A Demand-Response Framework in Balance Groups through Direct Battery-Storage Control

G. Chasparis M. Pichler T. Natschläger

Software Competence Center Hagenberg GmbH, Austria

Naples, Italy
26th June 2019

Demand Response in Residential Buildings

- **Recently, we observe**
  - A constant increase in the number of battery storage systems.
  - A need for larger absorption rates of renewable energy
- **We need:**
  - to incentivize users to provide "*flexibility*"
  - to effectively *coordinate* flexibility extraction

Demand-Response Approaches

- **Commitment-based approaches**
  - The users commit to *reduce load* during peak-hours
  - The operator *distributes* the desired aggregated demand to the users

  (e.g., Ruiz et al (2009), Chen et al. (2014))

Demand-Response Approaches

- **Commitment-based approaches**
  - The users commit to *reduce load* during peak-hours
  - The operator *distributes* the desired aggregated demand to the users

  (e.g., Ruiz et al (2009), Chen et al. (2014))

- **Incentive-based approaches:**
  - The users provide *preferences* over availability and cost functions
  - The operator computes optimal flexibility extraction that *minimize cost*

  (e.g., Herter (2007), Triki & Violi (2009), Xu et al (2016))

Demand-Response Approaches

- **Commitment-based approaches**
  - The users commit to *reduce load* during peak-hours
  - The operator *distributes* the desired aggregated demand to the users

  (e.g., Ruiz et al (2009), Chen et al. (2014))

- **Incentive-based approaches:**
  - The users provide *preferences* over availability and cost functions
  - The operator computes optimal flexibility extraction that *minimize cost*

  (e.g., Herter (2007), Triki & Violi (2009), Xu et al (2016))

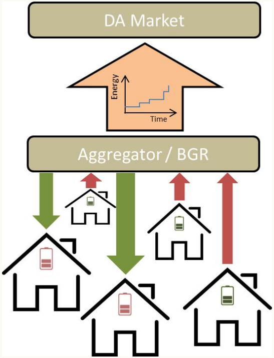
- **Combination of the two (*demand-response aggregation*)**
  - The operator *directly* extracts flexibility when necessary
  - In return, the operator offers to the owners a compensation

  (e.g., Parvania et al (2013), Iria et al (2017), Nan et al (2018))

Demand-Response Aggregation: *Requirements & Objective*

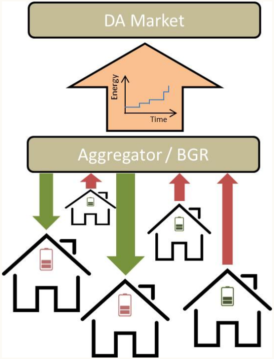
- *Features/requirements*:
  - optimizing *flexibility* extraction
  - optimizing over a *future time horizon*
  - optimizing over *multiple households*

- *Objective*
  - Respond to *load reduction/increase goals*
  - Participate in a *wholesale* electricity spot-market (e.g., Day-ahead, Intra-day)



Demand-Response Aggregation: *State-of-the-art & Challenges*

- So far, *analysis*
  - is primarily restricted to *single* households
    (e.g., Mohsenian-Rad (2016), He et al (2016), Jiang & Power (2016))
  - includes *detailed modeling* of the battery and cycle costs
    (e.g., He et al (2016))
  - has taken into account *uncertainty* and *imperfect forecasts*
    (e.g., Jiang & Power (2016))



- *Challenges*,
  - *computationally efficient* methods for a coordinated response of a pool of battery-storage systems
  - *dynamic-programming scheduling problem* with equilibrium constraints

Setup and Goal of this paper

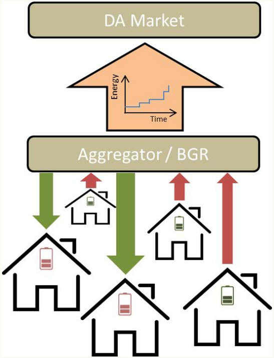
- *Austrian market organization*
  - *balance-group* (BG) organization
  - every prosumer is part of a BG
  - feed-in and off-take are *cleared* in 15min

- *Incentives for strategic behavior*

  (O1) *Market participation:* The BG may exchange electricity in a spot-market

  (O2) *Imbalance optimization:* Reduce current imbalances to zero, or generate imbalances

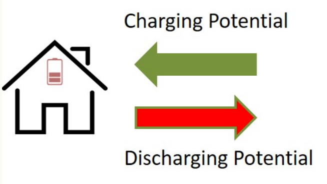
- *Goal* of this paper:
  - *formalize* these two (instantaneous) optimization problems
  - *provide building blocks* for a large scale *dynamic* optimization



Outline

Outline

Energy Potential



Energy Potential

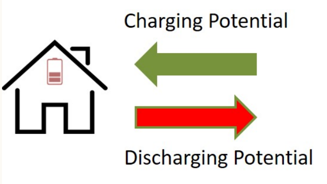
Energy potential or flexibility of a household i, for a time interval ΔT, is defined as the amount of energy that can be "*charged*" to or "*discharged*" from the household.

- **Charging (power) potential:**

$$V_{c,i}(t) \doteq \overline{P_{g,i}}(t) - P_{g,i}(t) \geq 0$$

  - $\overline{P_{g,i}}(t)$: maximum (positive) power from the grid
  - $P_{g,i}(t)$: power from the grid under baseline operation

Energy Potential



Energy Potential

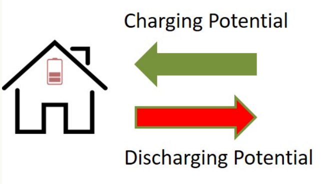
Energy potential or flexibility of a household i, for a time interval ΔT, is defined as the amount of energy that can be "*charged*" to or "*discharged*" from the household.

- **Discharging (power) potential:**

$$V_{d,i}(t) \doteq \underline{P}_{g,i}(t) - P_{g,i}(t) \leq 0$$

  - $\underline{P}_{g,i}(t)$: maximum (negative) power to the grid
  - $P_{g,i}(t)$: power from the grid under normal operation

Energy Potential



Energy Potential

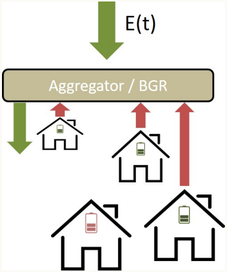
Energy potential or flexibility of a household i, for a time interval ΔT, is defined as the amount of energy that can be "*charged*" to or "*discharged*" from the household.

- **Example:** When the battery is currently *charging* with rate $c_i(t) \geq 0$, the charging (energy) potential is:

$$V_{c,i}(t) = \underbrace{c_{\max,i} \cdot \min\{\Delta T^*_{c,i}(t), \Delta T\}}_{\textit{maximum charging energy}} - \underbrace{c_i(t) \cdot \min\{\Delta T_{c,i}(t), \Delta T\}}_{\textit{current charging energy}}$$

Outline

Opportunity Costs



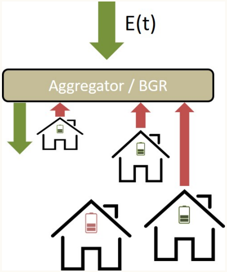
Opportunity Costs

Independently of the way that the BRP is currently utilizing the battery, the opportunity costs of activation can be defined as follows:

$$C_{\mathrm{act},i}(P'_{g,i}(t)) = \underbrace{U^*_{\mathrm{base},i}(t)}_{\text{optimal baseline operation}} - \underbrace{U_{\mathrm{BRP},i}(P'_{g,i}(t))}_{\text{BRP intervention}}$$

under the selected by the BRP power exchange with the grid.

Opportunity Costs (cont.)



Opportunity Costs: *Revenues under Baseline Operation*

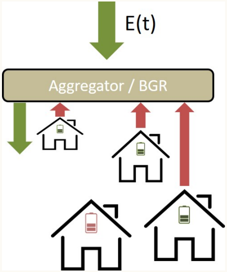
What would have been the revenue when the user maximizes its own utility:

$$U^*_{\text{base},i}(t) = \max_{P_{g,i} \in [\underline{P_{g,i}}, \overline{P_{g,i}}]} U_{\text{base},i}(P_{g,i})$$

where

$$U^*_{\text{base},i}(Pg,i) \doteq U_{\text{e.sell},i}(P_{g,i}) + U_{\text{b.store},i}(P_{g,i}) - C_{\text{e.buy},i}(P_{g,i}) - C_{\text{b.loss},i}(P_{g,i}) - C_{\text{b.wear},i}(t)(P_{g,i}).$$

Opportunity Costs (cont.)

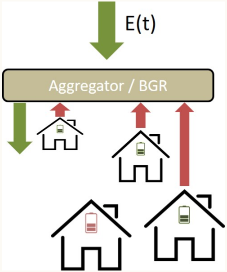


Opportunity Costs: *Revenues under BRP intervention*

What is the revenue of the household when the BRP intervenes:

$$U_{\mathrm{BRP},i}(P'_{g,i}) = U_{\mathrm{e.sell},i}(P'_{g,i}) + U_{\mathrm{b.store},i}(P'_{g,i}) - C_{\mathrm{e.buy},i}(P'_{g,i})) - C_{\mathrm{b.loss},i}(P'_{g,i}) - C_{\mathrm{b.wear},i}(P'_{g,i}),$$

Generic Activation Costs



Generic Activation Costs

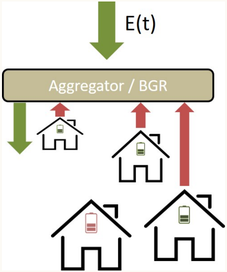
The user submits a linear activation curve that values its own preferences over the use of the battery. For example, when the BRP wants to establish a positive imbalance:

$$C_{\mathrm{act},i}(t) = \alpha_i(t) \cdot V_{c,i}(t) \cdot \beta_{c,i}(t)$$

under the selected by the BRP power exchange with the grid, for some positive constant $\beta_i(t)$ and activation parameter $\alpha_i(t) \in [0, 1]$.

Outline

Generic Activation Costs



Market Participation

We need to compute the optimal subset of participants and their schedules to generate a specific commitment $E(t) > 0$ at time interval t. In the case of generic costs,

$$\begin{array}{ll} \min & \mathbf{z}_c(t)^{\mathrm{T}}\mathbf{a} \\ \text{s.t.} & V_c(t)^{\mathrm{T}}\mathbf{a} = E(t) \\ \text{var.} & \mathbf{a} \in [0,1]^N \end{array}$$

Market Participation Optimization (cont.)

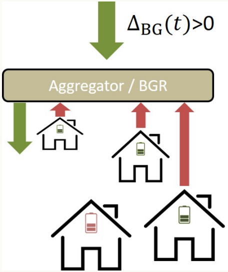
Optimal activation for $E(t) > 0$

```
procedure OPTIMALACTIVATION(V_c, z_c, E(t))
    order participants i = 1, 2, ..., N as follows
            β_{c,1} ≤ β_{c,2} ≤ ... ≤ β_{c,N}
    for i = 1, 2, ..., N do
        if i ≤ k* then
            α*_i = 1
        else
            if i = k* + 1 then
                α*_i = ( E(t) − Σ_{j=1}^{i−1} V_{c,j} ) / V_{c,i}
            else
                α*_i = 0
    return a*
```

$$\beta_{c,1} \leq \beta_{c,2} \leq \ldots \leq \beta_{c,N}$$

$$\alpha_i^* = \left(E(t) - \sum_{j=1}^{i-1} V_{c,j}\right) / V_{c,i}$$

Imbalance Optimization



Market Participation

We need to compute the optimal subset of participants to minimize a current imbalance, say $\Delta_{\mathrm{BG}} > 0$

$$\begin{array}{ll} \min & -\mathbf{z}_d(t)^{\mathrm{T}}\mathbf{a} + \lambda_{\mathrm{imb}}(t)\left(\Delta_{\mathrm{BG}}(t) + V_{d,i}(t)^{\mathrm{T}}\mathbf{a}\right) \\ \text{var.} & \mathbf{a} \in [0,1]^N \end{array}$$

Outline

Summary

Summary:

- We described a framework for *activation optimization* in balance groups.
- Essential building blocks:
  - energy potential calculation
  - opportunity/activation costs
- *Recall:* This is an optimization that applies to single interval ΔT.

Future Work:

- Day-ahead optimization for spot-market participation
- Upcoming paper in DACH+ Energy Informatics 2019

Snap-shot of Day-ahead Optimization