# Borehole Thermal Energy Storage in combination with District Heating

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## ABSTRACT

Braedstrup District Heating Plant in Denmark has extended its traditional natural gas production plant for heat and power to also include thermal solar panels, borehole thermal energy storage, heat pump and an electric boiler.

This gives the district heating plant a huge flexibility in its energy production and enables it to actively contribute to the grid balancing that becomes more and more urgent as the proportion of power supplied by sustainable energy sources such as sun and wind increases.

A borehole thermal energy storage has been constructed to store the excess of solar energy, that the district heating plant produces during the summer. The energy is to be stored from summer to winter and will be recovered by a heat pump.

The pilot plant has at the time of writing been running for little more than 6 months and the preliminary results looks promising in terms of recovery rates.

The district heating plant can now actively participate in grid balancing whether there is a critical overflow on the power grid or there is a shortage of power due to lack of sunshine and/or wind.

## 1. INTRODUCTION (CHAPTER TITLE, BOLD CAPITALS, 3 PT SPACING BEFORE AND AFTER)

Sustainable energy sources have many benefits such as reducing carbon footprint and saving limited resources. However, the extended and still growing use of wind and sun to produce energy creates a new problem: Sustainable energy production rarely meets the immediate demand. Depending on weather or the time of the day, the production may be significantly higher or lower than the actual demand. Large production may result in a critical overflow on the power grid (Energinet, 2009). Low production demands a back-up capacity, typically in the form of carbon or nuclear based power plants. The only solution to this problem is storage of energy. This may be as electrical or as thermal energy.

But this again has its problems. Storage of electrical energy is either still relatively expensive (batteries) or includes a relatively large conversion loss as in the case of power to gas (Bossel et. al. 2003).

Another option is to store thermal energy. This option is particularly attractive in cases where waste heat or excessive heat production is available.

## 2. BRAEDSTRUP DISTRICT HEATING PLANT

At Braedstrup District Heating Plant a Borehole Thermal Energy Storage (BTES) is now being tested on a pilot scale.

The Braedstrup District Heating Plant is constructed as a Combined Heat and Power Plant (CHP). The original layout was natural gas powered generators combined with natural gas boilers. It is a relatively small plant with ca. 1.500 connected consumers. The annual production is ca. 30 GWh power and 45 GWh heat. Originally the plant also has a 2.000 $m^3$ water-based buffer tank for accumulating thermal energy.

In 2007 8.000 $m^2$ of thermal solar panels were installed in order to assist the heat production. These panels were able to produce about 3.600 MWh of heat pr. year or roughly 8 % of the annual heating demand. However, from time to time during the summer, the heat production was larger than the demand (Braedstrup).

The immediate success with the solar panels opened for a new initiative to develop the solar assisted CHP plant even further. But the problem with the excess heat production during the summer had to be handled through some form of thermal energy storage.

Strongly inspired by German experiences with BTES it was decided to work along these lines. After a feasibility study that included a test borehole and TRNSYS model of the efficiency of a BTES under the given geological conditions, a pilot plant was designed. The model showed an expected 20 % loss on the full scale plant under stable operation.

Apart from constructing the BTES it was decided to increase the water based buffer from 2.000 to 7.500 $m^3$. The area of thermal solar panels was increased from 8.000 to 18.600 $m^2$. Moreover it was decided to install a 10 MW electric boiler and a 1,4 MW heat

pump. Finally it was decided to construct a 19.000 $m^3$ BTES.

The full scale BTES is 10 times the size of the pilot plant. This means the full scale consists of a 500 borehole/190.000 $m^3$ BTES and 50.000 $m^2$ of thermal solar panels.

### 2.1 The borehole thermal energy storage

The BTES consists of 48 boreholes to a depth of 45 meters. The boreholes are placed in a hexagonal pattern with a distance of 3 meters between the boreholes. This was found to be the optimal distance in order to achieve a uniform temperature distribution in the entire storage after one season of heating. The hexagonal pattern also makes it possible to enlarge the pilot BTES to the full scale plant.

The geology turned out to be mixed layers of clay till, sand and gravel, which is a disadvantage in relation to thermal conductivity and thermal capacity (Banks, 2008). This was confirmed by laboratory tests and a Thermal Response Test that was carried out in the test borehole. This showed an average thermal conductivity of 1,42 W/mK and an average thermal capacity of 1,9 $MJ/m^3K$. These values are relatively low, but found to be acceptable.

The primary groundwater was found to be below 50 meters below the surface. In relation to storage of thermal energy this is an advantage. Any groundwater flowing through the storage would have transported some of the thermal energy away (Banks, 2008).

The 48 boreholes have been equipped with double loop borehole heat exchangers (BHE) of PE-Xa that will withstand the expected high temperatures of up to 95°C. A thermally enhanced grout has been pumped in the boreholes to provide an efficient thermal contact between pipes and borehole wall. Also the grout will seal off the boreholes in order to avoid the risk of groundwater contamination from the surface.

The BTES is covered by an insulating lid in order to reduce heat-loss to the surface. The lid is constructed with a semipermeable membrane in order to let moisture escape the storage and keep rainwater from penetrating it.

The BTES is monitored from 5 boreholes that each contains 20 temperature sensors. The sensors are placed from 0 to 59 meters below the surface. Four of the monitoring boreholes are placed within the storage at varying distances from the active boreholes. One monitoring borehole is placed 5 meters outside the storage in the direction of the groundwater flow.

## 3. OPERATION

The charging of the storage started 23 May 2012 and continued until 18 October when the discharging started. As to be expected in a pilot project there were some initial difficulties related to the technical equipment. This gave an irregular running-in of the storage as seen in figure 1.

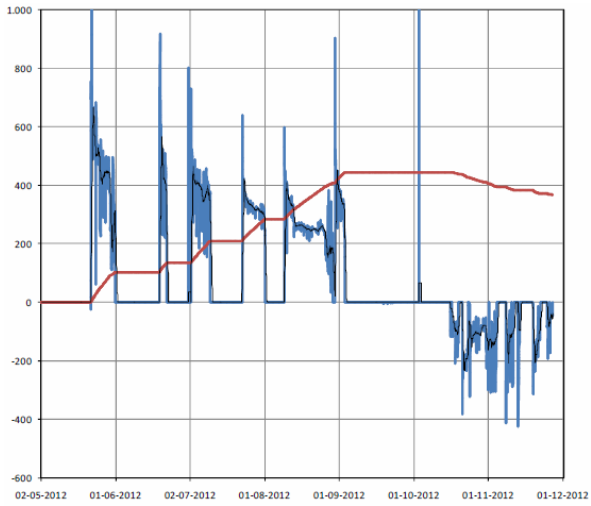



**Figure 1: Blue shows the charging effect in kW and red shows the accumulated stored effect in MWh.**

During the total period of charging of 147 days, a total of 445 MWh of thermal energy has been stored in the BTES.

After 40 days of discharging 77 MWh was recovered. The discharging has continued from this time onwards.

The initial temperature in the storage was a quite uniform 8°C. At the end of the charging period measurements show an even temperature distribution in the storage between 40 and 50°C. After 40 days of discharging, temperatures between 25 and 35°C can be observed.

No temperature increase has been observed outside the storage or in the underlying groundwater.

Preliminary calculation on the energy loss in the pilot plant is somewhat higher than the 20 % predicted in the modelling on the full scale plant. The loss in the pilot plant is expected to be around 40 %.

However there are several reasons for this difference:

- Irregular operation in the initial phases
- Late start of the discharge
- Initial heat loss to the immediate surrounding geology
- Energy loss to evaporation of soil moisture
- Lower volume to surface ratio due to scale

Particularly evaporation of soil moisture can explain a large energy loss from the storage.

The results from the relative short period of operation are considered positive.

## 4. GRID BALANCING AND THERMAL ENERGY STORAGE

The unique combination of natural gas powered generators and boilers, thermal solar panels, short term water based thermal storage, electric boiler, seasonal BTES and a large heat pump gives Braedstrup DHP a huge flexibility in its energy production.

In case of energy overflow on the grid, the DHP can use electrical energy to run the heat pump using some of the energy stored in the BTES. Or they can run the electric boiler. In case of electric power shortage, they can run the generators to produce electricity and at the same time produce heat for their consumers.

The main object will always be to supply the connected consumers with heat. But instead of being dependent on natural gas, the DHP can now also utilize its own thermal solar energy or electrical energy produced by sun, wind or other sustainable sources.

## 5. CONCLUSIONS

A BTES, an electric boiler, a large heat pump, an array of solar panels combined with more traditional natural gas powered boilers and generators enables Braedstrup CHP DHC to participate actively in balancing the power grid.

In case of overflow, the heat pump or the electric boiler can be turned on in order to take up some of the surplus, sustainably produced electricity. In case of a deficit, the natural gas power generator can be turned on to produce electricity for the grid and at the same time produce heat for the consumers of the DHP.

The constructed pilot BTES consists of 48 boreholes and charging started in May 2012. During the period of charging 445 MWh of surplus solar thermal energy were stored in the BTES. Discharge started in October 2012 and is on-going.

Preliminary heat loss is calculated to be about 40 % but is to a large extent due to loss to evaporation of soil moisture. This is a one-time loss.

Monitoring has shown that the temperature increase and the subsequent temperature decrease in the storage are uniformly distributed. At the same time no temperature increase can be seen 5 meters from the storage or in the groundwater under the bottom of the storage.

The results from the relative short period of operation are considered positive.

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