

THE BORNHOLM POWER SYSTEM

An overview

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ABSTRACT: The Bornholm power system is a Danish distribution system located on the island Bornholm situated just south of Sweden. ØSTKRAFT is the distribution system operator supplying electricity to more than 28,000 customers at Bornholm. The peak load was 56 MW in 2007. The Bornholm power system is part of the Nordic interconnected power system and power market, and it has many of the characteristics of a typical Danish distribution system. With respect to area, electricity demand and population Bornholm corresponds to approx. 1% of Denmark. The wind power penetration in 2007 was more than 30%, and the system can be operated isolated in islanding mode. The Bornholm power system therefore is a unique facility for experiments with new SmartGrids technologies, and it is part of the experimental platform for power and energy, PowerLabDK. The key figures of the Bornholm distribution system is given in this paper.

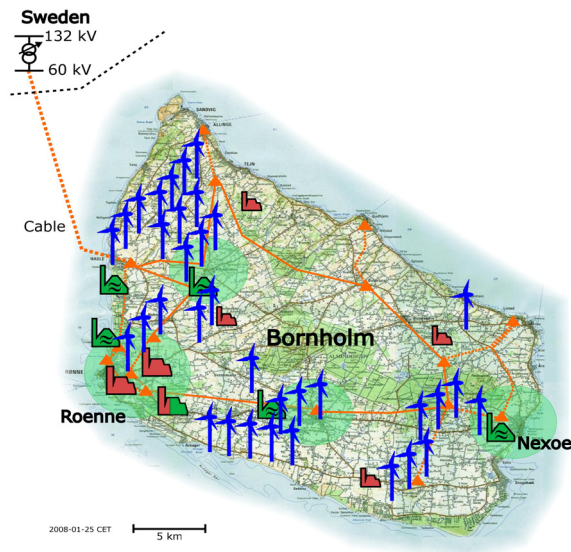


Figure 1. The island of Bornholm with major generation units and 60 kV grid. Total area is 588.5 km².

Keywords: Bornholm, distribution system, wind power, smartgrids, SCADA, key figures.

Abbreviations:

OLTC	On-load tap changer
Trf.	Transformer
CHP	Combined heat and power
EXTRACT	Operation mode of steam cycle power plant with steam extraction

I. THE BORNHOLM POWER SYSTEM

The Bornholm power system consists of the following main components:

- The 132/60 kV substation in Sweden
- The connection between Sweden and Bornholm
- The 60 kV network
- The 10 kV network
- The 0.4 kV network
- The load
- The customers
- The generation units
- The control room
- The communication system
- The biogas plant “Biokraft”
- The district heating systems

II. THE 132/60 kV SUBSTATION IN SWEDEN

E-ON is a power company in the southern part of Sweden. The company owns the equipment in the TOMELILLA and BORRBY substations. From the substation TOMELILLA there is a 132 kV overhead line to the substation BORRBY. In TOMELILLA substation at the 132 kV BORRBY feeder the SCADA system measures the following values:

- The voltage in kV
- The active power in MW
- The reactive power in MVar

The BORRBY substation has two 132/60 kV transformers. One of them supplies the connection to HASLE on Bornholm, the other BORRBY CITY. In BORRBY substation at the 60 kV HASLE and BORRBY CITY feeders the SCADA system measures the following values:

- The voltage in kV
- The active power in MW
- The reactive power in MVar

The E-ON SCADA system has the following archives:

- 10 seconds instantaneous values (14 days)
- 1 minute average values (1 month)
- 1 hour average values (1 year)

The transformer in the BORRBY substation cannot be operated as an OLTC transformer, because the tap changer

is fixed. Consequently, the position is not transferred to E-ON's control room in Malmø. Data for the transformer can be found in Table 1.

Rating	Voltage	Short-circuit voltage, uk
63 MVA	135kV±9x1.67% / 69 kV	9.997 %

Table 1. Data for the BORRBY 132/60 kV transformer.

III. THE CONNECTION TO SWEDEN

Energinet.dk is the transmission system operator in Denmark. The company owns the equipment between the BORRBY substation in Sweden and the HASLE substation at Bornholm.

The 60 kV side of the transformer in the BORRBY substation is connected to the 60 kV substation HASLE at Bornholm, by the overhead lines/cables shown in Table 2.

Type	Dimension [mm ²]	Length [km]
Overhead line	127 Cu	4.2
Cable	400 Cu	0.7
Cable (offshore)	240 Cu	43.5
Cable	400 Cu	1.4
		49.8

Table 2. Connection between BORRBY and HASLE.

The steady state model (pi equivalent) for the connection between BORRBY and HASLE has the electric constants shown in Table 3.

R' [Ω/km]	X' [Ω/km]	B' [uS/km]
0.1402	0.1225	46.553

Table 3. Data for the connection BORRBY to HASLE.

IV. THE 60 KV NETWORK AT BORNHOLM

Østkraft is the distribution system operator at Bornholm [1]. The company owns the power system equipment on the Bornholm island.

In the HASLE substation at the 60 kV BORRBY feeder the Østkraft SCADA system measures the following values:

- The voltage in kV
- The current in A
- The active power in MW
- The reactive power in MVar

The Østkraft SCADA system has the following archives:

- 10 seconds instantaneous values (14 days)
- 1 minute average values (1 month)
- 1 hour average values (1 year)

In the HASLE substation at the 60 kV BORRBY feeder the settlement system measures the following values:

- The active power in MW
- The reactive power in Mvar

These values are stored as 15 minutes average values.

The 60 kV network at Bornholm is meshed and consists of the following elements:

- 16 60/10 kV substations
- 23 60/10 kV OLTC transformers 219 MVA
- 22 60 kV lines
 - Length of overhead lines 73 km
 - Length of cables 58 km

These elements are connected as shown in Figure 2.

Year	Name	No. of Trf.	Trf. [MVA]	10 kV feeders
1959	Olsker	2	8.0	6
1959	Bodilsker	2	14.0	6
1967	Aakirkeby	2	16.0	10
1974	Østerlars	1	6.3	4
1977	Snorrebakken	1	10.0	6
1980	HASLE	2	20.0	7
1981	Nexø	2	20.0	6
1983	Rønne Syd	1	10.0	4
1984	Allinge	2	20.0	4
1988	Svaneke	1	10.0	6
1988	Viadukten	1	10.0	7
1989	Rønne Nord	1	10.0	6
1990	Poulsker	1	10.0	5
1994	Vesthavnen	1	10.0	4
1998	Gudhjem	1	4.0	4
	Værket	2	41.0	9
		23	219.3	94

Table 4. 60/10 kV substations.

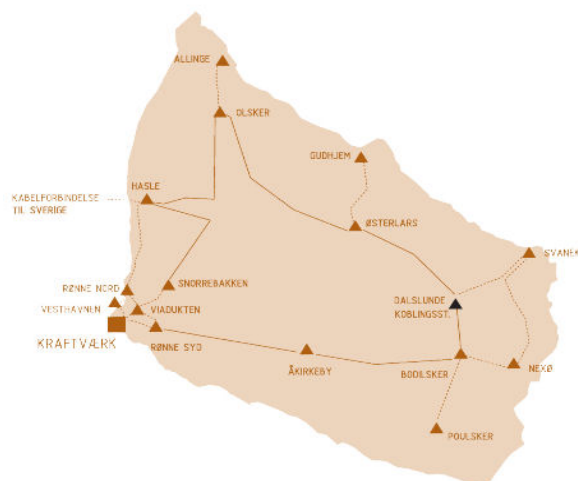


Figure 2. The 60 kV network in 2007.

In general the following values are measured on the 10 kV side of a 60/10 kV transformer:

- The voltage in kV
- The current in A
- The power factor (cos phi)
- The transformer tap changer position

In a number of 60 kV lines, the voltage and current are also measured. One frequency measurement is present in the SCADA system (HASLE substation).

V. THE 10 KV NETWORK

The 60/10 kV OLTC transformers keep the 10 kV voltage to a value around 10.5 kV. The 10 kV network consists of the following elements:

- Overhead lines 184 km
- Cables 730 km
- Feeders 91
- Average no. of feeders per substation 6

The SCADA system measures the current at each feeder.

VI. THE 0.4 KV NETWORK

The 0.4 kV network consists of the following elements:

- Overhead lines 478 km
- Cables 1,409 km
- 1,006 10/0.4 kV transformers 268 MVA
 - Average kVA per transformer 268
 - Average customer per transformer 29

VII. THE LOAD

The 2007 load was as follows:

- Peak load 56 MW
- Energy 262 GWh
- Equivalent full load hours 4,152 h

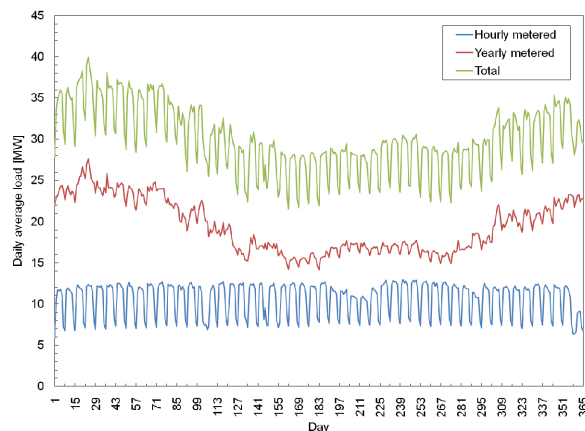


Figure 3. Daily average load in 2007.

VIII. THE CUSTOMERS

The number of customers is 28,310. Of these 302 (1.08%) consumers have a yearly demand above 100,000 kWh. Approximately 30% of the load originates from the customers with a yearly demand above 100,000 kWh.

For the large customers (>100,000 kWh/year) active and reactive demand is measured as 15 minutes average values. The rest are metered manually once a year. The measurements are stored in the SONWIN settlement system.

IX. THE GENERATION UNITS

The generation capacities are as follows (see Table 5 and appendix 1):

- 14 diesel generators (oil) 34 MW
- 1 steam turbine (oil) 25 MW
- 1 steam turbine (oil/coal/wood chips) 37 MW
- 35 wind turbines 29 MW
- 1 gas turbine (biogas) 2 MW

The 14 diesel units and the 2 steam units are able to control both voltage (10.5 kV) and frequency. The 6 newest wind turbines are able to control active and reactive power.

Both active and reactive power is measured and stored as 15 minute average values for all production units with a yearly generation above 100,000 kWh.

				Heat	Power
Year	No.	Type	Fuel	[MJ/s]	[MW]
1967	1	Diesel	Oil		4.5
1968	2	Diesel	Oil		4.5
1971	3	Diesel	Oil		5
1972	4	Diesel	Oil		5
1974	5	Steam	Oil		25
1995	6	Steam	Oil/coal		
		No heat		0	37
		“Extract”		35	33
		“CHP”		35	16
2007	7	Diesel	Oil		10x1.5
2008	-	Diesel	Biogas		2

Table 5. Data for diesel, steam and biogas units.

The wind turbines generated 79 GWh in 2007. This corresponds to 30.2 % of the load. Detailed information about the wind turbines can be found in Appendix 1 and [2].

X. THE CONTROL ROOM

The control room is able to control:

- The tap changers at all 60/10 kV transformers
- The capacitor banks in 60/10 kV substations
- The active power and voltage reference of the following units
 - 5 diesel generators 34 MW

- 2 steam turbines 65 MW
- The frequency regulator in the following units
 - 1 steam turbine 37 MW
- The power reference of wind turbines
 - 6 wind turbines 11 MW

The main tools at the control room are:

- The SCADA system ABB Network Manager
- The SCADA system VESTAS ONLINE for 6 controllable wind turbines
- The 60 kV and 10 kV network
- The 14 diesel generators
- The 2 steam turbines

In the ABB NETWORK MANAGER measurements are stored as 10 seconds instantaneous values, 1 minute average values and 1 hour average values.

In the VESTAS ONLINE system measurements are stored as 10 minute average values.

XI. THE COMMUNICATION SYSTEM

To support the communication between e.g. the relays and the RTU's in the substations, an optical fibre network has been established.

XII. BIOGAS PLANT

The 2 MW biogas plant Biokraft A/S generates energy from biomass, primarily animal manure and organic waste [3]. The biomass is mixed in three reactors and generates biogas, after which it is converted into electricity and district heating. The degassed slurry is transported back to farms as fertiliser.

The plant produces approx. 6,000,000 m³ biogas, which generates approx. 14,500 MWh electricity and approx. 12,000 MWh heat. The amount of degassed slurry produced on a yearly basis is approx. 85,000 tons.

XIII. DISTRICT HEATING

Total heating requirement at Bornholm is approx. 560,000 MWh/year. Currently, this is covered by three heating sources: District heating, buildings with electric heating and individual boilers.

	Heat production [MWh]	No. of users	Fuel			
			Straw	Oil	Coal	Waste
			[%]	[%]	[%]	[%]
RVV	154,731	5,000		2	68	30
Nexø	35,000	1,659	98	2		
Klemensker	8,900	275	98	2		
Lobbæk	6,700	160	85	15		
Østermarie	150	10		100		
Total	205,481	7,104	24	2	50	24

Table 6. Heat production at Bornholm 2006

The district heating sector of Bornholm is made of five distribution areas. Data for these areas are given in Table 6. For the moment no data exists for the areas Åkirkeby and Hasle.

XIV. RESEARCH, DEVELOPMENT AND DEMONSTRATION

The Bornholm power system is part of PowerLabDK, an experimental platform for power and energy [4]. PowerLabDK is a unique research platform, ranging from flexible multi-purpose university laboratories to large-scale experimental facilities and a complete full-scale power distribution system. The facilities are interconnected and integrated experiments can be performed. Measurements from the Bornholm system are available in the Intelligent Control Lab at the university.

PowerLabDK enables development of the future intelligent electricity system that can handle the future expansion of renewable energy sources and a long-term vision of a fossil-free society.

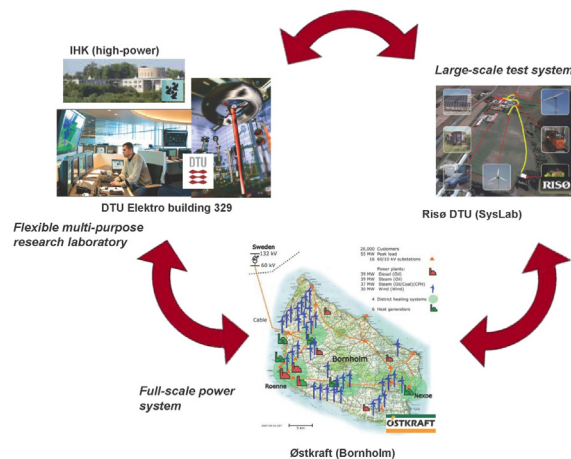


Figure 4. The concept of PowerLabDK; an experimental platform for power and energy including the Bornholm power system.

The Bornholm power system can be used for research, development and demonstration activities of the future SmartGrids [5]. Extensive data and measurements are available, so the Bornholm power system can be analysed and simulated and impact of new solutions and technologies can be assessed [6]. Physical implementation of solutions can be done to evaluate the impact in large scale. The following examples of ongoing activities illustrate the possibilities. The activities fall within the areas:

- Flexible demand and power market
- Island operation
- Wind power integration
- Integration of electric power and transportation systems

Demand as Frequency Controlled Reserve

This activity investigates the feasibility of demand as a frequency controlled normal and disturbance reserve [7]. The project has been done by Centre for Electric Technology (CET) at Technical University of Denmark and Ea Energy Analysis (Ea) and funded by the PSO program. The activity is currently followed by a demonstration of 200 appliances (bottle coolers, electric heating, home automation systems etc.) with this functionality installed in the Bornholm system. The demonstration is done by CET, Ea, Vestfrost, Danfoss and Østkraft and is funded by the EUDP program.

Islanding operation of distribution systems (micro-grids)

The Bornholm power system is able to intentionally go from interconnected operation with the Nordic power system to isolated islanding operation and back. During islanding operation the shedding of wind power is necessary to avoid unwanted power oscillations, which lead to uncontrolled oscillations in the power plant control. Extensive measurement has been performed during islanding transitions and operation to enable investigation of the islanding transition and the impact of the wind power during islanding [8, 9]. The work is part of the More Microgrid project funded by the EU 6th framework programme.

Control Architecture for Intentional Islanding

A new control architecture for intentional islanding of distribution systems during emergencies in the transmission system has been developed. The developed architecture is based on islanding security regions [10]. Measurements and data from Bornholm have been used for the project. The work is done in a PhD project, which is part of the NextGen project funded by Energinet.dk.

Coordinated Frequency Control of Wind Turbines

This activity has the main objective to develop a coordinated frequency control scheme of wind turbines and other frequency reserves. A new frequency control methods for double fed induction generation wind turbines has been developed [11]. Extensive measurements and simulations of the Bornholm system with special focus of the modern Vestas wind turbines have been done. Experiments testing the developed methods are under planning. The activity is carried out within an Industrial PhD project in collaboration between Vestas and CET.

Application of Phasor Measurement Units (PMU's)

Novel measurement equipment, phasor measurement units (PMU's), which with high time accuracy has the ability to measure voltage angle differences in the power system has been installed in the Bornholm system. The PMU's can be used for advanced monitoring and control of power systems.

EDISON, system integration of electric vehicles

In the EDISON project optimal system solutions for electric vehicle system integration, including network

issues, market solutions, and optimal interaction between different energy technologies is develop [12]. An EDISON virtual power plant for intelligent integration of the vehicles will be developed and tested. The Bornholm power system provides an optimal platform for a field test of the developed solutions and the first electric vehicles are currently driving at Bornholm. The EDISON project has a number of Danish and international partners under the management of Danish Energy Association and funded by the PSO program.

XV. FUTURE DEVELOPMENT AND ACTIVITIES

The municipality and local community of Bornholm have a vision of Bornholm as a green island. This includes goals of becoming 100% based on renewable energy, utilization of Bornholm as an experimental facility for the future energy system and creation of green job and development on the island. The strategy is branded under the label Bright Green Island [13].

Specific developments of the energy system, which currently is under consideration, includes MW-class photo voltaic (PV) roll-out, extension of the wind power capacity and smart meters.

Examples of future research, development and demonstration activities which can utilize the Bornholm system as experimental facility are:

- Development of new electric power market for real-time balancing and ancillary service provision
- Utilization of energy storage for system balancing and services
- Virtual power plant implementations for demand and generation aggregation
- Modern communication solutions for power systems e.g. based on IEC61850
- Demonstration of improved active power control by demand as frequency controlled reserve
- Demonstration of the future active distribution system

XVI. REFERENCES

- [1] Østkraft Net A/S, *Annual Report 2007*, Østkraft Net A/S, Rønne, Bornholm, Denmark, 2008. Available online: www.oestkraft.dk.
- [2] Danish Energy Agency, *Register of wind turbines*. Available online: http://www.ens.dk/en-US/Info/FactsAndFigures/Energy_statistics_and_indicators/OverviewOfTheEnergySector/RegisterOfWindTurbines/
- [3] Biokraft A/S, *Biokraft A/S webpage* (in Danish). Available online: <http://www.biokraft.dk>.
- [4] *PowerLabDK webpage*. Available online: <http://www.powerlab.dk>.
- [5] Z. Xu, M. Gordon, M. Lind, J. Østergaard, Towards a Danish power system with 50% wind — Smart grids activities in Denmark, *IEEE PES General Meeting*, 2009. DOI: 10.1109/PES.2009.5275558

- [6] V. Akhmatov, J.E. Nielsen, J. Østergaard, A.H. Nielsen, Wind power system of the Danish island of Bornholm: Model set-up and determination of operation regimes, *WVEC2009*, Seoul, South Korea, 2009.
- [7] Z. Xu, J. Østergaard, M. Tøgeby, C. Marcus-Møller, Design and Modelling of Thermostatically Controlled Loads as Frequency Controlled Reserve, *IEEE PES General Meeting*, Tampa, Florida, 2007. DOI: 10.1109/PES.2007.386014.
- [8] Y. Chen, Z. Xu, J. Østergaard, Frequency analysis for planned islanding operation in the Danish distribution system – Bornholm, *UPEC*, Padova, Italy, 2008. DOI: 10.1109/UPEC.2008.4651467.
- [9] Y. Chen, Z. Xu, J. Østergaard, PMU Frequency Data Processing for A Planned Islanding Operation in Bornholm, *Nordic Wind Power Conference*, Bornholm, Denmark, 2009.
- [10] Y. Chen, Z. Xu, J. Østergaard, Control Mechanism and Security Region for Intentional Islanding Transition, *PES General Meeting*, Calgary, Canada, 2009. DOI: 10.1109/PES.2009.5276000
- [11] G.C. Tarnowski, P.C. Kjær, P.E. Sørensen; J. Østergaard, Variable Speed Wind Turbines Capability for Temporary Over-Production, *IEEE PES General Meeting*, Calgary, Alberta, Canada, 2009. DOI: 10.1109/PES.2009.5275387.
- [12] J. Østergaard, A. Foosnæs, Z. Xu, T.A. Mondorf, C.A. Andersen, S. Holthusen, T. Holm, M.F. Bendtsen, K. Behnke, Electric Vehicles in Power Systems with 50% Wind Power Penetration: The Danish Case and the EDISON programme, *European Conference Electricity & Mobility*, Würzburg, Germany, 2009.
- [13] Regional Municipality of Bornholm, *Bright Green Island Bornholm*, 2. edition, Rønne, Bornholm, Denmark, August 2009. Available online: <http://www.bornholm.dk/resources/12379.pdf>.

XVII. BIOGRAPHIES



Jacob Østergaard is professor and head of Centre for Electric Technology at Technical University of Denmark (DTU), Department of Electrical Engineering. He came to DTU in 2005 and before this he worked for the Research Institute for Danish Electric Utilities in 10 years. He received his M.Sc. E.E. degree from DTU in 1995. His research field covers SmartGrids with special focus on wind power integration, new control and network architectures and flexible demand. He serves in several professional boards and committees including the board of directors of Balslev Rådgivende Ingeniører A/S and the EU SmartGrids Advisory Council. He is a senior member of IEEE. E-mail: joe@elektro.dtu.dk.



John Eli Nielsen was born in Denmark 1944. He received his M.Sc.EE. degree from The Technical University of Denmark in 1974 and his Industrial PhD degree in 1976. He has been working for the distribution system operator NVE for 7 years and the transmission system operator Elsam/Eltra/Energinet.dk for 25 years. Currently, he is working for Technical University of Denmark as associate professor. His experience lies in the area of planning and operation of power systems. He is a member of IEEE and has for many years been the Danish representative in CIGRE Study Committee 39 – *Power System and Control*. E-mail: jen@elektro.dtu.dk.

APPENDIX 1 Data for Wind Turbines

Year	Nominal power [kW]	Voltage [kV]	Area
1992	225	0.4	Rutsker
1992	225	0.4	Rutsker
1992	225	0.4	Rutsker
1996	225	0.4	Bodilsker
1996	225	0.4	Bodilsker
1996	225	0.4	Bodilsker
1980	55	0.4	Klemensker
1982	30	0.4	Bodilsker
1988	130	0.4	Nyker
1988	130	0.4	Nyker
1989	18	0.4	Vestermarie
1999	660	10.0	Rutsker
1999	11	0.4	Østermarie
2002	30	0.4	Rutsker
2002	660	10.0	Olsker
2002	900	10.0	Bodilsker
2002	900	10.0	Bodilsker
2002	900	10.0	Bodilsker
2002	800	10.0	Knudsker
2002	800	10.0	Knudsker
2002	800	10.0	Knudsker
2002	1,300	10.0	Rutsker
2002	1,300	10.0	Rutsker
2002	1,300	10.0	Rutsker
2002	1,300	10.0	Åker
2002	1,300	10.0	Åker
2002	1,300	10.0	Åker
2002	1,300	10.0	Åker
2002	1,300	10.0	Åker
2002	1,300	10.0	Åker
2006	1,750	10.0	Rutsker
2006	1,750	10.0	Rutsker
2006	1,750	10.0	Rutsker
2006	2,000	10.0	Åker
2006	2,000	10.0	Åker
2006	2,000	10.0	Åker
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