Energy management and storage control with PV

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Energy management?

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement No 308991.
Energy management?

[Graph showing energy profiles with labels for PV power and power to the grid over a time span from 04:00 to 20:00 on 7th Feb, with peaks around 12:00 and 16:00, and a comparison between PV power and power to the grid.]
Energy management: goal?

- Maximize the gains from PV
- Minimize the cost of operation of a system
- Abide local grid regulations
- Understand power flows and local matching of consumption and production
Energy management: what?

- Controllable load
  - Match production and consumption

- Energy storage
  - Reshape power profile

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Energy management: three use cases

- Electrical and thermal: cooling dominated
  Sub-zero cold store
  electrical chiller 200kW
  passive thermal storage
  PV 250 kWp

- Electrical and thermal: heating dominated
  Medium size office building
  heat pump 2*16 kWth
  passive/active thermal storage
  PV 120 kWp (upscaled)

- Electrical only
  PV plant 3MWp
  electrical battery storage

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Case study: grid profile tracking
- Provide PV plant power to the grid as a trapezium per day
- Starquattro, Carinola, Italy. 3MWp

Solutions:
- Optimize largest trapezium inside the power profile and curtail any excess production
- Place a large enough battery and store the excess power to fill a larger trapezium
- Optimize the ‘large enough size’ every day to maximize gains by taking into account the battery storage investment costs.
- Place an optimal size battery and store the excess power to fill a larger trapezium
Electrical only: optimization problem

- Cyclic boundary condition: start and end of day halfway full battery
- Parameters to optimize
  - Maximum trapezium,
    - Start and stop time of the ramp up,
    - Start and stop time of the ramp down,
    - Height of the trapezium,
  - ..with battery,
    - The charge and discharge profiles (and thus state of charge) of the battery,
  - ..with optimal sizing
    - The cost optimal size of the battery
Optimization results

Original PV profile
Sunny day 4th August

Largest trapezium, no battery

Largest trapezium, large battery
400 kWh
Optimization results

Original PV profile
Low and variable irradiance, 7th November

Largest trapezium, no battery

Largest trapezium, large battery 400 kWh
Optimization results

- Battery size optimization needs a cost model for the battery

Tesla powerwall\(^1\) specifications are used

- $3000 (€2661) for 7kWh
- Roundtrip efficiency 92%
- 3.3 kW peak 7 kWh installed

Multiple batteries may be installed together for installations with greater energy need, up to 90 kWh total for the 10 kWh battery and 63 kWh total for the 7 kWh battery.

\(^1\) http://www.teslamotors.com/powerwall
Optimal battery sizes & netto gains

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Results battery case

Energy Curtailed in all seasons and year (4 weeks)

% of available PV power

- no battery (1)
  - winter: 27
  - spring: 17
  - summer: 20

- large battery [400 kWh] (2)
  - winter: 9
  - spring: 3
  - summer: 1

- optimal battery [0-730 kWh] (3)
  - winter: 7
  - spring: 2
  - summer: 6

- optimal fixed size [160 kWh] (4)
  - winter: 14
  - spring: 5
  - summer: 2

Highcharts.com
Results battery case

Energy recuperated and possible gains achieved

<table>
<thead>
<tr>
<th>Condition</th>
<th>Energy</th>
<th>Gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>No battery (1)</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>Large battery [400 kWh] (2)</td>
<td>97</td>
<td>88</td>
</tr>
<tr>
<td>Optimal battery [0–730 kWh] (3)</td>
<td>96</td>
<td>92</td>
</tr>
<tr>
<td>Optimal fixed size [160 kWh] (4)</td>
<td>95</td>
<td>91</td>
</tr>
</tbody>
</table>

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Electrical and thermal: heating case

- Improving state of the art: cost minimization vs Rule Based Controller (RBC)
  - Optimize heat production in the Kalkkaai 3E building
    - Integrate meteo predictions, future disturbances and measurement feedback
    - Keep control of zone temperatures
    - Optimize heating profiles for production unit(s) (gas boiler, heat pump)

- Investigate flexibility of the system
  - Optimal control of the heat production with PV integration
    - lower feed-in tariff (flexible controller)
    - no feed-in tariff (no feed-in controller)
Case study: demonstration case

- Implementation and testing of a model predictive controller (MPC)

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Results demonstration case: MPC vs RBC energy performance

Results demonstration case: MPC vs RBC comfort vs energy

Flexibility with a thermal heating case?

- Investigate flexibility of the system
  - Integrate PV by redefining the system as prosumer
    - Heat pumps consume electricity
    - PV produce electricity

- Two scenario’s:
  - lower feed-in tariff (flexible controller)
    - Only the energy part of the electricity price\(^1\) is remunerated (42.7 %)
  - no feed-in tariff (no feed-in controller)

\(^1\)http://www.sibelga.be/nl/tarieven/tarieven-netgebruik/waaruit-bestaat-uw-energiefactuur/factuur-elektriciteit
### Results

- **Lower feed-in tariff (42.7% of the electricity take-off tariff)**

<table>
<thead>
<tr>
<th></th>
<th>Reference tracking [%]</th>
<th>Flexible controller [%]</th>
<th>Flexible controller with TES [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational costs</td>
<td>100.0</td>
<td>95.8</td>
<td>93.4</td>
</tr>
<tr>
<td>Electricity use</td>
<td>100.0</td>
<td>111.0</td>
<td>112.0</td>
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<tr>
<td>Electricity use heat pumps only</td>
<td>100.0</td>
<td>104.0</td>
<td>104.0</td>
</tr>
<tr>
<td>Supply cover factor¹</td>
<td>54.2</td>
<td>65.4</td>
<td>68.2</td>
</tr>
<tr>
<td>Demand cover factor²</td>
<td>41.1</td>
<td>48.6</td>
<td>50.6</td>
</tr>
</tbody>
</table>

- **No feed-in tariff**

<table>
<thead>
<tr>
<th></th>
<th>Reference tracking [%]</th>
<th>No feed-in controller [%]</th>
<th>No feed-in controller with TES [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational costs</td>
<td>100.0</td>
<td>87.1</td>
<td>85.0</td>
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<tr>
<td>Electricity use</td>
<td>100.0</td>
<td>123.0</td>
<td>118.0</td>
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<tr>
<td>Electricity use heat pumps only</td>
<td>100.0</td>
<td>108.0</td>
<td>107.0</td>
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<tr>
<td>Supply cover factor</td>
<td>54.2</td>
<td>73.6</td>
<td>73.4</td>
</tr>
<tr>
<td>Demand cover factor</td>
<td>41.1</td>
<td>52.6</td>
<td>52.9</td>
</tr>
</tbody>
</table>
Results

- Max temperature limit
- Min temperature limit
- Reference tracking
- Flexible controller
- No feed-in controller
- Reference tracking constant COP

Zone temperature (degC)

Reference tracking constant COP
Reference tracking
Flexible controller

Heat pumps power (W)


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Highcharts.com
Electrical and thermal: Cooling case

- Match PV power with consumption of an electrical chiller in a cold store
  - Cooling of a sub-zero cold store (-20 degC) is a large electrical load
  - Thermal load is typically high when PV has high production
  - Precooling and subcooling is not limited by thermal comfort
  - Disturbances when product arrive/leave

- Compare flexibility by response to price incentive
  - High-low tariff (day-night) (optimal consumption controller)
  - .. lower feed-in tariff (flexible controller)
  - .. no feed-in tariff (no feed-in controller)
Optimization results

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Compare all controllers

comparison different controllers

<table>
<thead>
<tr>
<th>Controller</th>
<th>Energy Use</th>
<th>Supply Cover Factor</th>
<th>Demand Cover Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference tracking RBC</td>
<td>100</td>
<td>43.7</td>
<td></td>
</tr>
<tr>
<td>Optimal consumption controller</td>
<td>95.1</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Flexible controller</td>
<td>98.4</td>
<td>54.5</td>
<td></td>
</tr>
<tr>
<td>No feed-in controller</td>
<td>100</td>
<td>56.4</td>
<td></td>
</tr>
</tbody>
</table>

energy use  supply cover factor  demand cover factor

Highcharts.com

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Compare per scenario: costs

comparison different controllers

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Reference Tracking RBC</th>
<th>Optimal Consumption Controller</th>
<th>Flexible Controller</th>
<th>No Feed-in Controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>100</td>
<td>74.1</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Low</td>
<td>100</td>
<td>80.4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>No</td>
<td>100</td>
<td>72.9</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
## Conclusions energy management

<table>
<thead>
<tr>
<th>Case</th>
<th>Details</th>
</tr>
</thead>
</table>
| Electrical case               | • Adding a battery is a cost effective measure to reshape a PV plant’s power profile to a trapezium  
                               |   • Battery size can be optimally determined to maximize gains          |
| Electrical & heating case     | • +30% lower heating costs for demonstration case                        |
|                               |   • Accurately modelling the system is important and allows optimization |
|                               |     - non-constant heat pump efficiency                                  |
|                               |     - thermal model of the building                                      |
|                               | • Limited flexibility potential, not a good match PV production and consumption |
| Electrical & cooling case     | • Large flexibility potential                                            |
|                               |   • Accurately modelling the system is important and allows optimization |
|                               |     - chiller model                                                      |
|                               |     - thermal model of the building                                      |