INTERFLEX SWEDISH DEMO IN MALMÖ – CROSS-CARRIER INTEGRATION FOR ENHANCED FLEXIBILITY IN LOCAL ENERGY COMMUNITIES AND MICROGRIDS

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ABSTRACT

This paper discusses how the thermal side of a local energy community can offer flexibility to the electrical grid. In this regard, a model is presented in which a heat pump is used to connect low temperature heating and cooling networks and create flexibility being powered by renewables. This is done in combination with an overall control strategy aligning with production and demand across different energy carriers integrating the heat pump model with the thermal storage capacity offered by heating/cooling grids presenting the theoretical demand response opportunities in technical terms.

INTRODUCTION

InterFlex project is a response to the Horizon 2020 Call for proposals, LCE-02-2016 (“Demonstration of smart grid, storage and system integration technologies with increasing share of renewables: distribution system”). In this project, six demonstrations projects are conducted in five EU Member States (Czech Republic, France, Germany, the Netherlands and Sweden) in order to provide deep insights into the market and development potential of the orientations that were given by the call for proposals, i.e., demand-response, smart grid, storage and energy system integration.

Within the scope of InterFlex, E.ON as a DSO and heat network operator addresses the enhancement of the distribution system flexibility in two different urban and rural demonstrations in Sweden. The urban demo implemented in Malmö which is the focus of this paper, features the integration of different energy carriers to enhance on-site utilization of renewable generation flexibilities associated with different energy carriers, such as district heating and cooling. For this purpose, electric heat and cooling generators can be used for providing heat and cooling in thermal networks.

In particular, the heat pump technology offers the the possibility to use electricity efficiently for heating and cooling of buildings and can thus provide flexibility for the electricity grid. In this project, therefore, the heat pump is examined in different applications. One area of application presented in this paper is the use of central heat pumps as an additional heating system in local district heating networks. The idea behind this concept is to operate the central heat pump on the basis of the demand of the electricity grid. If there is a surplus of electricity, the heat pump can be operated as an auxiliary heating system in order to provide flexibility for the electricity grid on the one hand and to replace part of the conventional heat supply on the other. For this purpose, an existing building complex is considered as a pilot project, which is shown schematically in Fig. 1. The building complex consists of several buildings with heating and cooling demands, which are covered by local thermal networks. These local thermal networks are connected to and supplied by the central district heating and cooling networks. This is represented in Fig. 1 by the central supply units on the left side. In addition, a heat pump is used to couple the two local thermal networks to recycle the heat dissipated for comfort cooling and to use as large a proportion as possible for the supply of domestic hot water and heating.

To achieve high efficiency, the heat pump is integrated into the return lines of the two networks. The higher temperatures in the return line of the cooling network represent better conditions for heat supply with the heat pump. The idea is to provide part of the heating and cooling demands simultaneously by using the heat pump.

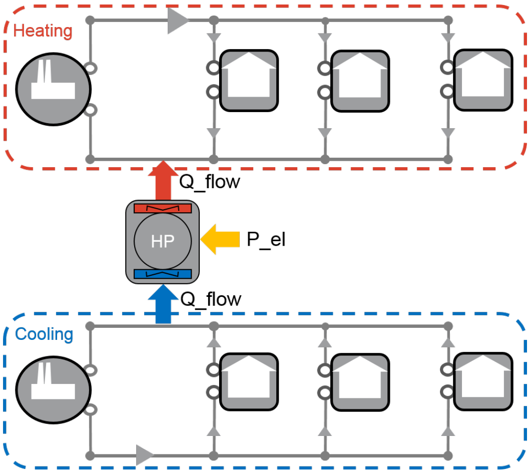

Fig. 1 Coupling of heating and cooling grids via a heat pump

To provide flexibility for the electricity grid with this concept, the heat pump can be operated on the basis of signals from the electricity grid. This is made possible by the fact that the heat pump is used as an additional system and the security of supply is guaranteed by conventional supply systems. This concept realizes the coupling of the heating, cooling and electricity systems.

This paper presents a dynamic simulation model that couples thermal networks for heat and cooling via a heat pump. This model represents the energy system of the implemented pilot project in Malmö and is used to test various heat pump control strategies. Three different scenarios are presented in the paper. The first scenario represents a demand-driven control that is currently being applied in the pilot project. The second scenario describes the integration of decentralised renewable energies using the example of a PV system, the third scenario represents a frequency-based control of the heat pump. In the third scenario, the heat pump is controlled by the frequency of the grid.

MODEL DESCRIPTION

In order to investigate the concept described above of coupling two thermal networks with a heat pump and to test different control strategies for the heat pump a dynamic simulation model in the simulation environment Modelica/Dymola is used. The system model is composed of the coupled models of the thermal networks for heating and cooling, the models for the conventional energy supplies, as well as the substation models, which represent the energy consumption of the buildings. For this purpose, component models of the AixLib library and the IPBSA library were used [1], [2]. The main component models are the detailed model of an on/off-controlled heat pump of the AixLib library and the plug flow pipe model of the IPBSA library for modelling the thermal networks [3]. The model of the heat pump is parameterised with manufacturer data so that the real performance of the heat pump is well reproduced. In addition, the use of the plug flow pipe model enables to simulate storage effects and heat losses of the thermal networks. The energy consumption of the buildings is represented by hourly aggregated measured values.

Boundary conditions

The heat pump has a maximum heating capacity of 63 kW and can provide a maximum outlet temperature at the condenser of 65 °C. The maximum heat demand of the building complex and the maximum cooling demand are respectively, 600 kW and 500 kW. Accordingly, the heat pump is operated for most of the time as an additional heating system, since the maximum capacity is not sufficient to cover the entire demands. Most of the annual heating (1.35 GWh) and cooling demands (1.06 GWh) are met by connection to the district heating and cooling networks. The supply temperature for the heating network depends on the outdoor temperature and lies in the range between 40 °C – 60 °C, while the supply temperature for the cooling network is fixed at 6 °C.

SCENARIO ANALYSIS

The described dynamic simulation model is used to test different control strategies of the heat pump.

In the first scenario, the demand driven scenario, the heat pump is controlled on the basis of demand. The heat pump is only operated if there is a sufficiently high heat and cooling demands at the same time, so that the heat and cooling provided by the heat pump can effectively used. This scenario represents the control strategy currently used in the pilot project. In the first stage, the technical implementation of the concept is tested.

In the second scenario, the integration of decentralized renewable energy is investigated by extending the system model with a photovoltaic system model. Only the power provided by the PV system is used to operate the heat pump. Therefore, the heat pump is operated to support the conventional supply system if heat and cooling demands exist and PV power is available simultaneously. The PV system is a typical source of fluctuating renewable electricity, and the use of the electricity for thermal purposes reduces the amount of electricity fed into the distribution network.

The third scenario, the frequency-based control, describes the use of the frequency support scheme that regulates the heat pump based on the frequency of the electrical distribution network.

Scenario 1: Demand driven

In the scenario of purely demand-driven control of the heat pump, 170 MWh of cooling and 230 MWh of heat are provided by the heat pump. This corresponds to 16.2 % and 17.0 % of the total annual cooling and heating consumption. Thus, despite the small output of the heat pump compared to the peak demand, a large proportion of the cooling and heat demand was provided by the heat pump through the use of electricity. Fig. 2 shows the on/off-signal of the heat pump for the first 30 days of the year. It can be seen that the heat pump can be operated almost the entire time continuously, because the heating and cooling consumption is large enough during this period. The simulation results are used for the verification of the simulation model by comparing the network temperatures and the thermal performance of the heat pump with measured values.

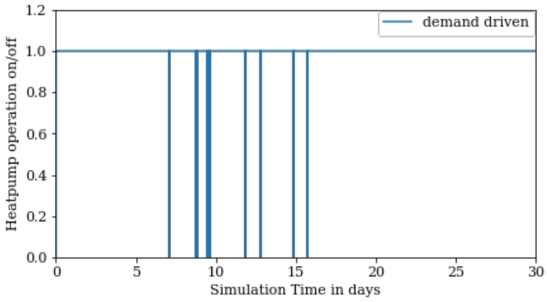

Fig. 2 Demand driven on/off-signal of heat pump

Scenario 2: Demand and PV driven

In the second scenario, the additional consideration of the PV system leads to significantly shorter operating times for the heat pump. Fig. 3 shows that the on/off-signal from the first scenario is superimposed by the PV power. The heat pump is operated during the day when the PV system generates power. Only in a few cases is the heat pump switched off despite the availability of PV power if the demand is too low as shown in scenario 1. This control of the heat pump results in 100 MWh of the annual heat demand (7.4%) and 70 MWh of the cooling demand (6.7%) being provided by the heat pump. Compared to the purely demand-driven scenario, the proportions are reduced, but only renewable electricity from the decentralised PV system was used for this purpose. This results in a very efficient operation of the heat pump in terms of primary energy. In addition, this approach increases the internal PV power consumption so that the grid is relieved by lower feeds at low voltage levels.

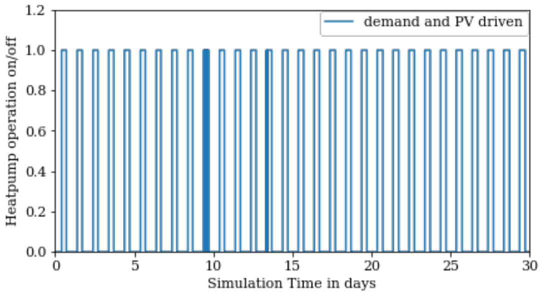

Fig. 3 Demand driven and PV power based on/off-signal of heat pump

Scenario 3: Frequency-based control

In the third scenario, the dynamic simulation model is coupled with the following frequency-based support scheme.

The Frequency support scheme

A frequency control functionality has been designed in association with frequency deviation and Rate Of Change Of Frequency (ROCOF) [4]. This controller with a sampling rate of 0.1 s receives as input the frequency data and calculates a cumulative controller signal ($C(t)$) as follows:

$$C(t) = K_f \Delta f(t) + K_r \left(\frac{d(\Delta f(t))}{dt}\right) \tag{1}$$

K_f is a positive gain that controls the overall sensitivity due to the frequency deviation, Δf, and K_r (positive quantity) controls the relative weight of the rate-of-change term, $\frac{d(\Delta f(t))}{dt}$.

The control action of the hybrid controller benefits also from the contribution of ROOF which is maximum just after the generation outage and it is nil when frequency achieves the nadir. Therefore, as observed in Fig. 4, $C(t)$ consisting of frequency deviation and ROCOF allows for an approximately constant response during the whole fast transient period (t_1, which is around 10 s depending on the system dynamics).

In this scenario, more emphasis has been put on the falling of frequency than the raise of it. Therefore, by setting higher deadband for the positive ROCOF and lower deadband for the negative ROCOF, the controller shows more sensitivity to negative ROCOF than the positive one.

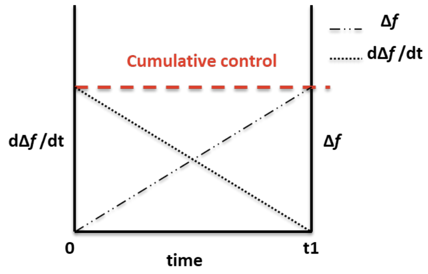

Fig. 4 Schematic description of the hybrid frequency support scheme

In this paper, the UK frequency data has been used to observe the controller action performance. Fig. 5 shows the frequency data for a typical winter day (December 1st 2016). In Fig. 6, the calculation of corresponding frequency deviation, ROCOF, and the controller action for this set of data are shown

The activation time of this type of frequency control is before the primary frequency control action. This requirement eliminates the use of conventional communication-based centralized control action. Hence, as frequency deviation, and ROCOF are dependent on the geographic location of the point of measurement in the grid [5], the decentralized control unit will be much more responsive rather than a centralized controller for the operation of thermally controllable loads.

Implementation of the frequency support scheme

For this purpose, the control signal of the heat pump is determined on the basis of the proposed frequency support scheme. This on/off control signal is based on the value of $C(t)$. Fig. 7 shows the electrical power consumption of the heat pump with frequency-based control for one day. As observed, the heat pump output power has been changed more frequently around 10 O'clock which corresponds to the higher sensitivity of the controller for negative ROCOF. Furthermore, compared to the other two scenarios, the heat pump is switched on and off significantly more often. The heat pump is switched on and off 35 times on this day, with an average operating time of 7-8 minutes.

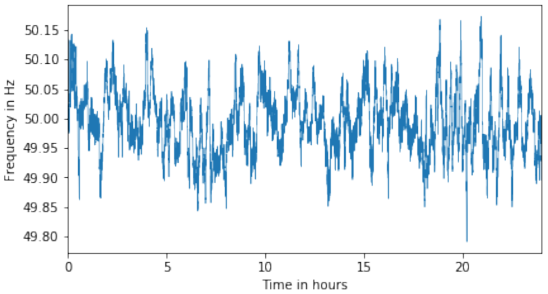

Fig. 5 Distribution system frequency data for a sample day

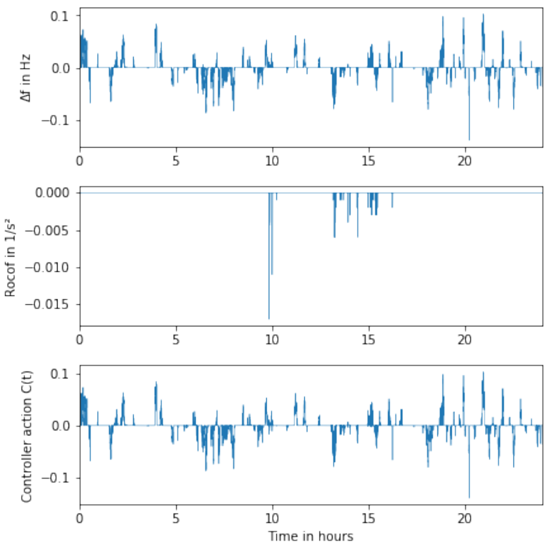

Fig. 6 Frequency deviation, ROCOF and the corresponding controller action

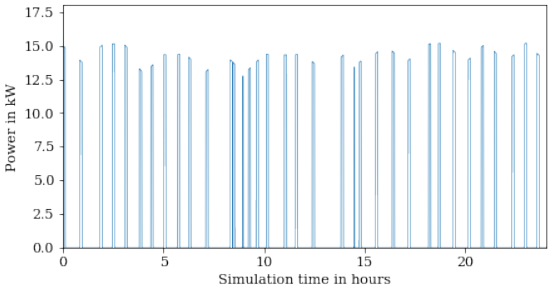

Fig. 7 Power consumption of the heat pump with frequency based control

CONCLUSION

In this study, three different scenarios have been defined to investigate the flexibility enhancement in a local energy community. The results of the first scenario maps to the on-site implemented project pilot. Also, the results of the second scenario shows convincing interaction between the thermal and electrical grids which can be exploited in the islanding operation of future microgrids. The results of the third scenario show potentiality in bringing flexibility to the electrical grid by using the thermal storage capacity of the thermal grid. This provides flexibility for the electrical grid. However, to make the operation of this frequency support scheme feasible for the thermal grid, step-wise signals rather than the on/off-signals can be used in combination with modulating heat pumps.

ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 Framework Program for Research and Innovation under grant agreement No. 731289.

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