Algorithms for the control and sizing of renewable energy communities

Miguel Manuel de Villena, Samy Aittahar, Quentin Gemine, Damien Ernst

Montefiore Institute, Dept. of Electrical Engineering and Computer Science
University of Liège, Belgium
Graph-Based Optimization Modelling Language

A modelling language geared towards the representation of linear programs

- involving the optimization of discrete time dynamical systems over a finite time horizon
- that exhibit a natural block structure that may be encoded by a sparse connected graph
- draws on a combination of concepts from both *Algebraic Modelling Languages (AMLs)* and *Object-Oriented Modelling Languages (OOMLs)*

AMLs

- Models are built with algebraic (linear) expressions involving parameters (known) and variables (unknown)

OOMLs

- Models are built with blocks that are assembled (connected)
- Blocks can be seen as nodes, and the connections as edges => Graph

**Graph-Based Optimization Modelling Language (GBOML)**

Optimization problem is a graph where nodes consist of a set of algebraic expressions involving parameters and variables and are connected by edges
Graph-Based Optimization Modelling Language

Each node consists of a set of variables, a set of constraints linking the variables, and an objective function, nodes are:

- **Generic** – a few classes of nodes can simulate a broad range of problems
- **Parametrised** – readily adapted to a particular problem by tuning hyper-parameters
- **Abstract** – represent technologies (e.g. generation, storage) or processes (e.g. energy conservation)

The edges connecting the links:

- Represent relationships between the nodes
- Link the output variables of one node to the input variables of another

**Advantages of GBOML**

- Models are built in a modular way and encoding them is easy
- Post-processing is simple (data stored in common formats)
- Possibility of using decomposition algorithms and specialized solvers to exploit the graph-based structure of the problem (faster solving)
Graph-Based Optimization Modelling Language

Illustrative example: a microgrid

Links

\[ \text{pv\_output} = \text{pv\_generation} \]
\[ \text{bat\_output} = \text{bat\_discharge} \]
\[ \text{bat\_input} = \text{bat\_charge} \]
\[ \text{electric\_demand} = \text{demand} \]

Balance constraints

\[ \text{pv\_generation} + \text{bat\_discharge} \]
\[ = \text{bat\_charge} + \text{demand} \]
Problem of sizing energy systems

Energy systems can be represented by a set of nodes:

- they **represent technologies** (e.g. generation, storage) or **processes** (e.g. energy conservation)
- different energy systems can be **readily modelled** using a number of **generic nodes**
- they contain **variables representing quantities** (e.g. energy, money)
- **relationships** between technologies and processes are represented by **edges**

Optimal sizing of energy systems means determining:

- total **capacity of generation** (e.g. PV node) deployed in kWp
- total **capacity of storage** (e.g. battery node) deployed in kWh
- optimal **location** of these assets (which nodes)
- optimal **operation** of these assets (process nodes) over the lifetime of the system
Example of energy system – remote energy hub

Problem – feasibility assessment of the following process:

• Electricity generation in North Africa
• Synthesis of methane with this electricity and liquefaction
• Delivery and regasification in Europe.

The entire supply chain is modelled and optimised in an integrated fashion over a time horizon of one year with hourly resolution.

Objective

• Determine optimal capacities of all the technologies involved
• Minimise total system cost (CAPEX & OPEX) over the lifetime of the project
Example of energy system – remote energy hub
Example of energy system – remote energy hub

Results

- Different scenarios are studied
- Cost of synthetic methane in Europe is calculated as the ratio of total (annualised) system cost to 100 TWh HHV (higher heating value) of methane volume delivered (per year)

<table>
<thead>
<tr>
<th>Generation technology</th>
<th>Investment funding</th>
<th>Cost of methane</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV panels only</td>
<td>From capital markets at 7% WACC</td>
<td>199.0 EUR/MWh</td>
</tr>
<tr>
<td>Hybrid wind and PV</td>
<td>From capital markets at 7% WACC</td>
<td>148.5 EUR/MWh</td>
</tr>
<tr>
<td>PV panels only</td>
<td>Zero financing costs</td>
<td>124.4 EUR/MWh</td>
</tr>
<tr>
<td>Hybrid wind and PV</td>
<td>Zero financing costs</td>
<td>87.4 EUR/MWh</td>
</tr>
</tbody>
</table>
Problem of sizing RECs

Several assumptions are inherent to the sizing problem of RECs

- **Central planning & Operation** – a central planner, the ECM, decides on the investment decisions and operates the system
- **Perfect foresight** – future demand and production of the REC members are known
- **One-off investment** – investments in generation or storage are made at the beginning of the time horizon only
- **Operational decisions** – the operational decisions (e.g. charge/discharge) are made every hour

Required inputs:

- load profiles of REC members;
- solar irradiation data;
- electricity prices of the REC members (retailer tariffs);
- electricity prices inside the REC (including margin for the ECM).

Objective – maximisation of the net present value (NPV) of the REC

Output – optimal sizing configuration (PV & battery deployment) for each REC member
Problem of sizing RECs
Energy management system for RECs

Goal of the energy management system (EMS)

- Automatically control the REC in real-time (controllable assets such as batteries or sheddable loads) so as to minimise the sum of the electricity bills
- Help the ECM distribute the local production (electricity generated by REC members) among the REC members ex-post (decision making solution)

How local production is distributed

- Repartition keys – represent the proportion of total local generation allocated to each REC member
- Optimised after physical delivery of electricity (ex-post)
Energy management system for RECs

ECM

Optimal Repartition keys

Request computation of repartition keys

EMS

EMS

Retrieves measurements:
- PV production
- State of charge
- Electricity demand
- ...

Send control actions:
- Battery charge
- Battery discharge
- Shed load
- ...

REC
Repartition keys – concept

- $P$ is the total electricity production
- $y_i$ is the local production sold by REC member $i$
- $k_i$ is the proportion of total local production allocated to REC member $i$
Repartition keys – optimisation

Objective

- Minimisation of the sum of electricity bills of the REC members

\[ B = \sum_{i=1}^{l} \left[ \xi_i^b \cdot (C_i^n - a_i) + \xi_i^l - a_i - \xi_i^l + y_i - \xi_i^s \cdot (P_i^n - y_i) \right] \]

Constraints

- Repartition keys
- Energy balance

\[ a_i = k_i \cdot \sum_{i \in I} P_i^n \]
\[ \sum_{i \in I} a_i = \sum_{i \in I} y_i \]
\[ y_i \leq P_i^n \]
\[ a_i \leq C_i^n \]
Repartition keys – results

- Community with 24 REC members:
  - 23 net consumers
  - 1 net producer
- One year of operation

Computing **optimal repartition keys** for optimising the **financial exchanges** within an REC can induce **substantial savings** (up to 50% cost reduction for some members)
Joint optimisation of the controllable assets (e.g. batteries, sheddable or flexible loads) and the repartition keys – algorithm based on model predictive control and artificial intelligence

• At each time step we solve an open-loop problem along predicted scenarios for the consumption and the production of each member.

• We compute a sequence of commands to minimise the sum of the electricity bills of the REC members.

• Scenarios of production and consumption are predicted using artificial intelligence techniques (deep learning).

• Results show that it is important to simultaneously optimise the controllable assets and the repartitions keys.
Related works

[1] Manuel de Villena, Miguel; Mathieu, Sébastien; Vermeulen, Eric; Ernst, Damien. “Allocation of locally generated electricity in renewable energy communities”. Link: http://hdl.handle.net/2268/250878

[2] Aittahar, Samy; Manuel de Villena, Miguel; Castronovo, Michael; Boukas, Ioannis; Gemine, Quentin; Ernst, Damien. “Towards the online planning and local production allocation for renewable energy communities with batteries”. Link: Working paper

[3] Berger, Mathias; Bolland, Adrien; Miftari, Bardhyl; Djelassi, Hatim; Ernst, Damien. “Graph-Based Optimization Modeling Language: A Tutorial”. Link: http://hdl.handle.net/2268/256705

[4] Berger, Mathias; Radu, David; Detienne, Ghislain; Deschuyteneer, Thierry; Richel, Aurore; Ernst, Damien. “Remote renewable hubs for carbon-neutral synthetic fuel production”. Link: http://hdl.handle.net/2268/250796