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Energy sector coupling: electric-thermal interaction through heat pumps

Integrids

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

23rd October 2018

NOI Techpark Südtirol/Alto Adige
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How heat pumps may be leveraged in the management of smart grids

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I U A V

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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 m^3
  - ✓ Occupancy: 0.025 people/m^2
  - ✓ Lighting + electric appliances:
    - Maximum intensity: 8 W/m^2
    - Daily energy: 84 Wh/(m^2·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_{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

Step	Installed peak power of PV modules		Battery pack capacity	
	Step code	Installed peak power [kW] (%, referred to the reference size, equal to 37.8 kW)	Step code	Capacity [kWh] (%, referred to the reference size, equal to 37.8 kWh)
0	PV0	0.0 (0%)	BP0	0.0 (0%)
1	PV1	9.5 (25%)	BP1	18.9 (50%)
2	PV2	18.9 (50%)	BP2	37.8 (100%)
3	PV3	28.4 (75%)	BP3	56.7 (150%)
4	PV4	37.8 (100%)	BP4	75.6 (200%)
5	PV5	47.3 (125%)	BP5	94.5 (250%)
6	PV6	56.8 (150%)	BP6	113.4 (300%)

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 ($P_{Needs,-h}$).
    - The hourly profile of solar radiation level expected in the next 24 hours ($_{PSun,-h}$).
    - The current state of charge of the battery pack ($C_{BP,t=0}$).
    - 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 $P_{Needs,Max}$:
    - 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:

- Luigi Schibuola, Massimiliano Scarpa, Chiara Tambani, Demand response management by means of heat pumps controlled via real time pricing, Energy and Buildings, Volume 90, 2015, Pages 15-28, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2014.12.047.
- Luigi Schibuola, Massimiliano Scarpa, Chiara Tambani, Influence of charge control strategies on electricity import/export in battery-supported photovoltaic systems, Renewable Energy, Volume 113, 2017, Pages 312-328, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2017.05.089.