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An Investigation of Energy Storage Possibilities in Single Family Houses for Smart Grid Purposes ⋆

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Abstract: In Denmark it will be a challenge in near future to balance the electrical grid due to a large increase in the renewable energy production mainly from wind turbines. Smart grid solutions which exploit all storage capacities are essential to meet this challenge. In this work single family houses with heat pumps and floor heating are investigated for storage capability. The aim is to shift energy consumption a few hours in time to mitigate the effect of fluctuating production from wind and other renewable energy sources on the grid. Based on measurements in six inhabited houses for approximately a year prediction models are analysed. The main topic of this work is to investigate how behaviour of inhabitants affect the quality of predictions. Unfortunately the output of the models for single inhabited single family houses seems to give large standard deviations of the predictions, and aggregated models for use in a coordinated control scheme could improve the possibility to use thermal capacity in houses as dynamical storages.

1. INTRODUCTION

Problems with balancing electricity supply and demand in the grid have emerged in Denmark in recent years. The problems are mainly due to power production from wind turbines, they can suddenly increase or decrease production depending on weather conditions. These rapid production changes are not always predictable and can therefore have severe consequences for grid stability. These problems will grow in the near future due to an increased number of wind turbines. In Denmark at present wind power meets 30 % of the electricity demand, however this covers variation from a minimum of 2-3 % to peaks more than 100 % of the instantaneous power demand. The Danish government wants the wind energy percentage to be larger than 50 % in 2020, [1]. As conventional power plants are phased out gradually, alternative sources of ancillary services must be found. One of the approaches to obtaining alternative ancillary services is the smart grid concept, where demand-side devices with flexible power consumption take part in the balancing effort.

One flexible power consumption device is a heat pump. In Denmark a great number of single family floor heating systems using small heat pumps (5 kW-15 kW) has been installed in the recent years. These installations have large energy storage capacities in the concrete floors giving a possibility of moving energy consumption to times where a high production of wind energy takes place with only minor discomfort and thereby they are very flexible power consumers.

The Danish Energy Agency estimates that more than 50,000 small heat pumps are installed for heating single-family houses corresponding to 6-7 % of the total electricity consumption. The small heat pumps are used outside the district heating areas which cover about 54 % of the total heat consumption in Denmark.

The major part of the electricity in Denmark is traded on the Nord Pool Elspot market, [2]. The day-ahead market, Elspot, is the main arena for trading power in the Nordic region. Here, contracts are made between seller and buyer for the delivery of power the following day, the price is set and the trade is agreed. Daily trading is driven by the members planning their production or consumption. A buyer needs to assess how much energy he will need to meet the demand the following day, and how much he is willing to pay for this energy, hour by hour. The seller, for example the owner of a power plant, needs to decide how much he can deliver and at what price, hour by hour. These needs are reflected through orders entered by buyers and sellers into the Elspot trading system. It should be noticed that wind power is the greatest uncertainty in this bidding round. Elspot calculates the hour by hour price. Put simply, the price is set where the curves for selling and buying bids meet. The intra-day imbalances must be treated by buying or selling power at the Regulating power market. Trading at the Regulating power market is more expensive than trading on the Elspot market.

In a normal heat pump control system room temperature is controlled automatically to a set point. An ON/OFF control ensures that this room temperature is within a certain temperature band (comfort band). This leaves some freedom to move energy consumption still respecting the comfort band. This has previously been suggested by numerous authors, [4], [5], [5], [6], [7]. A central controller is suggested using an internet connection to each house, furthermore it is chosen to use direct control of the heat pump power. The central controller can be placed and

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operated by a balance responsible party (BRP). The BRP is a private retailer company that buys and sells electric power from producers (wind mill owners, decentralized heat plants etc.) and consumers (factories, private households etc.) and trades this on the electricity markets, e.g., the Nord Pool Elspot market. The BRP predicts the wind energy production and this information is used to optimize control of the heat pumps. A 36 hour's time interval is interesting because this is the time horizon for the Nord Pool day-ahead Elspot marked. It can be shown that Nord Pool Elspot prices are closely connected to wind energy production; this implies that buying most power to the heat pumps when the price is low will move the consumption to times where the wind energy production is high. If the BRP buys power at Nord Pool market for the heat pumps according to this price estimate still respecting user comfort, this can shift consumption according to the wind energy production, resulting in a lower price for heating a house and a lower price for balancing the electricity grid.

The Elspot prices are valid for one hour, so the energy is bought hour by hour. To make an hour by hour energy plan for each heat pump it is a challenge is to predict the correlation between the power from the heat pump and the indoor temperature.

2. DEMANDS TO A DYNAMIC MODEL.

To predict the energy demands models of houses are essential. There are two demands for the models, namely to help purchasing energy on the Nord Pool Spot market and to control the individual heat pumps. The latter must ensure the house temperature is within given comfort limits and at the same time ensure the used energy is following the pre-described plan as close as possible. The Nord Pool day-ahead market trades energy in 1 hour slots which calls for a model with a sampling time of 1 hour. The BRP purchase energy hour by hour where each hour purchase must be greater than 10 MWh; this means that purchase for a number of houses must be aggregated and sometimes also aggregated with other energy consuming units.

The relation between power input and house indoor temperature has a time constant significantly larger than the 1 hour interval meaning that a dynamic model is necessary. The regulating power market use 15 minutes slots and thereby demands a sampling time less than a quarter of an hour.

The heat pumps can be turned ON or OFF at any time, but to keep a satisfying performance most manufacturers have implemented a minimum ON-time e.g., 20 minutes. This and a sampling time of 5 minutes for sampling the transducers in the demonstration houses leads to a sampling time of 5 min. for controlling the indoor temperature. The demands for the models are similar therefore it is chosen to use the same continuous model and discretize this using different sampling times.

To purchase energy on the spot market the model must be able to predict the energy consumption necessary to keep the indoor temperature within the comfort limits. The indoor temperature is affected by the weather conditions and the behaviour of the inhabitants. Ordinary control of the temperature can be based on a SISO model, power from heat pump is input and indoor temperature is output, weather conditions and inhabitants may be seen as disturbances. Though in our case we need to move energy consumption and therefore prediction of the impact of moving energy consumption in time is necessary.

The model must fulfil the following demands

- Describe the indoor temperature as function of power from heat pump and disturbances from weather and inhabitants.
- Describe the power needed to keep the temperature within temperature limits.
- Describe the effect of changing power consumption.

The demands will be tested using 300 days data from measurements of six inhabited houses. Here the model will be simulated using measured input data and the output (indoor temperature) will be compared to the measured indoor temperature. The prediction of the needed power can be tested using simulations where the input is the indoor temperature and the output is the needed heat pump power. Similarly the impact of changing power consumption can be tested.

3. DESCRIPTION OF THE TEST SET-UP

In the figure 1 the overall concept in the project is shown. The houses are equipped with add-on sensors measuring room air temperature, water temperatures and flow for the heat pump. A special control box was constructed for the project 'Styr din varmepumpe' [3]. The READY! project has access to a number of boxes in individual houses. The boxes connect the internet to the sensors and to the electronics of the heat pump, making it possible to start and stop the pumps. The BRP has access to various information useful in the control algorithm; this information includes local weather forecast and the actual sensor readings from each house. From the weather forecast and other information (consumption estimates, state of power plants etc.) the BRP is able to make an estimate of hourly prices for electricity. The BRP is in regular contact with the Transmission System Operator (TSO), the latter is the responsible for the grid balance. Finally the BRP can make bids on the Nord Pool Elspot market.

To achieve an appropriate amount of energy to trade on on the Nord Pool spot market a large number of houses must be included in the portfolio. The additional cost of control equipment in each house must be kept low. Therefore the number of sensors must be limited. In the READY! project each house has one indoor temperature sensor, one outdoor temperature sensor, and sensors for measuring the heat power and electrical power to the heat pump. In inhabited houses the indoor temperature is usually varying for different locations. The position of the transducer has been determined by a field engineer and though he has tried to find a spot with representative temperature there is danger that draught and solar radiation makes it inappropriate for the control system. Even with several temperature sensors the temperature profile can be difficult to determine.