GSy-e Energy Community Optimization Model

1 Introduction

The Grid Singularity Exchange platform (GSy-e) can be used for modeling and deployment of local energy markets (LEMs) [1]. The structure of the grid with the energy communities as specified in the GSy-e is shown in fig. 1. The energy community consists of a number of houses / members and each one of them consists of a combination of load, PV generation and battery storage units. GSy-e allows peer-to-peer energy trading between members of the same or different communities through the Asset API [1]. It also allows the grid management through the Grid Operator API. A grid operator (DSO, DNO or TSO) can implement through this API various grid fee strategies influencing the trading behavior. The grid fees can be applied at two levels: a) at the community level when energy is traded between the community members and b) at the grid level when energy is traded between the community and the grid or the other communities.

This document provides the mathematical description of a deterministic model that optimizes the operation of an energy community as specified in the GSy-e. The objective of the optimization model is to minimize the total operation cost of the community for some period of time and it can be used to calculate the optimal quantities of energy that the community members should trade each period in order to achieve that goal. The mathematical formulation is given in the following section. There is also a nomenclature of the model parameters and variables in section 3.

2 Model description

The objective of the model is to minimize the total operation cost of an energy community over some time period. The total operation cost consists of an energy cost part and a grid cost part (1).

The energy cost $COST_t^{energy}$ includes the cost of the energy $P_t^{L2,buy} \cdot \delta_t$ bought from the grid at the market rate λ_t^{market} minus the revenue from the energy $P_t^{L2,sell} \cdot \delta_t$ sold to the grid at the feed in tariff λ_t^{feedin}. The period length δ_t given in hours, is used to transform the power into energy quantities. If the period length is hourly, then δ_t can be excluded.

The grid cost $COST_t^{grid}$ consists of a community cost part $COST_t^{grid,com}$ for the energy transferred into the houses of the community, and an external grid cost part $COST_t^{grid,ext}$ for the energy transferred between the community and the grid (3). The community fee λ_t^{com} is only applied to the energy imported

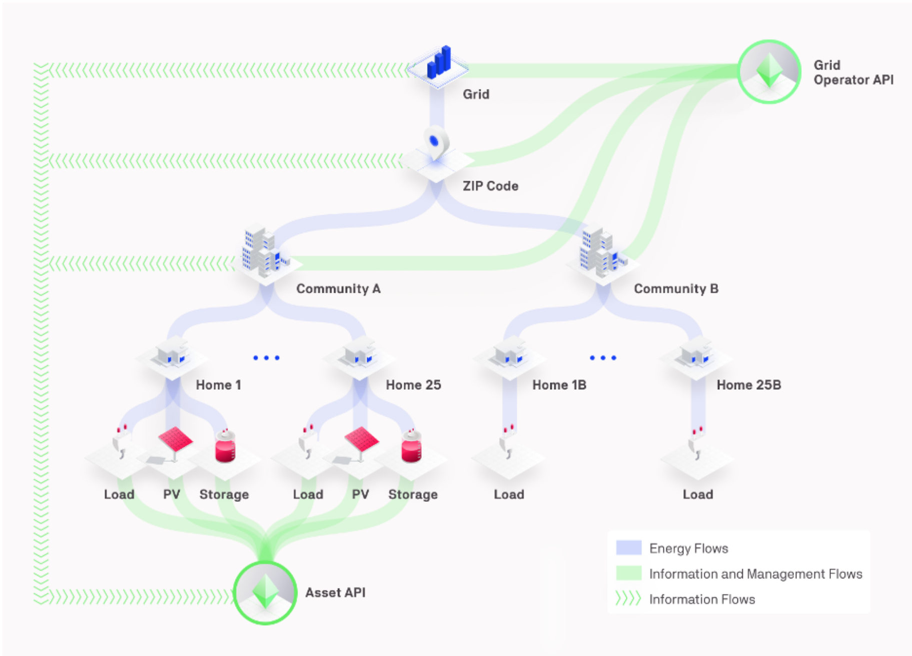

Figure 1: Grid structure and energy assets in the Grid Singularity Exchange [1]

from the community houses $P_{t,h}^{L1,buy} \cdot \delta_t$. The sum over all community houses consist the community grid cost (4). When the community exchanges energy with the grid, a fee is applied. This is λ_t^{grid} for the imported energy $P_t^{L2,buy} \cdot \delta_t$ and $\lambda_t^{com} + \lambda_t^{grid}$ for the exported energy $P_t^{L2,sell} \cdot \delta_t$. The reasoning behind these fees is to penalize the export of the locally generated power and instead to maximize the self-consumption inside the community.

The power balance at the house level defines that the difference between the exported power $P_{t,h}^{L1,sell}$ and imported power $P_{t,h}^{L1,buy}$ in a period t and house h is equal to the difference between the power generation $gen_{t,h}$ in the house (usually PV) and the house load $load_{t,h}$ plus the difference between the house battery discharging rate $B_{t,h}^{-}$ and charging rate $B_{t,h}^{+}$ at that period (6).

The power balance at the community level is given by (7). This defines that the difference between the exported power $P_t^{L2,sell}$ and imported power $P_t^{L2,buy}$ in a period t is equal to the sum over all community houses of the differences between house power exports $P_{t,h}^{L1,sell}$ and power imports $P_{t,h}^{L1,buy}$.

The battery energy balance equation calculates the battery's state-of-charge (SOC) $SOC_{t,h}$ (8). η_h^+ and η_h^- are the charging and discharging efficiencies respectively. The SOC (9) is limited above by the battery capacity soc_h^{max} and below by a minimum level soc_h^{min} which is applied in order to extend the battery life by avoiding deep discharges. The charging and discharging powers of the battery are also limited above (10,11)

2.1 Mathematical formulation

2.1.1 Objective function

$$min \sum_{t \in T} \left(COST_t^{energy} + COST_t^{grid} \right) \tag{1}$$

2.1.2 Energy cost

$$COST_t^{energy} = \lambda_t^{market} \cdot P_t^{L2,buy} \cdot \delta_t - \lambda_t^{feedin} \cdot P_t^{L2,sell} \cdot \delta_t \ \forall t \tag{2}$$

2.1.3 Grid cost

$$COST_t^{grid} = COST_t^{grid,com} + COST_t^{grid,ext} \ \forall t \tag{3}$$

$$COST_t^{grid,com} = \sum_{h \in H} \left(\lambda_t^{com} \cdot P_{t,h}^{L1,buy} \cdot \delta_t \right) \ \forall t \tag{4}$$

$$COST_t^{grid,ext} = \lambda_t^{grid} \cdot P_t^{L2,buy} \cdot \delta_t + \left(\lambda_t^{com} + \lambda_t^{grid} \right) \cdot P_t^{L2,sell} \cdot \delta_t \ \forall t \tag{5}$$

2.1.4 Power balance

$$P_{t,h}^{L1,sell} - P_{t,h}^{L1,buy} = gen_{t,h} - load_{t,h} + B_{t,h}^{-} - B_{t,h}^{+} \ \forall t, \forall h \tag{6}$$

$$P_t^{L2,sell} - P_t^{L2,buy} = \sum_{h \in H} \left(P_{t,h}^{L1,sell} - P_{t,h}^{L1,buy} \right) \ \forall t \tag{7}$$

2.1.5 Battery energy balance

$$SOC_{t,h} - SOC_{t-1,h} = \eta_h^{+} \cdot B_{t,h}^{+} \cdot \delta_t - \frac{B_{t,h}^{-}}{\eta_h^{-}} \cdot \delta_t \ \forall t, \forall h \tag{8}$$

$$soc_h^{min} \leq SOC_{t,h} \leq soc_h^{max} \ \forall t, \forall h \tag{9}$$

$$B_{t,h}^{+} \leq b_h^{+,max} \ \forall t, \forall h \tag{10}$$

$$B_{t,h}^{-} \leq b_h^{-,max} \ \forall t, \forall h \tag{11}$$

3 Nomenclature

Indices and Sets:

t	Index of time period, $t \in T$
h	Index of house, $h \in H$

Parameters:

λ_t^{market}	Market price for buying electricity, [€/kWh]
λ_t^{feedin}	Feed-in price for selling electricity, [€/kWh]
λ_t^{com}	Community fee for transferring electricity, [€/kWh]
λ_t^{grid}	Grid fee for transferring electricity, [€/kWh]
$gen_{t,h}$	Power generation, [kW]
$load_{t,h}$	Electricity load, [kW]
soc_h^{min}	Battery minimum state of charge, [kWh]
soc_h^{max}	Battery minimum state of charge, [kWh]
$b_h^{+,max}$	Battery maximum charging rate, [kW]
$b_h^{-,max}$	Battery maximum discharging rate, [kW]
η_h^+	Battery charging efficiency
η_h^-	Battery discharging efficiency
δ_t	Length of the period t, [h]

Positive variables:

$P_t^{L2,buy}$	Power imported to community, [kW]
$P_t^{L2,sell}$	Power exported from community, [kW]
$P_{t,h}^{L1,buy}$	Power imported to house, [kW]
$P_{t,h}^{L1,sell}$	Power exported from house, [kW]
$B_{t,h}^+$	Battery charging rate, [kW]
$B_{t,h}^-$	Battery discharging rate, [kW]
$SOC_{t,h}$	Battery state of charge, [kWh]

Variables:

$COST_t^{energy}$	Energy cost, [€]
$COST_t^{grid}$	Grid cost, [€]
$COST_t^{grd,com}$	Grid community cost, [€]
$COST_t^{grid,ext}$	Grid external cost, [€]

References

[1] "GSy Exchange SDK," Aug. 2022, original-date: 2020-01-21T16:41:50Z. [Online]. Available: https://github.com/gridsingularity/gsy-e-sdk