# RESILIENT AND SUSTAINABLE DISTRICT HEATING USING MULTIPLE HEAT SOURCES

This article gives a description of the Danish district heating company, Hvide Sande District Heating, which has become independent of fossil fuels by using wind and solar energy. This has resulted in lower consumer heating prices in a time when other fossil fuelled district heating plants are raising their heating prices due to higher fossil fuel prices. The article describes the flexibility that daily optimization tools must have to be used to handle the multiple heat sources and the participation in the multiple electricity markets, and the need of digital twins for the medium- and long-term planning of the plant.



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Hvide Sande, at the West coast of Jutland in Denmark, is a small fishing town. The district heating plant provides heat to 1,637 consumers. From being a natural gas fired Combined Heat and Power (CHP) plant, it has in recent years become more resilient by investing in a solar collector, wind turbines, a heat pump, an electrical boiler as well as more thermal storage capacity. Today, it is independent of natural gas. Fact-box 1 shows the present production units and storages at Hvide Sande District Heating.

The two thermal storages of 2,000 m<sup>3</sup> and 1,200 m<sup>3</sup>, respectively, are able to store around 200 MWh-heat, which allows a very flexible market-based production on the different production units. The heat delivered to consumers can thus be produced many hours or days before delivery.

However, to take advantage of this flexibility, a vast digitalization of the plant together with advanced bidding methods have been required.

Figure 1 shows a picture of the Hvide Sande fishing town. The solar collector is shown in front, the three wind turbines are placed close to the North Sea and the two red arrows points at the two thermal storages, the one placed at the solar collector site and the other placed at the site with the CHPs, heat pump and electric boiler. The production units are shown in details in this **YouTube film** 

#### Planning of day-ahead bids in Hvide Sande

Even in the day-ahead market, the daily market-based productions are a challenge to plan. The manager has before 12 o´-



Figure 1: The small fishing town Hvide Sande at the West coast of Jutland in Denmark. The red arrows show the location of the two thermals storages.

#### Factbox 1:

#### Present production units and storages at Hvide Sande District Heating:

- 2 natural gas fired gas engine Combined Heat and Power units each 3.7 MW-elec and 4.9 MW-heat
- 3 wind turbines each 3 MW-elec
- Heat pump of 5 MW-heat
- Electrical boiler of 10 MW-heat
- Solar collector of 9,500 m<sup>2</sup>
- Hot water storages at plant of 2,000 m<sup>3</sup>
- Hot water storages at solar collector site of 1,200 m<sup>3</sup>
- Gas peak boilers

clock the day before to decide for each of the hours tomorrow how much electricity he wants to sell and how much electricity he wants to buy in each hour, and at which prices.

Because of the large thermal storages, the manager must look more days ahead, when deciding the bids for tomorrow as well as considering the heat amount in the thermal storage right now. His decisions are based on forecasts more days ahead on wind velocity, solar radiation, ambient temperatures, and forecasts more days ahead for Day-ahead prices.

Furthermore, what complicates the Day-ahead bidding in Hvide Sande, is that the wind turbines are behind own meter (is private wire operated). This means that the electricity delivered by the wind turbines and used by the heat pump avoids grid and tax payment. Therefore, the sale price bids for the wind turbine production shall typically be split into two parts. The amount of the wind turbine production matching the consumption of the heat pump shall be offered at a lower price compared to the wind turbine production that will be exported, which shall be offered to the variable operation and maintenance costs of the wind turbines.

## Hvide Sande participates in three out of four balancing markets

Factbox 2 gives an overview of the balancing markets in West Denmark. Hvide Sande District Heating participates regularly in three out of these four balancing markets. It participates in the FCR, mFRR and mFRR EAM markets.

#### **Participating in FCR**

To participate in the FCR market, bids must be made symmetric in 4-hour blocks and shall be able to be activated in 30 seconds. The electrical boiler can easily fulfil an activation in 30 seconds. Note that to make a symmetric bid on the electrical boiler, the offered capacity has at least to be traded in Dayahead market in the same 4-hour block. As an example, if a 2 MW symmetric bid in FCR is given for the electrical boiler from 00:00 to 04:00 tomorrow, at least 2 MW must be purchased in the Day-ahead market in the same hours, which will allow both positive and negative frequency regulation of 2 MW to be made on the electrical boiler.

Also, FCR-bids, are regularly being made on the CHPs. A gas engine CHP cannot regulate in 30 seconds if it is not running. So, what Hvide Sande District Heating has done is only to sell 80% of the CHP capacity in a certain 4-hour block in the Dayahead market. Thus, being able to offer the remaining 20% of the capacity in the FCR market.

#### **Participating in mFRR**

The mFRR market is an hourly reserve market. Winning a mFRR capacity bid in a certain hour tomorrow, gives an obligation for the plant to make an offer of this capacity into the mFRR EAM market. However, the plant decides itself at which prices the upward regulation is offered.

When it is windy or sunny it will often be cheaper to produce the heat on the heat pump, the electrical boiler, or the solar

#### Factbox 2:

#### The balancing markets in West Denmark

#### FCR, Frequency Containment Reserves

The FCR market is a rather small market, and as the name of the market indicate, this market shall not bring the frequency back to 50 Hz, but only contain a frequency problem, e.g., stop a reduction in frequency.

A production unit shall be able to be activated in maximum 30 seconds, and the activation shall be able to be maintained 20 minutes.

The bids are split into 4-hour blocks and is symmetric, that is the won FCR shall be able to deliver both positive and negative frequency regulation.

Gate closure is 8 a.m. the day before, and there is Marginal pricing. That is all won bids gets the same price. There is no payment for energy activation.

#### FRR, automatic Frequency Restoration Reserves Month ahead market.

The reaction time is maximum 15 minutes. The bids are symmetric. The prices are settled as Pay-as-bid.

### mFRR, manual Frequency Restoration Reserves

The reaction time is maximum 15 minutes. Asymmetric bids are allowed, either for upwards regulation or for downward regulation. Hourly bids and there are Marginal pricing. Gate closure 9.30 the day before.

#### mFRR EAM, Energy Activation Market in mFRR

Gate closure is one hour before the operating hour. For won mFRR bids in a certain hour it is obligatory to make an offer of this capacity into the mFRR EAM in that hour. Marginal pricing.

The mFRR EAM market is often called the regulating power market.

Figure 2: The red arrow points at a won activation of the two CHPs in mFRR EAM. The green prices show the prices in the Day-ahead market. The blue prices show the upward regulation prices and the yellow prices show the downward regulation prices in mFRR EAM. The lower graph shows the content in the two thermal storages. As is seen, the heat produced in the won activation of the two CHPs is partly stored in the thermal storages.



collector, rather than producing the heat on the CHPs. In such an hour tomorrow, it is obvious to offer the CHPs in the mFRR market, and when coming to the hour and if there is not sufficient content in the thermal storages the obligatory activation bid can be made sky high to avoid winning the activation.

The heat pump is operated in many hours. In these hours it is again possible to offer mFRR, because closing a heat pump reduces the electricity consumption and thus offers an upward regulation.

#### **Participating in mFRR EAM**

As mentioned, after winning an mFRR bid in a certain hour it is obligatory for the plant to make an offer of this capacity into the mFRR EAM. However, even if it has not won an mFRR bid in a certain hour, it may still offer activation in mFRR EAM. The simple starting point for making bids in mFRR EAM is to make it as the opposite bid as won in Day-ahead. As an example, if 1 MWh purchase bid has been won on the heat pump in Day-ahead in a certain hour, the opposite bid of 1 MW can be offered as upward regulation in mFRR EAM. Note that winning an upward regulation on the heat pump has the consequence that less heat is produced, which may have the consequence that the thermal storages will be emptied, and the gas boilers must be started. But that is in fact the way bidding prices are calculated - as the economic consequences of winning a bid. At www.emd-international.com/livedata we show online the operation of Hvide Sande District Heating. Figure 2 shows an example of a won activation of the two CHPs in mFRR EAM.

#### **Digital twin of Hvide Sande District Heating**

This article illustrates that daily optimization tools must be

used for the daily planning of bidding amounts and bidding prices in the different electricity markets. However, it is also important that the manager maintains a digital twin of the plant. The daily optimization will often give inspiration to new investments to be made. It is also about finding the right balance between investments in production units, storages, and grid infrastructures and regularly the manager has to make budgets for the coming periods. That is what the digital twin shall be used for. In Figure 3 is shown the digital twin that Hvide Sande District Heating is using. An overview of different digital twin tools is shown in this article



Figure 3: Hvide Sande District Heating is using the energyPRO energy system analysis tool for making the digital twin of the grid and plant, that it uses for budgetting and investment analysis.



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