Smart system of renewable energy storage based on Integrated EVs and batteries to empower mobile, Distributed and centralised Energy storage in the distribution grid
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local Electricity retail Markets for Prosumer smart grid pOwer services

This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement No 646476.
• Introduction
• System architecture
• Business model
• Conclusions
Introduction

**INVADE** (2017-2019) (EU Horizon 2020 INNOVATION ACTION)

**TARGETS**

Develop a complete **new business models** and **local energy markets** at distribution network where:

- **consumers** are the **center**
- consumers can buy and sell **“neighborhood energy”** which is produced locally by solar panels, wind turbines and other **decentralized energy production**
- use of **electrical vehicles** energy and **batteries** to facilitate mobile, distributed and centralized **energy storage**
- will be **tested** in pilots sites: EMPOWER (3), INVADE (5)

Partners:
- Smart Innovation Østfold AS (NO)
- Schneider Electric Norge AS (NO)
- eSmart Systems AS (NO)
- Fredrikstad Energi Nett AS (NO)
- CITCEA-UPC (ES)
- University of St. Gallen (CH)
- Malta Intelligent Energy Management Agency (MT)
- NewEn Projects GmbH (DE)
INVVADE (2017-2019) (EU Horizon 2020 INNOVATION ACTION)

Partners:
- Smart Innovation Østfold AS (NO)
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- eSmart Systems AS (NO)
- Lyse (NO)
- NTNU (NO)
- CITCEA – UPC (ES)
- EPESA (ES)
- Elaad (HO)
- Greenflux (HO)
- NewEn Projects GmbH (DE)
- VTT (FI)
- Albena (BU)
Background: generation = demand

Long term: adequacy
Mid/short term: guarantee of supply, firmness
Real-time: security of supply
Balancing Services.

The System Operator uses different tools to ensure the technical functioning of the system. One of the most common tools is based on controlling the frequency of the system.
### Figure 1.8 • Overview of different building blocks of electricity markets

<table>
<thead>
<tr>
<th>Long-term markets</th>
<th>Medium-term markets</th>
<th>Short-term markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-35 years ahead</td>
<td>3-4 years ahead</td>
<td>Day ahead</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(h-24)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30-60 minutes</td>
</tr>
</tbody>
</table>

- **New capacity**
  - PPA and long term contracts

- **Capacity**
  - Capacity market

- **Energy**
  - Forward markets
  - Day-ahead markets
  - Intraday market

- **Reserves**
  - Ancillary services and operating reserves procurement
  - Balancing/real time markets
  - System operations

**Key point:** A suite of interrelated markets is used to match generation and load in the short, medium and long term.
Introduction

System architecture
Why?

- Traditional business:
  - Centralized and hierarchical
  - Large power plants
  - Passive consumers
Why?

- Traditional business:
  - Centralized and hierarchical
  - Large power plants
  - Passive consumers
Why?

- Smart grid elements are already developed and deployed:
  - local renewable generation (PV, WP)
  - EV (V2G)
  - Storage systems
  - Demand response
  - ITCs
  - Power electronics
  - Microgrids

**DISTRIBUTED ENERGY RESOURCES (DERs)**

- Household with flexible thermal load
- Household with flexible EV charger
- Storage capability
- Flexible industries
- Flexible or passive generators
- Flexible charging stations (V2G capable)
- Passive household

**System architecture**

- LC: Local controller
- SM: Smart Meter
- CP: Charging point
- μGC: Microgrid controller
- BC: Battery controller

**Power System Infrastructure**

**Communication platform**

**UTILITY GRID**
Why?

- Smart grid elements are already developed and deployed:
  - local renewable generation (PV, WP)
  - EV (V2G)
  - Storage systems
  - Demand response
  - ITCs
  - Power electronics
  - Microgrids
Why?

- Interaction of participants: consumers, producers, prosumers, community storage units, distribution system operators (DSO).
- Allowing deployment of a platform for negotiation and trading of energy and flexibility in a community
  - Smart Energy Service Provider (**SESP**) EMPOWER
  - Flexibility Operator (**FO**) INVADE
EMPOWER: New local market model
EMPOWER: New local energy business model

The system is a peer-to-peer platform based on direct control of demand and supply. The flexibility operator (FO) takes decisions based on flexibility contracts. Third party platforms can be integrated.

Flexibility resources to be controlled are:
- Batteries
- Electric vehicles
- Photovoltaic panels
- Water heaters
- Heat pumps

Flexibility services for:
- End-users/prosumers reducing the electricity bill
- BRP to reduce imbalance penalties
- DSO to control grid congestions
• Use cases (UC):
  1. Mobile energy storage using EVs for V2G, V2B and V2H operations
  2. Centralized energy storage using an array of batteries at the sub-station or street level
  3. Distributed energy storage using individual batteries at the household level
  4. Hybrid level energy storage solutions addressing a combination of use cases 2 and 3
INVADE: New ecosystem based business model combining energy and ICT
Local Smart Grids Architecture aims to define \textbf{relationships} between the different agents:

- Mapping technically business models and local market.
- Design of communication and physical connections of the prosumers to the control and market cloud.
- Design of software architecture of the control and market clouds.

\textbf{How}

- to define the relationships between the different participants?
- to specify the control, the market and the communications interactions?
How?

- SGAM (Smart Grid Architecture Model)
  - Three-dimensional model
Application of SGAM to EMPOWER

System architecture

Use Case Description  Business Layer Analysis  Function Layer Analysis  Component Layer Analysis  Information Layer Analysis  Communication Layer Analysis

Markets cloud technical architecture

Control cloud technical architecture
Communication and physical connections

SGAM component layer

COMPONENT LAYER

Zones

DOMAINS

SGAM generic information layer

INFORMATION LAYER

SGAM generic communication layer

COMMUNICATION LAYER

No cooperation with DSO
Business model

distribution grids V2X charging managers buildings
parkings Self-consumption wind parks microgrids Unidirectional
electric vehicles V2G UPS aggregators HEV
street events home photovoltaics data centers
charging stations SESP Bidirectional transmission grids
smart cities B2G PHEV
# Flexibility services

<table>
<thead>
<tr>
<th>Flexibility customer</th>
<th>Flexibility services INVADE</th>
<th>Description (Flexibility usage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSO</td>
<td>Congestion management</td>
<td>Avoiding the thermal overload of system components by reducing peak loads where failure due to overloading may occur.</td>
</tr>
<tr>
<td></td>
<td>Voltage / Reactive power control</td>
<td>Using load flexibility by increasing the load or decreasing generation is an option to avoid exceeding the voltage limits. Voltage control is typically requested when solar PV systems generate significant amounts of electricity.</td>
</tr>
<tr>
<td></td>
<td>Controlled islanding</td>
<td>Preventing supply interruption in a given grid section when a fault occurs in a section of the grid feeding into it.</td>
</tr>
<tr>
<td>BRP</td>
<td>Day–ahead portfolio optimization</td>
<td>Shifting loads from a high-price time interval to a low-price time interval before the day-ahead market closure. It enables the BRP to reduce its overall electricity purchase costs.</td>
</tr>
<tr>
<td></td>
<td>Intraday portfolio optimization</td>
<td>Enabling value creation on intraday market, equivalent to the day-ahead market.</td>
</tr>
<tr>
<td></td>
<td>Self-balancing portfolio optimization</td>
<td>Reducing imbalance by the BRP within its portfolio to avoid imbalance charges. The BRP does not actively bid on the imbalance market using its load flexibility, but uses it within its own portfolio.</td>
</tr>
<tr>
<td></td>
<td>ToU optimization</td>
<td>Flexibility from high-price intervals to low-price intervals or even complete load shedding during periods with high prices.</td>
</tr>
<tr>
<td>Prosumer</td>
<td>Maximum power control</td>
<td>Reducing the maximum load (peak shaving) that the Prosumer consumes within a predefined duration (e.g., month, year), either through load shifting or shedding.</td>
</tr>
<tr>
<td></td>
<td>Self-balancing</td>
<td>Value is created through the difference in the prices of buying, generating, and selling electricity (including taxation if applicable).</td>
</tr>
<tr>
<td></td>
<td>Controlled islanding</td>
<td>Preventing supply interruption in a household/building during grid outages.</td>
</tr>
</tbody>
</table>
Flexibility management for prosumers

Base line

06:00 am

HEMS

05:59 am
OBJECTIVE FUNCTION: minimizing the prosumer electricity bill, having into account his comfort level and maximizing self-consumption as well.

Prosumer BUYS/SELLS electricity from/to the grid

\[
\text{min } o.f. = \sum_{i \in T}(p_{\text{retail,buy}} \cdot x_{t}^{\text{buy}})_{p\text{taxes}} - \sum_{i \in T}(p_{\text{retail,sell}} \cdot x_{t}^{\text{sell}})_{p\text{taxes}} + \text{flexibility penalization}
\]

Cost of electricity bought to the grid (PVPC tariff)
Revenues for selling electricity back to the grid
Flexibility (discomfort) penalization

\[
\text{flexibility penalization} = \zeta_{\text{battery,chg}} + \zeta_{\text{gen,d}} + \zeta_{\text{gen,r}} + \zeta_{\text{load,d}} + \zeta_{\text{load,r}} + \zeta_{\text{load,p}} + \zeta_{\text{load,v}}
\]

Battery
\[
\zeta_{\text{battery,chg}} = \sum_{t \in T} \sum_{b \in B} p_{b,\text{chg}} \cdot \sigma_{t,b}^{\text{chg}}
\]

PV Generation
\[
\zeta_{\text{gen,d}} = \sum_{t \in T} \sum_{g \in G} p_{g,\text{d}} \cdot (W_{g,\text{d}} - \psi_{t,g}^{\text{d}})
\]
\[
\zeta_{\text{gen,r}} = \sum_{t \in T} \sum_{g \in G} p_{g,\text{r}} \cdot (W_{g,\text{r}} - \psi_{t,g}^{\text{r}})
\]

EV charging point
\[
\zeta_{\text{ev}} = \sum_{t \in T} \sum_{e \in \text{ev}} p_{e,\text{ev}} \cdot \rho_{t,e}^{\text{ev}}
\]
\[
\zeta_{\text{load,d}} = \sum_{t \in T} \sum_{e \in \text{load,d}} p_{t,\text{load,d}} \cdot \delta_{t,\text{start,d}}^{\text{d}} + \delta_{t,\text{run,d}}^{\text{d}}
\]
\[
\zeta_{\text{load,r}} = \sum_{t \in T} \sum_{e \in \text{load,r}} p_{t,\text{load,r}} \cdot \delta_{t,\text{start,r}}^{\text{r}} + \delta_{t,\text{run,r}}^{\text{r}}
\]
\[
\zeta_{\text{load,p}} = \sum_{t \in T} \sum_{e \in \text{load,p}} \sum_{n=0}^{V_{t,n,n}} p_{t,\text{load,p}} \cdot \rho_{t,e}^{\text{load,p}}
\]
\[
\zeta_{\text{load,v}} = \sum_{t \in T} \sum_{e \in \text{load,v}} p_{t,\text{load,v}} \cdot \rho_{t,e}^{\text{load,v}}
\]

Constraints: Restrictions of the Prosumer model.
- Energy balance: generation = consumption
\[
\sum_{g \in G} \psi_{t,g}^{\text{gen,d}} + \sum_{g \in G} \psi_{t,g}^{\text{gen,r}} + \sum_{b \in B} \sigma_{t,b}^{\text{dis}} + \chi_{t}^{\text{buy}} = \chi_{t}^{\text{sell}} + \sum_{b \in B} \sigma_{t,b}^{\text{ch}} + \sum_{e \in \text{ev}} \phi_{t,e}^{\text{ev}} + \sum_{t \in T} \omega_{t}^{\text{load,d}} + \sum_{t \in T} \omega_{t}^{\text{load,r}} + \sum_{t \in T} \omega_{t}^{\text{load,p}} + \sum_{t \in T} \omega_{t}^{\text{load,v}}
\]
- Maximum energy imported/exported from/to the grid
\[
\chi_{t}^{\text{buy}} \leq X_{\text{max,import}} / N
\]
\[
\chi_{t}^{\text{sell}} \leq X_{\text{max,export}} / N
\]

Conclusions
Conclusions

• Developing a completely new market system for trading energy and flexibility locally
  – Most of the energy consumers use will be produced where it is used
  – Power electronics and automation facilitates flexibility

• Increased feed-in of decentralized renewable energy
  – Central power supply will only be used as a reserve
  – Power electronics facilitates proper operation of the system

• Based on Big Data, Cloud Computing and Artificial Intelligence
  – ICTs allow new roles in the energy market (prosumers, aggregators, SESP, ESCOs, ...) & many new business models.
  – Power electronics facilitates link between cloud and physical electricity delivery
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