Workshop "Energy sector coupling: electric-thermal interaction through heat pumps"

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How heat pumps may be leveraged in the management of smart grids

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IUAV - Main activities about smart grids

- Development/application of simulation codes and programs about building management strategies for heating/cooling systems fed by heat pumps...
  - ... with/without photovoltaic systems
  - ... with/without electricity storage units
  - ... with various smart grid coordination strategies (demand response, day-ahead and real-time tariffs, ...)
  - ... with focus both on the energy and economical perspectives

- 2 research activities as examples of IUAV activity in this field:
  1. Control of heat pump systems based on dynamic electricity tariffs
  2. Behaviour of battery-supported residential PV systems connected to smart grids, with a special focus on the interface with electricity distributors
BOUNDARY CONDITIONS FOR THE ANALYSES PERFORMED
Main background conditions

- Dynamic electricity tariffs extended to residential consumers
- Conventional HVAC system consisting of:
  - Heat pump
  - Heat storages
  - Low-inertia HVAC terminal units such as fan coils
- Typical medium apartment building:
  - 8 apartments (at first + second floor) + garages and warehouses (at the ground floor)
  - Heated volume: 2715 m³
  - Occupancy: 0.025 people/m²
  - Lighting + electric appliances:
    - Maximum intensity: 8 W/m²
    - Daily energy: 84 Wh/(m²·d)
  - Infiltration+Ventilation:
    - Garages and warehouses: 0.5 1/h, constant
    - Apartments: 0.3 1/h, constant
  - DHW: 50 l/(person·d) at 45°C
  - Design capacity:
    - Heating: 18.4 kW
    - Cooling: 21.1 kW
- Site:
  - City: Milan
  - Weather data: actual, for years 2012 and 2013
- Simulation procedure based on the superposition of:
  - the building envelope simulation (by means of building energy simulation software EnergyPlus)
  - the building system simulation (by means of NXT, a proprietary software developed at Università IUAV di Venezia, in C++)
Control of heat pump systems based on dynamic electricity tariffs

RESEARCH ACTIVITY 1
Introduction

- Object:
  - 3 heat pump control strategies are applied, whose action is based on:
    - the cost of electricity
    - on the level of the local electricity generation from photovoltaics

- Electricity price:
  - Actual hourly electricity prices in 2012 and 2013 + additional costs

- Possible side effects may consist in comfort issues → Definition of parameter “IPRL” (Index of Prompt Response-to-Load), defined as the ratio of the amount of heating/cooling loads postponed during the year (cumulated hour by hour, along the whole year) to the total heating/cooling loads.
The HVAC system

- The HVAC system consists of:
  - Inverter-driven heat pump, in 2 sizing levels:
    - 100%
    - 125%
  - Water heat storage unit aimed at DHW supply:
    - It contains the DHW ready for use (heated by the heat pump and pre-heated by the solar thermal loop)
    - Size in two levels:
      - 50 l/person
      - 100 l/person
  - Water heat storage for space heating/cooling:
    - Size in two levels:
      - 20 l/kW_{HPNominalCapacity}
      - 40 l/kW_{HPNominalCapacity}
The RES systems

- **PV system:**
  - Layout: integration onto the gable roof, on the side facing South.
  - Size: about 8 kW_p
  - Note: in this paper, it is intended to serve just the heat pump. In particular, it is sized to provide about 75% of the electricity yearly needed by the heat pump.

- **Solar thermal system:**
  - Size: covering 70% of DHW yearly energy needs
Control strategies

- **Simulated control strategies:**
  - Reference: it switches on/off the heat pump only based on the temperatures within the thermal storages through an on-off command with 5 K hysteresis.
  - Type A: the heat pump is switched on/off based on the current price of the electricity
  - Type B: the heat pump is switched on/off based on the ratio of the current price of the electricity to the maximum price forecast within the following 12 hours
  - Type C: the heat pump is switched on when:
    - the PV system is generating electricity
    - the PV system is not generating electricity and the HVAC system is requiring more than 15% of the heat pump nominal capacity

- In addition, the controller makes the heat pump to switch on when the water heat storage temperatures get too far (5 K) from the set-point supply temperatures.
Results

- Yearly electricity consumption and generation:
  - Strategy Type C achieves the best performance in heating and DHW preparation, because of its high operation frequency during midday hours.

- No significant variation of the energy consumption consequent to heat pump and water heat storage sizes → Focus on 40 l/kW\textsubscript{HP}

- Imported/exported electricity:
  - Type C achieves a smaller fraction of exported and imported electricity

- Type A, Type B, and Type C do not imply delays in heating/cooling supply, since they charge the water heat storages even when it is not strictly needed. Best: Type B.

- Costs:
  - Type C achieves the highest cost savings
Conclusions

- Proper control strategies make it possible to achieve relevant money savings and high degrees of energy self-consumption.
- Simultaneously, they may ensure good comfort levels.
- In particular, the best results were achieved by means of strategy Type C.
Behaviour of battery-supported residential PV systems connected to smart grids, with a special focus on the interface with electricity distributors.

RESEARCH ACTIVITY 2
Introduction

- **Object:**
  - Two predictive control strategies managing the charge of the electrochemical storage unit, in comparison with the conventional control strategy.
  - Parametric analysis on various combinations of photovoltaic system and battery pack sizes.

- **To estimate the effects in terms of grid imbalance:**
  - Quadratic imbalance coefficient, $k_Q$, equal to the quadratic imbalance between the building and the smart grid.
The PV system

- Ranges of PV peak power and battery pack size in the PV system parametric analysis → 43 combinations
- The PV system serves the building’s electricity needs as a whole
- Electrochemical storage units consist in Li-Ion cells

<table>
<thead>
<tr>
<th>Step</th>
<th>Installed peak power of PV modules</th>
<th>Battery pack capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Step code</td>
<td>Installed peak power [kW] (% referred to the reference size, equal to 37.8 kW)</td>
</tr>
<tr>
<td>0</td>
<td>PV0</td>
<td>0.0 (0%)</td>
</tr>
<tr>
<td>1</td>
<td>PV1</td>
<td>9.5 (25%)</td>
</tr>
<tr>
<td>2</td>
<td>PV2</td>
<td>18.9 (50%)</td>
</tr>
<tr>
<td>3</td>
<td>PV3</td>
<td>28.4 (75%)</td>
</tr>
<tr>
<td>4</td>
<td>PV4</td>
<td>37.8 (100%)</td>
</tr>
<tr>
<td>5</td>
<td>PV5</td>
<td>47.3 (125%)</td>
</tr>
<tr>
<td>6</td>
<td>PV6</td>
<td>56.8 (150%)</td>
</tr>
</tbody>
</table>
Control strategies

- Simulated control strategies:
  - Strategy 0: conventional battery charge control strategy
  - Strategy 1 and Strategy 2 use algorithms predicting possible profiles of electricity import/export in the next 24 hours, by means of simplified simulation of the energy flows involved in PV system operation, starting from the following data:
    - The hourly building’s electricity consumption profile taking place in the previous 24 hours ($P_{\text{Needs},-h}$).
    - The hourly profile of solar radiation level expected in the next 24 hours ($P_{\text{Sun},-h}$).
    - The current state of charge of the battery pack ($C_{\text{BP},t=0}$).
  - In particular:
    - Strategy 1 assumes a daily constant proportion between the share of electricity sent to the grid and the surplus electricity simultaneously generated by the PV modules.
    - Strategy 2 considers a constant value of the maximum export power during the next 24 hours, thus achieving a flat export profile.
Results

- Yearly shares of electricity sent to the building by the PV system as a whole and by the battery pack alone.
- Differences in yearly shares of exported electricity, in terms of percentage of yearly electricity needs and in terms of percentage of the counterpart value resulting from control strategy 0.
- Detailed statistics about the interface between the building and the national grid:
  - Frequency of occurrence of exported and imported power ranges, in terms of percentage of $P_{\text{Needs,Max}}$:
    - The control strategies influence mainly the exported power.
- Detailed statistics about the interface between the building and the national grid:
  - Yearly quadratic effective imbalance coefficient for every configuration.
    - Lower values of the yearly quadratic effective imbalance coefficient would be achieved in case of PV system sized for 75% of the yearly energy needs.
Conclusions

- By the proposed control strategies, the frequencies of occurrence of high values of exported electricity may be decreased by almost 100%, whereas medium-high values of exported electricity by 50%.
- Both of the control strategies are shown to be able to lower the yearly quadratic effective imbalance coefficient by around 15% in case of PV systems sized for Zero Energy Buildings (ZEBs), thus showing opportunities in the mitigation of electricity grid stresses from PV systems.
- The share of energy self-consumption may be increased by about 30% by means of medium-large battery packs.
THANK YOU
FOR YOUR KIND ATTENTION

More details in: