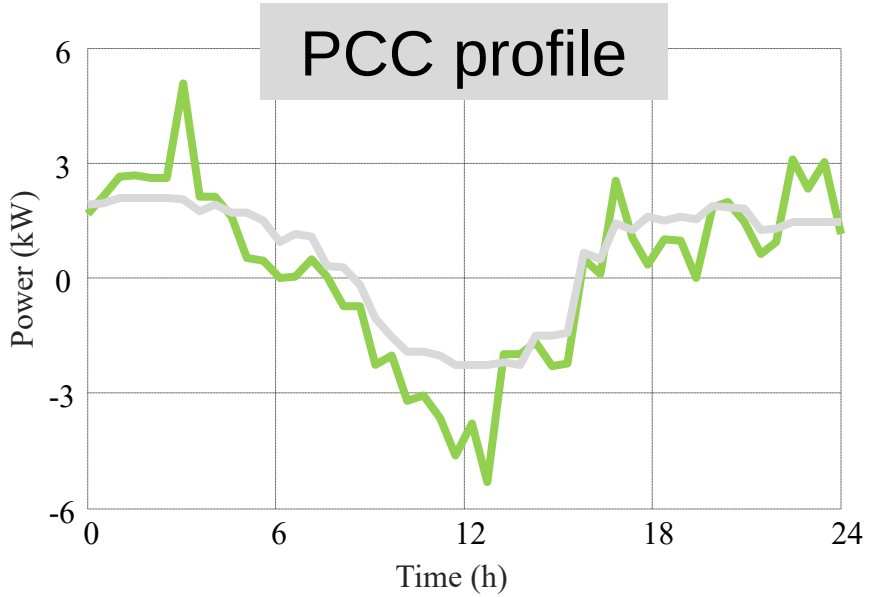
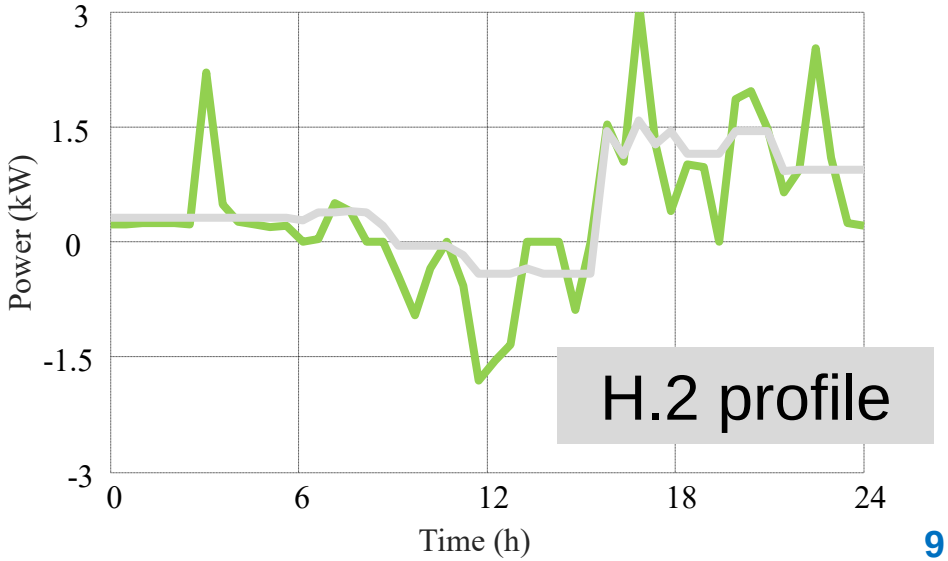
Iter. 4				





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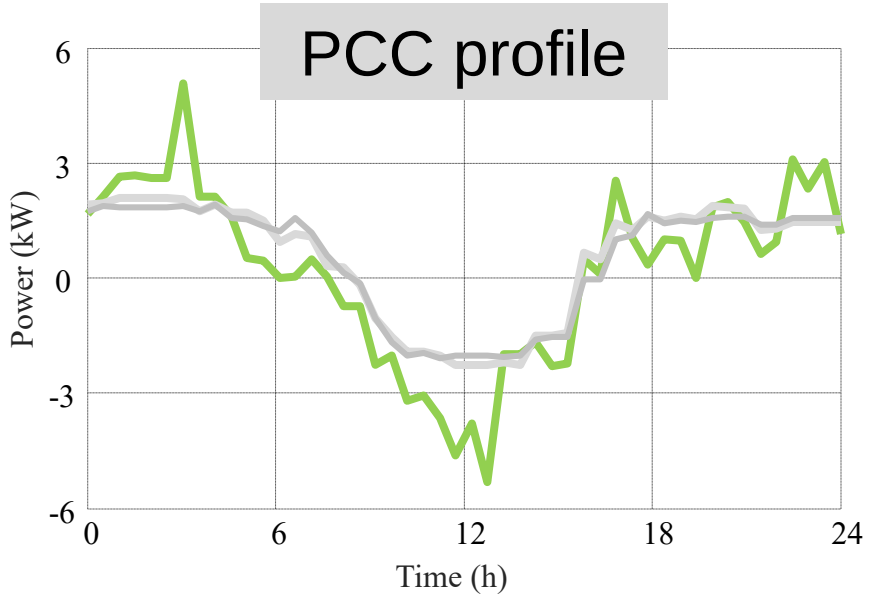
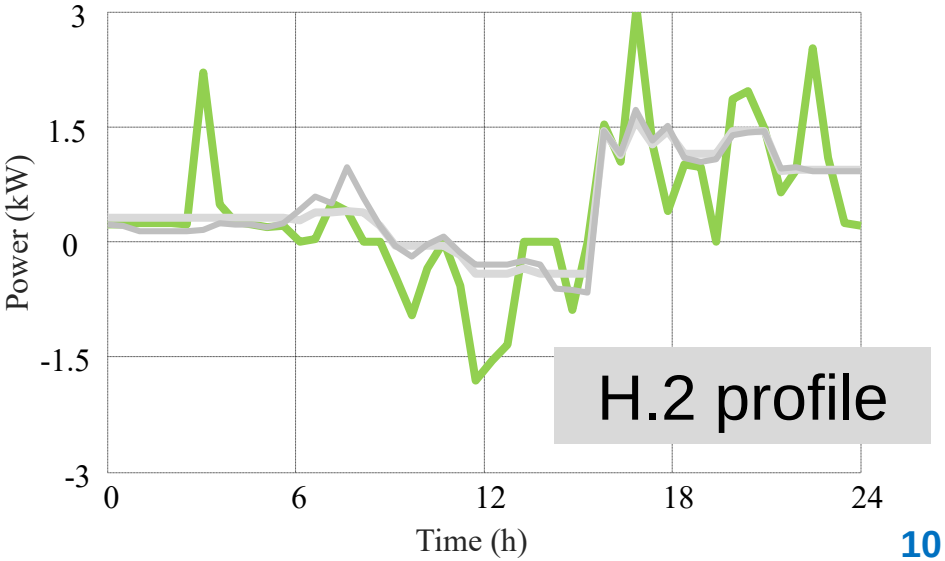
Iter. 4				





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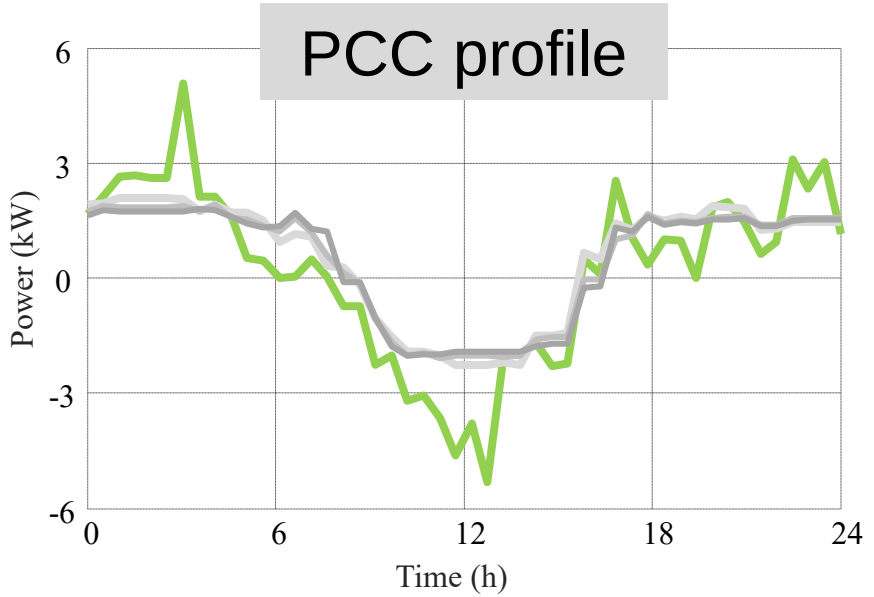
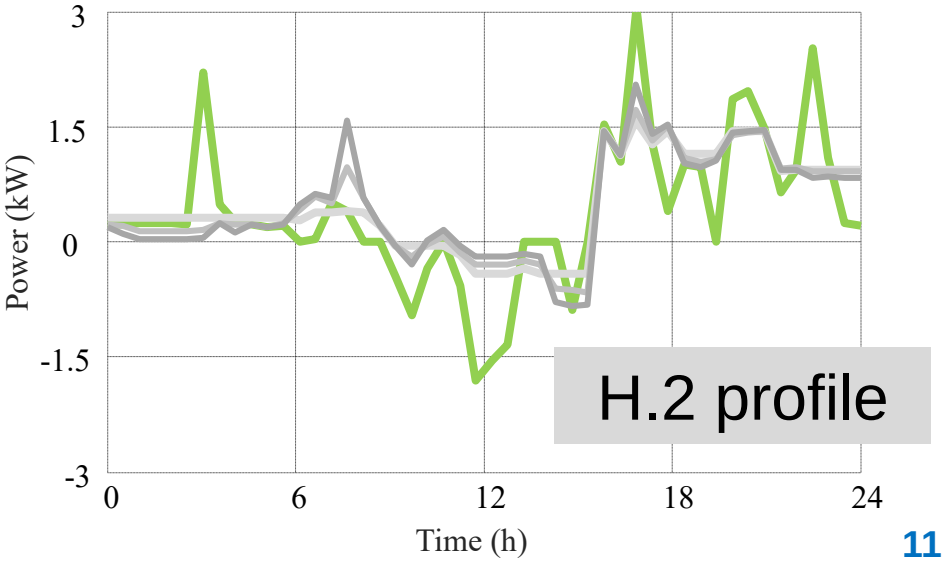
Iter. 3	58.56	-0.08	0.68	2.02
Iter. 4				





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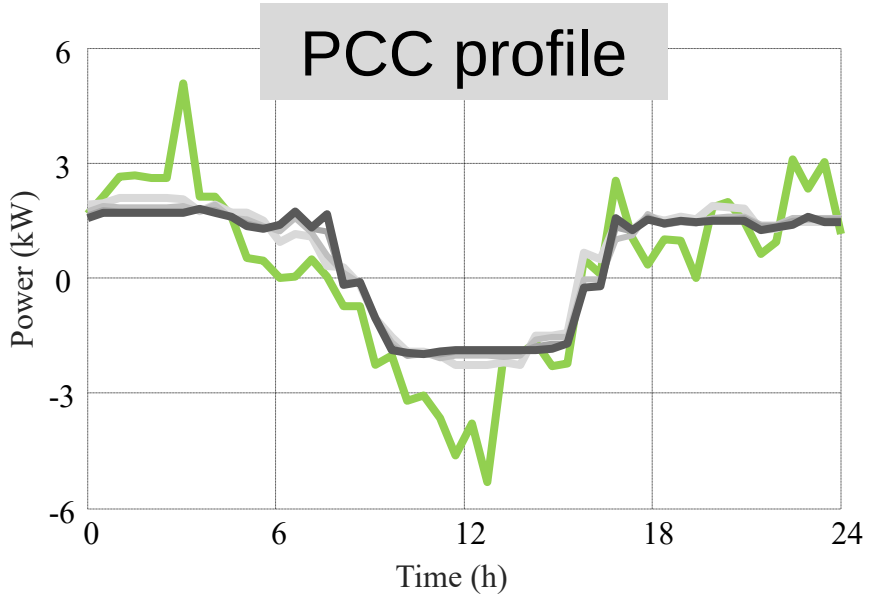
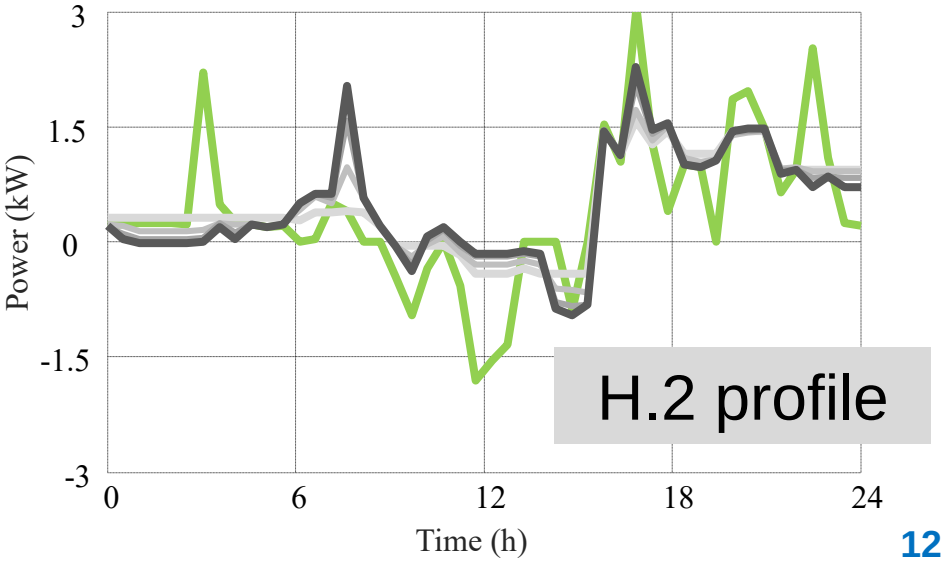
Iter. 3	58.56	-0.08	0.68	2.02
Iter. 4	**58.20**	-0.08	0.68	**2.04**

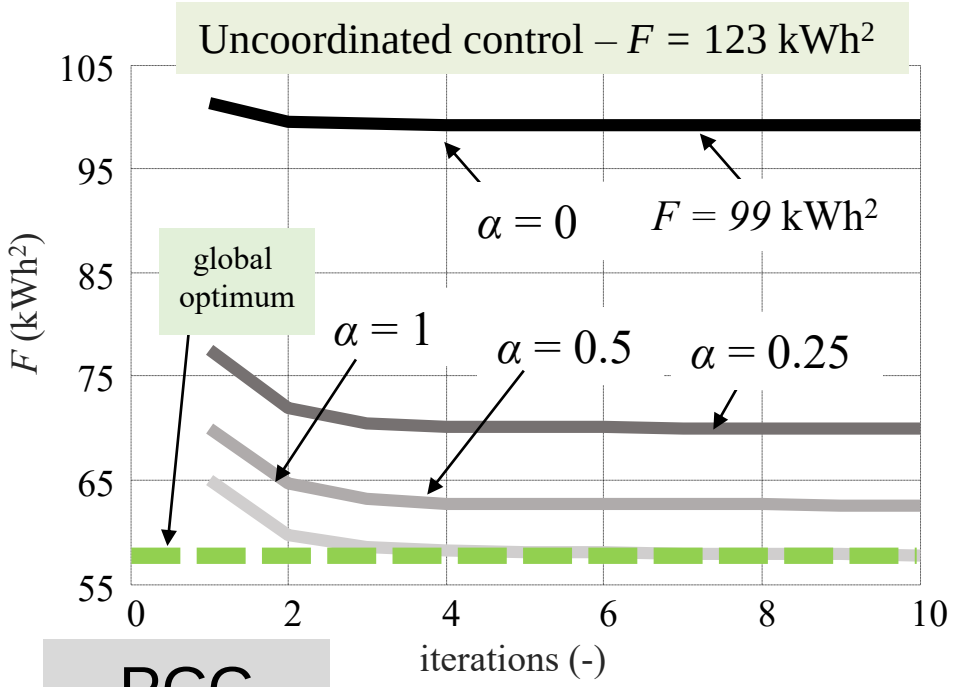


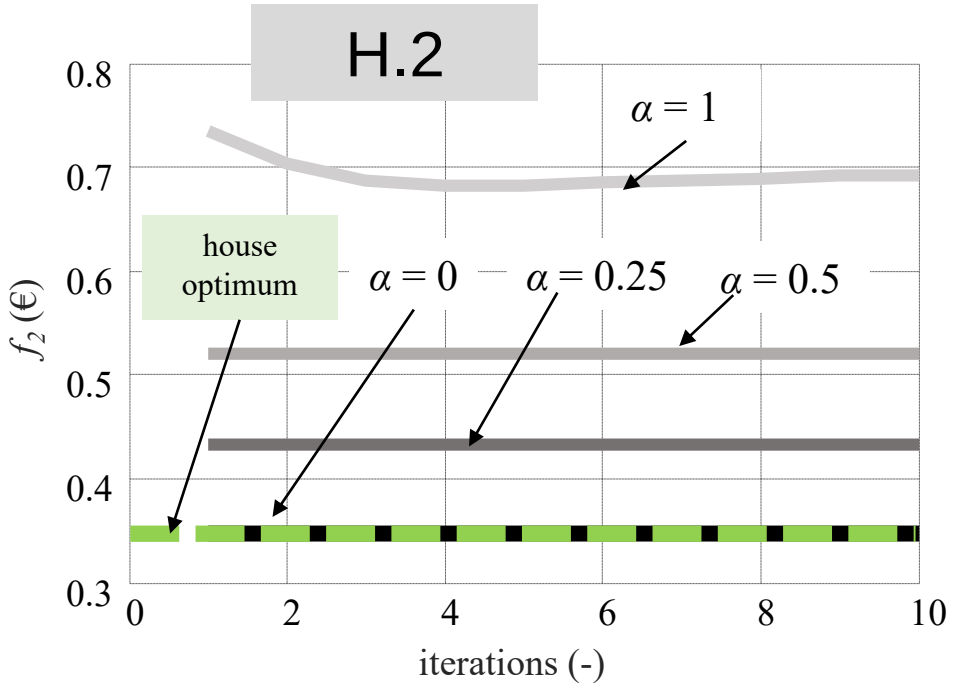


Obtained Results

Preliminary Tests with 3 Houses

- Arbitrage between users loss of revenue and global objective improvements.
- Improvement from uncoordinated control still possible without degrading user performances ($\alpha = 0$).

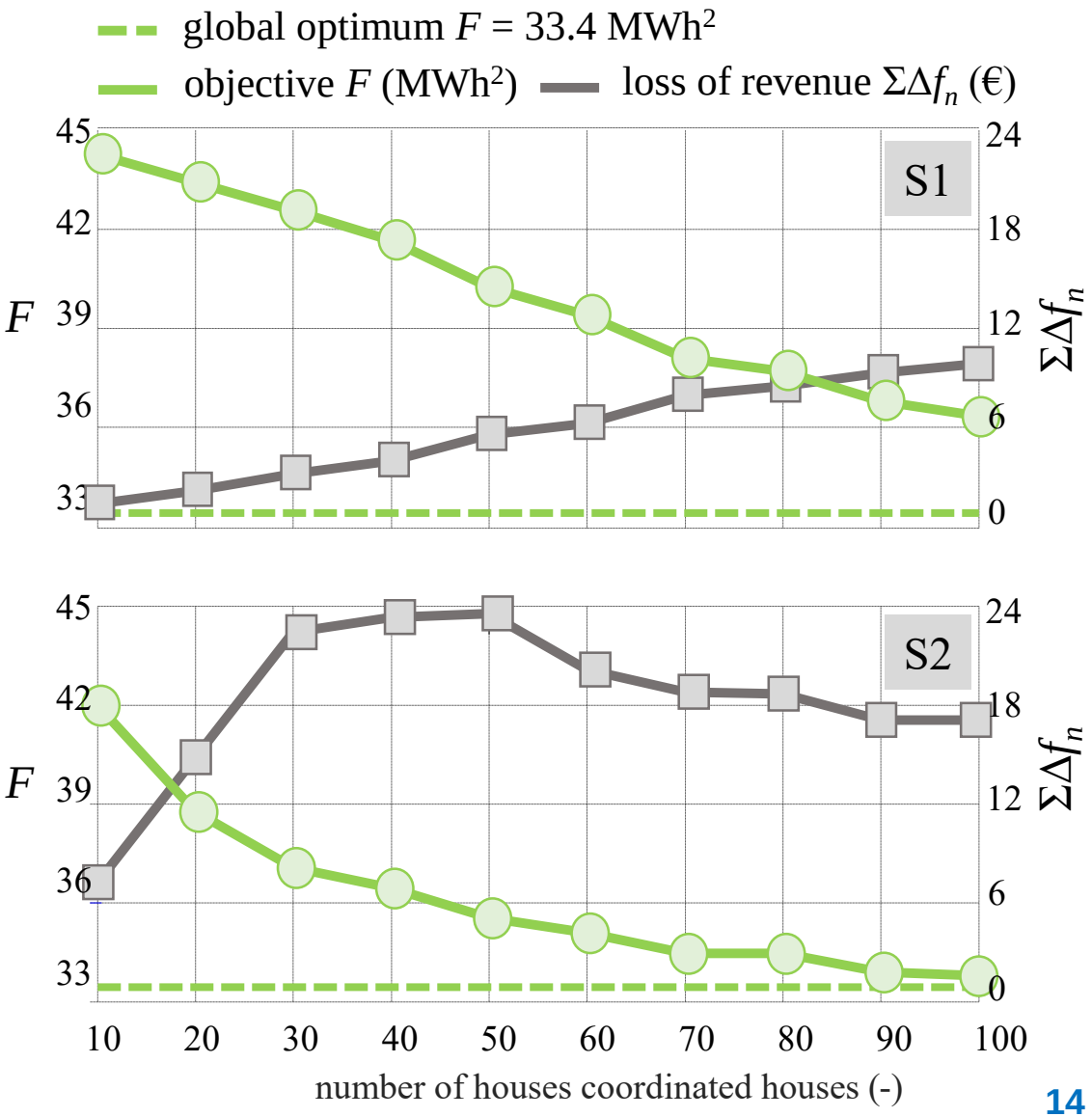




Obtained Results

Scalability to 100 Houses

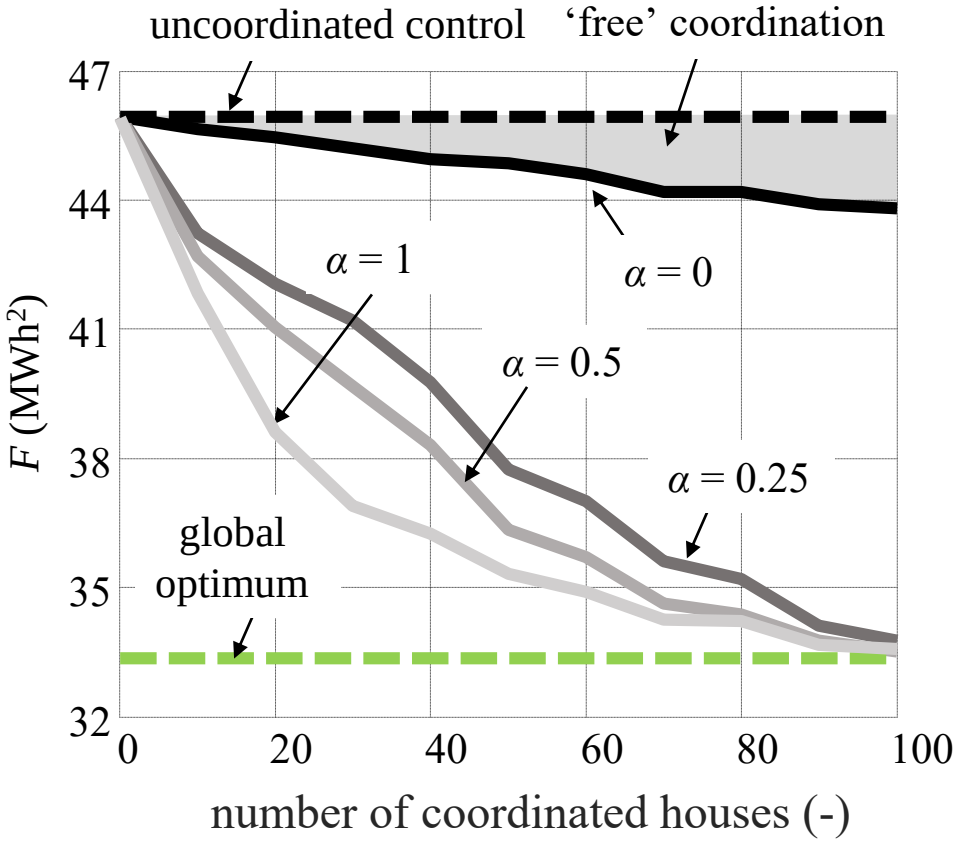
- System of 100 users with solar and storage- one day simulation.
- Increase the numbers of users in coordination – the others remain controlled at the individual level.
- System optimum improved with greater numbers of coordinated houses but with greater loss of revenue.
- Ability to curtail the solar generation (S2) improves the system optimum with greater loss of revenue.



Obtained Results

Scalability to 100 Houses

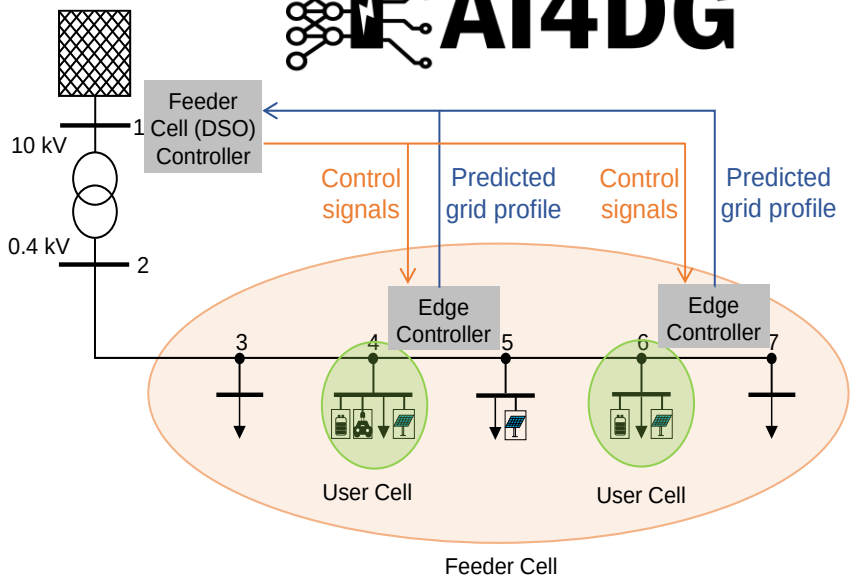
- Arbitrage between the number of coordinated users and their preferences.
- Improvement of the system objective still possible without decreasing users' performances ($\alpha = 0$).
- Global optimum reached with every house fully responsive ($\alpha = 1$).



Conclusions

- Successful implementation of coordination strategy with up to 100 houses with DERs 'behind the meter'.
- Coordination reaches global objective optimum with fully responsive houses – some improvements still possible without degrading users objectives.
- The more users, the less they need to degrade their objective to reach the same global target values.
- Furthers Works:
  - Investigation of pricing schemes or tailored user objectives to avoid iterations.
  - Include a decentralized real time control to comply with look-ahead scheduling.

AI4DG



Thank you