Ea Energy Analyses

Security of supply for Bornholm

Integration of fluctuating generation using coordinated control of demand and wind turbines

Demand side options for system reserves

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October 2007

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Introduction

The use of wind turbines in island systems is often considered problematic due to the fluctuating production patterns inherent in wind power. This can make frequency regulation difficult, especially if there is a high penetration of wind power along with relatively inflexible conventional power generators that are unable to react quickly to fluctuations in production patterns. If wind turbines are to be implemented effectively in island systems it is important that flexible frequency regulation is available that can quickly adjust to fluctuations in wind power generation.

Electricity demand amongst end-users could have the potential to provide increased flexibility in island systems as demand can react immediately to fluctuations in frequency through intelligent control devices. This would allow for a higher penetration of wind power and other fluctuating production in island systems without affecting the quality of power supply.

The island of Bornholm is connected to the Nordic electricity grid by a 60kV undersea cable to southern Sweden. This can provide all the power needs of the island. Bornholm does, however, have its own generating capacity in the form of wind turbines and a thermal power station that can supply the island with power when the cable is under repair or damaged. When Bornholm functions in islanding mode a number of wind turbines are disconnected from the grid as the coal-fired power station on the island is unable to adjust production quickly enough in order to accommodate even small fluctuations in wind power generation. This may be economically inefficient.

The aim of this report is to consider the options on Bornholm for maintaining wind turbine production when in islanding mode through utilising intelligent demand response to fluctuating production. This report focuses on identifying available demand capacity on Bornholm that can be utilised for frequency regulation when in islanding mode. This is achieved by looking at the power and heating demands on the island.

1 Electric demand

Bornholm has a peak demand for electricity of approximately 55 MW and a base load of 25 MW. The electricity demand is covered by the 60 MW capacity cable to Sweden, the coal-fired CHP plant in Rønne and 30 MW of wind turbine capacity[1].

This chapter will look at the potential for using demand to mitigate the effect of variable production on frequency stability when Bornholm's electricity system is

1 Master data register for wind turbines, Danish Energy Agency, 2007

in islanding mode as well as providing an indication of the level of demand capacity available for frequency regulation.

1.1 Potential demand response in the residential sector

Users with an annual consumption above 100.000 kWh are metered every fifteen minutes (in the data set used for this report the 15 minute readings have been aggregated to produce data on an hourly basis). The residual consumption is measured hourly as a single entity and comprises mostly households and small businesses. The average daily consumption patterns for consumption metered hourly and the residual consumption is shown below.

Figure 1: Daily average of consumption metered hourly and of residual consumption for 2006[2].

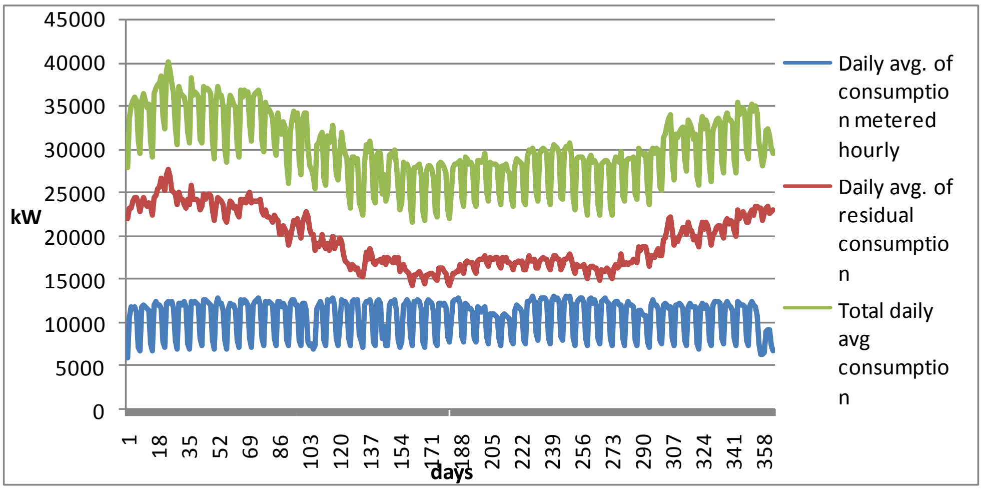
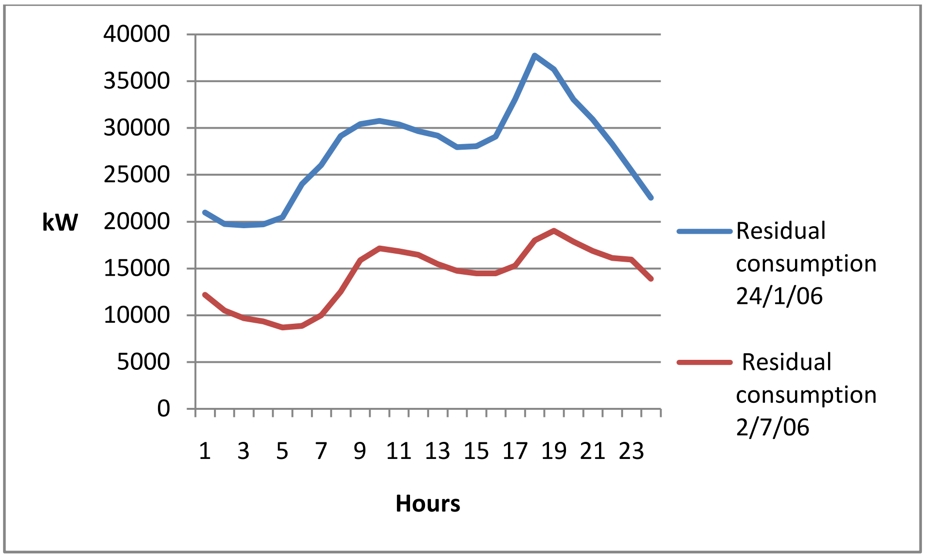


Figure 1 shows that consumption for hourly metered customers is stable throughout the year whilst residual consumption increases by 66% from the lowest summer consumption to the winter peak. The green line shows total power consumption on Bornholm and indicates that it is the residual consumption that is responsible for the greatest seasonal and daily variations.

The seasonal variation in residual consumption is illustrated in figure 2 below, which depicts the hourly load patterns of a typical winter day (24 January 2006) and a typical summer day (2 July 2006).

2 Background data supplied by Østkraft

Figure 2: Residual consumption on Bornholm on a winter day compared with a summer day[3]



The much higher consumption in winter should also be seen in the context of the large number of tourists that visit Bornholm in the summer months. There are approximately 35.000 tourist beds on the island and the population is almost double the permanent population during the high season[4]. Despite this residual consumption on a winter day is approximately twice as large as consumption on a summer day. This can only partially be attributed to increased use of electric lighting and greater electricity consumption for cooking. It is most likely an indication of the relatively widespread use of electric space heating on Bornholm contributing to increased demand in winter.

The rest of this chapter will focus on the residual consumption as electric heating is well suited to balancing frequency due to the thermal capacity of buildings, which allows for heating to be switched off for a period of time without a major reduction in comfort. This could provide capacity for frequency regulation in islanding mode.

The number of residual consumers that have electric heating and their electricity consumption is presented in the table below. The total consumption of consumers with electric heating is approximately 32.6 GWh annually.

Statistical data from 2006	Number	Demand (kWh)
Apartments with electric heating		
0-5,000 kWh/yr	162	507.478
5,000-10,000 kWh/yr	146	1.030.387
10,000-15,000 kWh/yr	23	264.403
15,000-20,000 kWh/yr	3	52.378

[3] Background data supplied by Østkraft

[4] Turismeerhvervet på Bornholm – netværksarbejde og omstrukturering, Per Åke Nilsson, 2002

20,000- kWh/yr	2	42.404
Total	336	1.897.050
Average consumption per unit		5.646
One- and two family houses with electric heating		
0-5,000 kWh/yr	535	1.757.507
5,000-10,000 kWh/yr	1.295	9.786.310
10,000-15,000 kWh/yr	503	6.027.466
15,000-20,000 kWh/yr	139	2.351.912
20,000- kWh/yr	26	613.311
Total	2.498	20.536.506
Average consumption per unit		8.221
One- and two family houses with heat pumps		
0-5,000 kWh/yr	7	25.917
5,000-10,000 kWh/yr	8	66.131
10,000-15,000 kWh/yr	6	70.091
15,000-20,000 kWh/yr	2	35.321
20,000- kWh/yr	0	0
Total	23	197.460
Average consumption per unit		8.585
Holiday homes		
0-5,000 kWh/yr	2.826	4.962.114
5,000-10,000 kWh/yr	475	3.253.777
10,000-15,000 kWh/yr	68	810.538
15,000-20,000 kWh/yr	24	414.023
20,000- kWh/yr	16	511.706
Total	3.409	9.952.158
Average consumption per unit		2.919
Total consumption for electric heating in domestic sector	6.266	32.583.174

Table 1: Residual consumers with electric heating, total demand and average consumption per unit[5]

The table above shows that the greatest demand for electric heating comes from family houses. When one considers that the average household on Bornholm without electric heating consumes approximately 3.680 kWh the above data indicates that on average, households with electric heating use 4.500 kWh for space heating annually. Electric heating in houses, therefore, accounts for approximately 11,2 GWh of the total electricity consumption on Bornholm, whilst electric heating in apartments accounts for approximately 1 GWh. It is difficult to determine the use of electric space heating in holiday houses in the same manner, but it is assumed that holiday houses have higher electricity consumption for space heating in relation to other uses when compared with domestic residences. Holiday houses are assumed, therefore, to consume 6 GWh for electric space heating for the purpose of this study. This gives a total consumption of approximately 18.2 GWh annually for electric space heating in

[5] Data supplied by Østkraft

households. Total annual consumption on Bornholm is in the vicinity of 255 GWh.

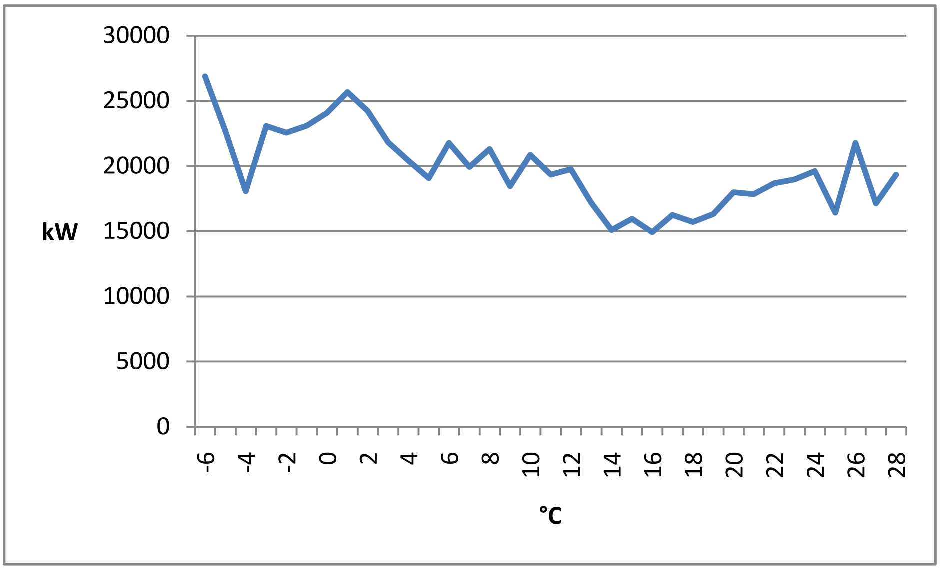
The amount of electric heating that can be used for frequency regulation in households on Bornholm is also reliant on the relationship between consumption by electric heating and temperature. This gives an indication of the capacity available for regulating consumption up and down during the heating season. The following section takes a closer look at this relationship.

1.2 Relationship between demand and temperature

The relationship between residual demand and temperature is an import factor for utilizing demand for regulating frequency. The steeper the increase in consumption per 1°C fall in temperature the more potential there is for using electric demand for space heating for balancing frequency from variable production.

The average demand for electricity at temperature intervals measured on Bornholm in 2006 is illustrated in figure 3 below.

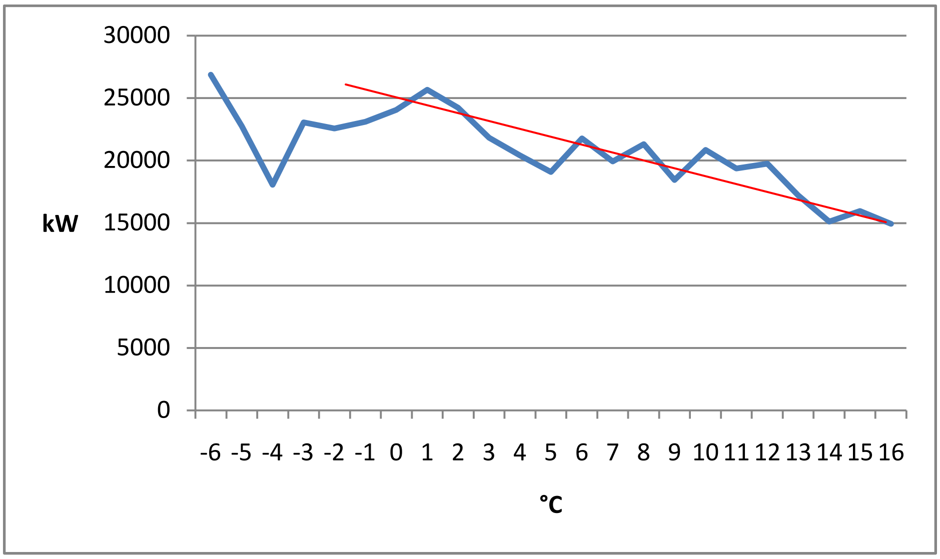
Figure 3: Average demand for residual consumers in relation to temperature, 2006[6]



It appears from the graph that the major gradient in the increase in demand that is of importance for this study appears when the temperature falls from 14°C to 0°C. These can be seen more clearly in a graph that only shows consumption at temperatures below 17°C as shown below.

[6] Background data supplied by Østkraft and Danish Meteorological Institute

Figure 4: Average increase in consumption at temperatures below 17°C



The red gradient in figure 4 represents the average increase in residual demand between 14°C and 0°C. Residual demand increases from 15 MW to 25 MW, which indicates an increase in demand of approximately 660kW per degree. This increase in demand includes other seasonal variations such as increased use of lighting and electricity for cooking, which do not provide capacity for frequency regulation.

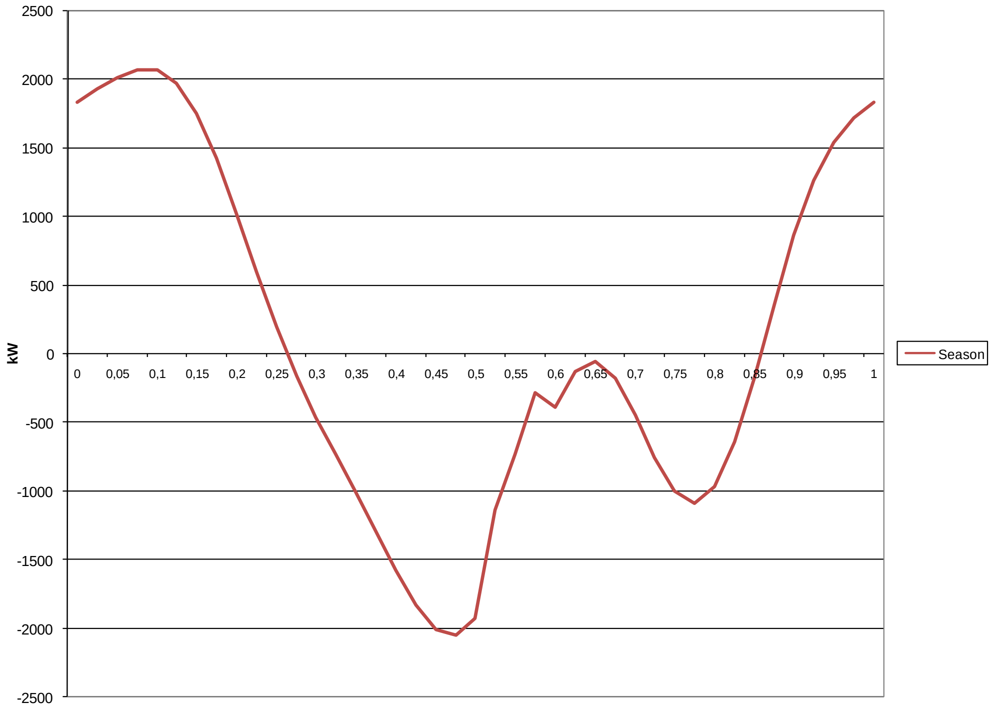
The residual demand on Bornholm has been analyzed using an advanced statistical methodology. The methodology[7] is a regression model with a number of Fourier curves that describe the impact of season and day. This methodology has successfully been used to analyze the electricity demand in a utility (Copenhagen) and countries (each of the four Nordic countries).

The central feature of the model is that the impact of temperature can be analyzed independently of seasonal impacts. As an example, in other more simple analyses the use of electricity for lighting in winter is wrongly associated with temperature.

The methodology shows that temperature can have an impact on the residual electricity demand of up to 10 MW, while the seasonal impact is 4 MW (seen in figure 5 as +/- 2MW).

[7] Regression model for the hourly electricity demand - based on calendar and temperature, Mikael Togeby, Elkraft, 2005

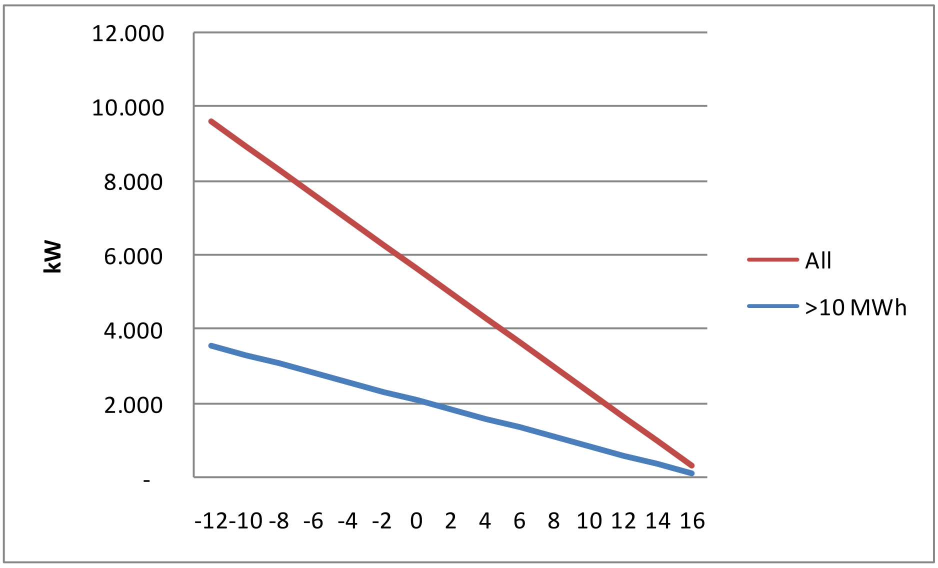
Figure 5: The impact of season. Zero on the x-axis is 1 January and 1 is 31 December. In addition to the smooth Fourier curves an extra 500 kW is added in the summer holiday (0.51-0.58 on the x-axis).



The analysis calculates the increase in demand caused by temperature alone on Bornholm is 332 kW per degree day. The simple analysis in this report suggests an increase in consumption of 660 kW per fall in degree centigrade, but this has not been adjusted for seasonal effects such as lighting etc. There is, therefore, a seasonal increase of 328 kW and a temperature related increase of 332 kW per fall in degree centigrade.

This indicates that there is approximately 5.6 MW of demand for electric heating from households when the temperature is 0°C. When one considers that the peak load on Bornholm is 55 MW the electric demand for space heating in households is 10% of peak load when the temperature is 0°C. Figure 6 indicates demand for electric space heating in households at different temperatures.

Figure 6: Demand for electric space heating at different temperatures. Upper line is the aggregated temperature dependent demand (mostly electric heating). Lower line is the calculated demand from the 812 single family houses with a demand above 10.000 kWh per year.



There may well be more demand for electric space heating on Bornholm than that in the residential sector. It has been calculated that the trade and industry sector in Denmark has a total of 270 MW of electric space heating[8]. Considering that Bornholm accounts for approximately 0.7% of Denmark's total electricity consumption[9] it can be assumed that the commercial sector has approximately 2 MW of electric heating demand on Bornholm.

The potential capacity for frequency regulation using additional electricity for space heating is most likely greater due to the heating requirements of the housing stock in Denmark being calculated at a temperature of -12°C. Figure 6 indicates that there may well be a demand capacity in electric space heating in households of 10 MW.

As it is only feasible to include a limited number of households with electric heating in a system for regulating frequency the largest consumers are of particular interest. Table 1 shows that there are 812 households with electric space heating that consume more than 10,000 kWh annually. The total consumption of these households is 11.1 GWh, which is ⅔ of total consumption in households with electric space heating. It is likely that these households have an average consumption for other electric appliances and a high consumption for space heating. This means that the 812 households consume approximately 3 GWh on appliances and lighting and 8 GWh on electric space heating. As there were 2.740 degree days on Bornholm it can be calculated that the 812 households account for 122 kW[10] of demand per one degree fall in tem-

[8] Priselastisk elforbrug hos de store elforbrugere, Energinet.dk, 2005

[9] Denmark's total electricity consumption is app. 35 TWh, Bornholm's is 255 GWh

[10] 8000MWh/(24*2740)°C.h = 0,122 MW/°C

perature. This is 37% of total demand in households for electric heating. It can, therefore, be assumed from figure 6 that the 812 households have approximately 4 MW of electric heating installed.

Electric heating capacity does not, however, cover all the needs for balancing frequency as dump load capacity is required that can be activated when frequency increases and electric heating is either already activated or is not available. An option for this dump load is electric heating elements in the district heating networks on Bornholm. The district heating networks are described in the next chapter.

2 District heating on Bornholm

Total heating requirements for Bornholm are approximately 560.000 MWh[11] annually. Currently this is covered by three heating sources; district heating, buildings with electric heating and individual boilers.

The district heating sector on Bornholm is made up of three distribution companies; Rønne Vand- & Varmeforsyning (RVV), the Regional Municipality of Bornholm and Nexø Halmvarmeværk. Energy data for 2006 for the district heating plants on Bornholm is given in table 2 below. There is only one CHP plant on Bornholm. This is owned by Østkraft and supplies heat to RVV.

	Produced heat (MWh)	No. of users	Heat production by fuel (%)			
			Straw	Oil	Coal	Waste
RVV	154.731	5.000		0,6	67,7	31,7
Nexø HP	35.000	1.659	97,4	0,6		
Klemensker HP	8.900	275	97,4	0,6		
Lobbæk HP	6.700	160	85	15		
Østermarie HP	150	10		100		
Total	205.481	7.104	24	1	51	24

Table 2: Total district heat production by distribution area and fuel on Bornholm[12]

A short description of each of the distribution companies, their distribution area and heat demand and production follows in this section.

2.1 Rønne Vand- & Varmeforsyning

RVV supplies the town of Rønne with heat and has approximately 5.000 customers.

Heat is purchased from two external suppliers; BOFA[13] waste incinerating plant and Østkraft's coal-fired CHP plant RVV also has an oil-fired reserve capacity plant, which is used when maintenance is being carried out on the other units. The supply from each unit is shown in table 3 below.

[11] Heating Plan, Bornholm, 2007

[12] Adapted from Heating Plan, Bornholm, 2007

[13] Bornholms Fælleskommunale Affaldsbortskaffelse I/S

Production unit, MWh	2003	2004	2005
Østkraft	112.254	109.003	104.884
BOFA	44.039	47.346	49.097
RVV reserve plant	1.248	353	530
Total heat production	157.541	156.702	154.511

Table 3: Production units supplying heat to RVV[14]

A short description of BOFA, Østkraft and RVV's reserve capacity follows.

BOFA

BOFA is a waste incineration plant that burns app. 23 tonnes of rubbish annually. The boiler has a capacity of 2.5 tonnes per hour, which is equivalent to approximately 6.5 MW_{heat}. BOFA supplies RVV with base load heat, which is approximately 6 MW. RVV has to purchase all heat produced by BOFA before resorting to other suppliers due to Danish regulation prioritising heat produced by waste incinerators above other sources. BOFA has no accumulation tank for storing heat.

Østkraft

Østkraft produces heat for RVV at its coal-fired CPH plant. Block 6 is the main production unit with a capacity of 35 MW_{heat}. A storage tank with a capacity of 6,700m^3 (270 MWh) is connected to block 6. Østkraft supplies heat to RVV for approximately seven months of the year when production at BOFA cannot meet demand.

Maximum heat demand in Rønne requires a capacity of 38 MW_{heat} on the coldest days of the year (-7^{o}C in 2006). There is sufficient capacity at BOFA and Østkraft to supply peak demand.

2.2 Regional Municipality of Bornholm

The regional municipality of Bornholm owns three heating plants; Klemensker Municipal Heating Plant, Lobbæk Municipal Heating Plant and Østemarie. Østermarie is a cooperative consisting of ten households and will not be considered in this project. Both Lobbæk and Klemensker produce heat from straw-fired boilers. A short description of each plant is provided below.

Klemensker

Klemensker has a 3.5 MW_{heat} straw-fired boiler that covers most demand requirements. A 3 MW_{heat} oil-fired boiler is used as reserve/peak load. This is responsible for about 1% of total production. A storage tank with a capacity of 400m^3 (16 MWh) is connected to the heating plant and is used to regulate sup-

[14] Table supplied by RVV, http://www.rvv.dk/default_2.asp?ID=482, unit converted from GJ to MWh.

ply and allow for maintenance without having to resort to using the oil-fired boiler.

The annual production at Klemensker is 8.000 MWh with production in January on average requiring 1.6 MW capacity and in July 0.3 MW. There is sufficient capacity in Klemensker to cover the requirements of the distribution area.

Lobbæk

Lobbæk has a 1.4 MW_{heat} straw-fired boiler and two 1 MW_{heat} oil-fired boilers. The straw-fired boiler is aging and there were plans to purchase a new one, however, these plans have recently been put on hold whilst the possibilities for utilizing heat from the newly established biogas plant nearby. There is no storage tank at Lobbæk.

The annual production of heat at Lobbæk is approximately 6.000 MWh with an average capacity in January of about 1,3 MW and in July 0,3 MW.

2.3 Nexø Heating Plant

Nexø produces all its energy using two 5 MW_{heat} straw-fired boilers. There is a reserve/peak load oil-fired 9 MW_{heat} boiler but this is seldom used. Nexø also has a storage tank with a capacity of 825m^3 (34 MWh).

Nexø has a base load of 1.7 MW_{heat} and a peak load of 9 MW_{heat}. The annual production of heat from Nexø is between 30.000 and 33.000 MWh.

2.4 Using district heating as dump load

Using district heating as dump load requires an electric heating element, which consists of two electrodes immersed in a salt solution with high conductivity. Heat is released when electricity moves between the electrodes. This is used to heat the district heating water through a heat exchanger after the heat exchanger connected to the unit's main boiler.

There are some important technical issues to be kept in mind when considering the installation of an electric heating element for regulating frequency. The element's annual production time may only be a few hours annually divided over many, very short intervals. Some of which will only last for a few seconds. This allows for a much larger capacity element to be connected to heating systems than would be considered if the element were to function as continuous reserve capacity rather than frequency regulating capacity.

If longer periods of operation are required it may be necessary to enter into an agreement with heating plants on guaranteeing a certain available amount of storage capacity when in islanding mode to ensure that elements can be activated for longer periods if necessary.

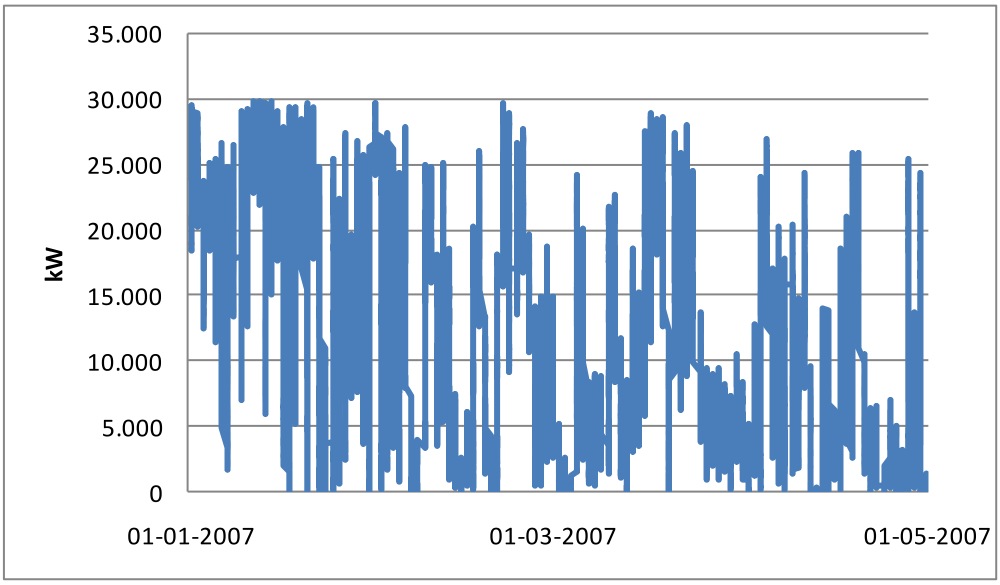
Heating elements do, however, have a restriction that they cannot be activated at full capacity, but generally are activated at 20% of full capacity and regulated up to full capacity within 5 to 12 minutes depending on the size of the element. This is necessary in order to maintain a balance in the saline solution. This means that it is necessary to consider the expected hours of production and the average length of activation for heating elements according to wind generation patterns before determining the required capacity and the positioning of the capacity.

The cost of installing an electric heating element varies considerably with the capacity. A heating element with a capacity of 4 MW costs approximately DKK 3.7 million, 10 MW approximately DKK 4.5 million and 16 MW DKK 5 million.

3 Dynamic of wind production on Bornholm

In order to provide an indication of the dimensions of the demand capacity required on Bornholm when in islanding mode the production data for wind power generation is needed. This give an indication of the level of intermittency in wind power production and provide an idea of the range of demand capacity required to maintain quality of supply in islanding mode. Wind turbine production data on Bornholm at fifteen minute intervals for the first four months of 2007 has been studied. This is shown in figure 7 below.

Figure 7: Wind power generation on Bornholm. Data is 15-minuttes values for the first four month of 2007



The figure shows that production varies from 0 to 30 MW, but generally large fluctuations in production will be relatively predictable using forecasting. It is the size and number of fluctuations in production over short periods that are important in dimensioning demand capacity. This is shown in the duration curve in for wind power generation in figure 8. This uses the same data set as in figure 7.

Figure 8: Duration curve for change in wind power. X-axis represents the number of 15 minute intervals during the 4 month period in which data was collected. Y axis represents the change in power production over 15 minutes.

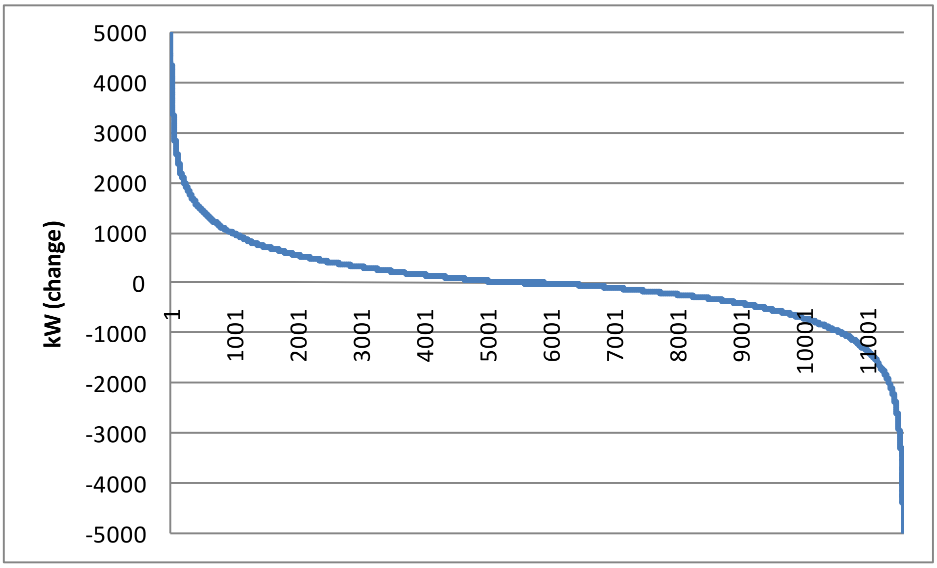


Figure 8 indicates that large fluctuations over 15 minute periods do not occur regularly. If one assumes that the existing generating capacity on Bornholm can be adjusted by 2 MW over a fifteen minute period then it can be assumed from the duration curve above that approximately 3 MW of flexible capacity is required as frequency regulation. This could be provided through a 10 MW electric element and the 4 MW of heating capacity in the 812 households.

Table 4 below shows the maximum and minimum changes in demand and wind power productions using the same data set.

MW	Value			Change from one quarterly value to the next		
	Min.	Average	Max.	Min.	Average (average absolute value)	Max.
Demand	14.0	31.8	57.6	-16.0	0 (0.99)	22.5
Wind power	0	11.7	29.9	-6.7	0 (0.56)	11.8
Demand and wind power *	-8.3	20.2	55.7	15.8	0 (1.20)	21.9

* A negative number indicate that wind power generation exceeds demand

Table 4: Maximum, minimum and average change for 15 minute intervals

Table 4 indicates that changes of more than 5 MW in a fifteen minute period can occur. Figure 8 indicates that during the course of the four months there were 10 occasions where production increased by more than 5 MW over a fifteen minute period and 6 occasions where production fell by more than 5 MW. This is less than one 15 minute period per thousand and should be addressed by regulating the wind turbines when in islanding mode.

4 Conclusion

This study indicates that approximately 3 MW of dump load capacity is required and 3 MW of demand capacity. This must be correlated with the modelling of wind turbine production being undertaken by CET.

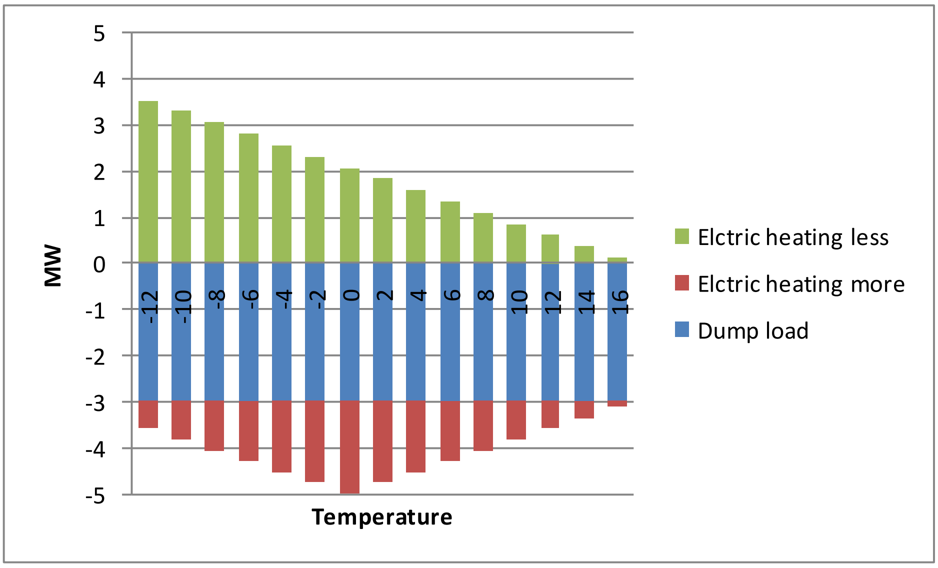
Dump load capacity in the form of a single 10 MW electric heating element could be installed due to the very short period of time that the full 3 MW of capacity would be required. The installation of a 10 MW element would allow for the 3 MW to be activated almost instantly. The cost of a 10 MW element is only marginally greater than a smaller element, which would not be able to be activated at the same rate.

When considering the district heating systems on Bornholm it would appear that Nexø is the best suited for installing a 10 MW element. Nexø has a year round demand for heat, which means that the element would be available at all times. Nexø also has an accumulation tank that can store hot water produced during frequency regulation. As dump load capacity can be built according to the requirements of the system this is not a limiting factor for implementing demand as frequency regulation.

It appears that 3 MW of demand capacity is required. This report has only considered electric heating. Bornholm has approximately 4 MW of heating capacity available in 812 households using 2.1 MW at 0°C, but further studies should be carried out on how this is utilised by the consumer and how much is actually available at any one time. Refrigerators and freezers are also available as demand capacity. This resource is quite stable but has a limited capacity.

It appears that there is potential for implementing frequency regulation using flexible demand on Bornholm. If wind power capacity is to be increased on Bornholm more demand capacity will be required in order to maintain frequency stability.

Figure 8: The availability of the suggested portfolio: 812 houses with electric heating used for up regulation (upper part of column) or down regulation (lowest part of column) and dump load as down regulation (middle part of column).



Next steps

Possible next steps could be:

- To determine the demand capacity available in residential refrigeration on Bornholm and other sources that can be used to complement electric space heating, such as commercial freezers and refrigeration.
- To study electric heating outside households. This could verify the estimated potential of 2 MW electric heating in trade and service
- Develop a more accurate understanding of the need for new types of reserves. Especially it is important to estimate how often the proposed capacities would be used. The longer periods of use, the more interesting is the district heating possibility of dump load
- A more accurate cost estimation for the infrastructure needed, as well a variable costs
- Estimation of other benefits, e.g. demand response in relation to normal operation, e.g. spot prices