

08. April 2008

Elaborate Project Description

Electricity Demand as Frequency Controlled Reserve - Implementation and practical demonstration

Active control of electricity demand is a key technology when creating a more dynamic, wind power friendly energy system. This demonstration project is about using electricity demand as fast reserves. This is an alternative to some of the most expensive reserves in the current electricity system.

Maintaining the power balance between supply and demand is of highest priority in power system operation. If a power plant trips, the system frequency will decrease, and the balance must quickly be re-established by using reserves. Today, the reserves are provided mainly by generation side resources, including extra capacity of generators and interconnection lines. The reserves are costly, e.g. in Nordel system 50 MW on the DC connection between Zealand and Germany is reserved for reserves, which could otherwise be used for transactions in the electricity market.

The reserves can be also provided by using frequency controlled demands with several advantages, e.g. fast responding speed, low costs and high dispersion at feeder level etc [1]. Most importantly, it can enhance the system stability for the future power system, where a high penetration of fluctuating renewable energy is foreseen, e.g. the new Danish Energy Policy recommends that 50 % of national electricity consumption should be supplied by wind generation by 2025 [11]. There are many demands existing in power system that can be used as reserve. Particularly, the thermostatically controlled loads such as heaters and refrigerators have cyclic on/off characteristic with considerable volume, which make them ideal to be used as frequency controlled reserve.

Using demand as reserve is not a new idea but with focuses on large size industrial loads in the past. In [2], a market based demand management program using low frequency relay to control industrial loads is reported. A similar program is implemented in the New Zealand power sys-

tem [3]. In Finland, 1000 MW industrial demands from wood processing, chemical and metal industrials are used as frequency controlled as well as manual reserve [4].

Domestic demands with small electricity consumption can also provide reserve, which was proposed as early as in 1979 [5]. The recent availability of low cost micro electronics makes the idea more attractive and motivates many researches in the field. The Pacific Northwest National Laboratory (PNNL) has suggested that individual household appliances suitable for temporary disconnection can provide fast reserve that can react within seconds, e.g. refrigerators and air conditioners [6, 7]. Similar suggestions have been made in UK by Short and Leach and Hirst [8, 9]. A pilot project using the *ComfortChoice* technology for controlling air conditioners to provide frequency activated reserve was carried out by the Long Island Power Authority in 2003 [10]. Due to the communication (two way paging) system used, the reserve is to be activated relatively slow within about 90 seconds.

Inspired by all relevant research activities, we have started our research on demand as frequency controlled reserve since the previous PSO project. In our previous research, theoretical investigation of the DFR technology has been carried out. The potential and economy of DFR compatible loads in Denmark has been investigated, several types of DFR control logic has been developed, power system impact has been evaluated, potential business models has been designed, and an implementation strategy has been suggested. The results show that the DFR technology is a promising technology from several perspectives. Technically, using DFR is feasible to provide reserves and enhance power system frequency control, while fulfilling power system requirements such as linear activation. Environmentally, the DFR technology is pollution free in contrast to traditional reserves from generation side. Economically, the cost of such reserve can be low and an attractive business model providing benefit for both society and the involved parties can be established. Seeing that renewable energy with fluctuating natures is continuously increased into power systems, frequency control will become critical in the future where e.g. 50% electricity consumption is recommended to be supplied by wind power by 2025 in Denmark. The DFR is a novel technology that can facilitate such trend by providing quality service in need at a low cost and zero pollution. If implemented, unique advantages in market competition can be gained to realize the business potential for Danish manufacturers. The draft report of the PSO project is attached with the application.

This project is our continual research effort of the same subject with extension for practical demonstration. The power system at Bornholm island is chosen to host the demonstration, and the local system operator Øskraft has committed their full support. The Bornholm system has encountered serious difficulty in maintaining system frequency during islanded operation period, where wind power has to be largely reduced. This challenge is also foreseen for future power system with an increased share of renewable energy. As such new technology including the DFR is needed to ensure the security of supply, and Øskraft has already been actively collaborating with several partners in this project to carry out research in their system. It should be highlighted that the research outcome from Bornholm system will be universal and can play a key role in developing new technology for Danish power system in the future. A detailed intro-

duction to the Bornholm including power system information and relevant research projects on-going therein is attached in the Appendices.

In our previous research project, focuses have been put on theoretical investigations and analyses. In the demonstration project, practical experiments will be done with the two generic types of frequency control of demand that have been developed:

- The external control: An on/off switch is controlled by the system frequency. When the frequency is below a set-point, e.g. 49.9 Hz, the switch is turned off. This is essentially “a box” that can control any device, and will act as an automatic disturbance reserve. The set-points can be designed so that the result is a classic proportional control for reserve. Figure 1 illustrates the control logic of this type.

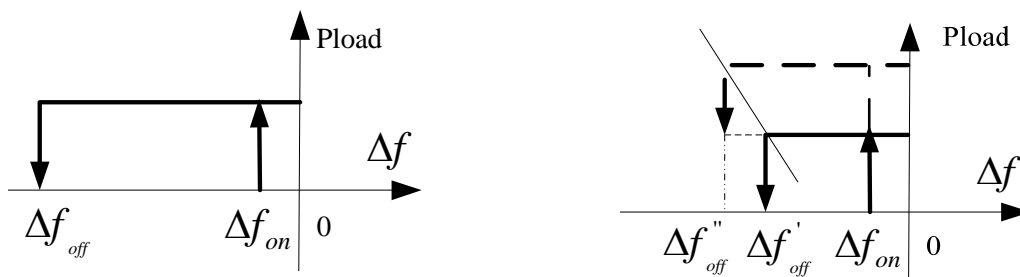


Figure 1 Illustration of external control type DFR for single load on the left and aggregated loads with proportional reserve activation design on the right

- The integrated control: A system where the set-points, e.g. a thermostat, are controlled by the frequency. The integrated control will be less disturbing for the end-user because it is interacting with the normal on/off cycle and only adjusting the length of the on or the off cycle. If the frequency falls the control will start to disconnect those devices that are in the end of their on-cycle. The integrated control is also active in the normal frequency interval (as normal frequency reserves) as well as in the over-frequency range. This makes the integrated control very suitable for normal frequency control reserve, which is important for a system with high penetration of fluctuating renewable generation, such as the Bornholm system in islanding operation mode [13]. Figure 2 illustrates the integrated control logic for aggregated heaters.

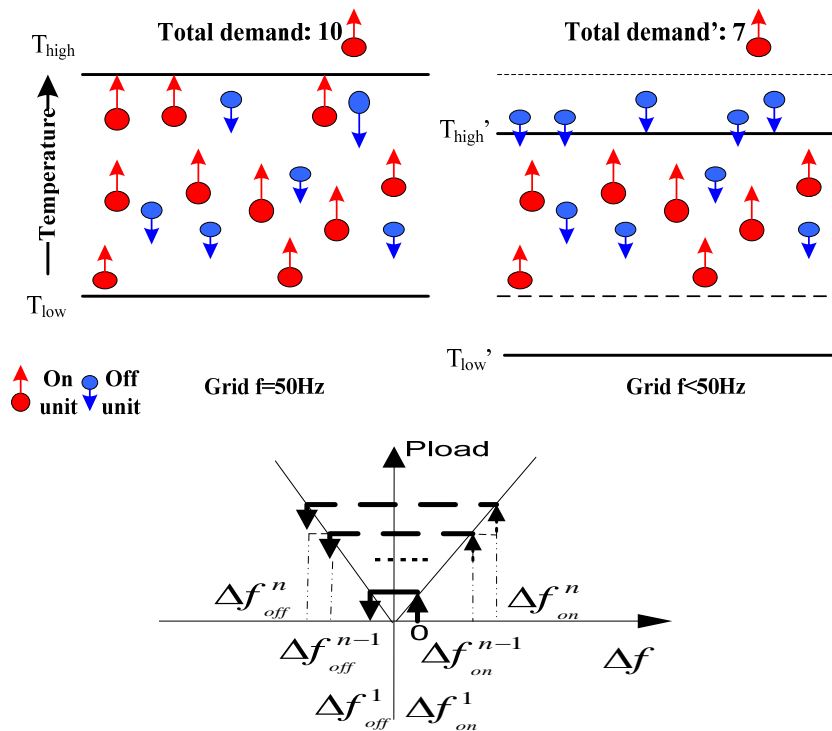


Figure 2 Illustration of integrated control of aggregated heater loads: the upper illustrates the behavior of aggregated 16 heaters with integrated control in response to a frequency dip, and the lower shows the control logic accordingly

For this project a prototype of the external control will be produced. In addition to the control feature, the box will also have capabilities for data collection and communication. The data features are only needed in the prototype for evaluation purpose. The prototype will be developed according to various devices, including Danfoss electric heating and Vestfrost cooling devices including refrigerators and freezers. It will also be developed for miscellaneous devices that can be tested in the demonstration. Some of the prototypes will be developed based on the home automation product from Electronic Housekeeper A/S, which is able to measure grid frequency [12].

The integrated control will be developed and tested in relation to Danfoss electric heating. Electric heating is very attractive from a control perspective, since it can be disconnected and re-connected very quickly. Other types of demand, e.g. compressors for heat pumps or cooling devices, have restrictions when to disconnect and can only re-connect after a certain resting period. Electric heating exists in more than 100,000 Danish houses and is expected to a certain market share in future low energy houses.

The Danfoss electric heating can be supplied with an advanced control system that allow the user to control set point, check temperatures and receive alarms. The system can be used via an internet or mobile phone interface. This system will be developed in a proto type to include the frequency control, and this system will be tested in a comprehensive field test.

The project will include a number of work packages:

- WP1. Development of a practical device for external control. This includes hardware design for frequency measurements, control logic and data collection and communication for data management. CET will be responsible for this work package.

- WP2. Development of integrated control in relation to the Danfoss electric heating. This will use the several features from the external control, but will be extended to include correction of temperature set-points for the electric heating. Danfoss will be responsible for this work package with assistance from CET.

- WP3. Development of external control in relation to the product from Electronic Housekeeper A/S. Since the hardware for frequency control is ready in the product, this will only involve re-programming the software inside. Ea will be responsible for this work package in close cooperation with CET.

- WP4. Development of frequency control for freezers or refrigerators of Vestfrost. Vestfrost will be responsible for this work package in close cooperation with CET.

- WP5. Laboratory test of devices that have been developed in Work Packages 1 to 4. The test will be conducted in the laboratory of DTU, and CET will be responsible for this task in close collaboration with all partners.

- WP6. Design and development of central data collection system (database-system) in order to collect data from all DFR devices in field test. CET will be responsible for the task with close collaboration from all partners.

- WP7. Design and implementation of demonstration. End users will be invited to take part of the practical test. The goal is to include: a) 50 end-users for the external control, b) 50 end-users for the integrated control in relation to electric heating, c) 50 miscellaneous appliances with external control based on the product from Electronic Housekeeper and d) 50 cooling devices from Vestfrost. In total 200 appliances. The setup of the field test is illustrated in Figure 3 below. This task includes developing a questionnaire to collect participants' evaluation of user impact of the tested system. It is the goal that a number of the end users are located on Bornholm to make synergy with other actual projects. Ea Energy Analyses is responsible for this work package in close cooperation with Østkraft.

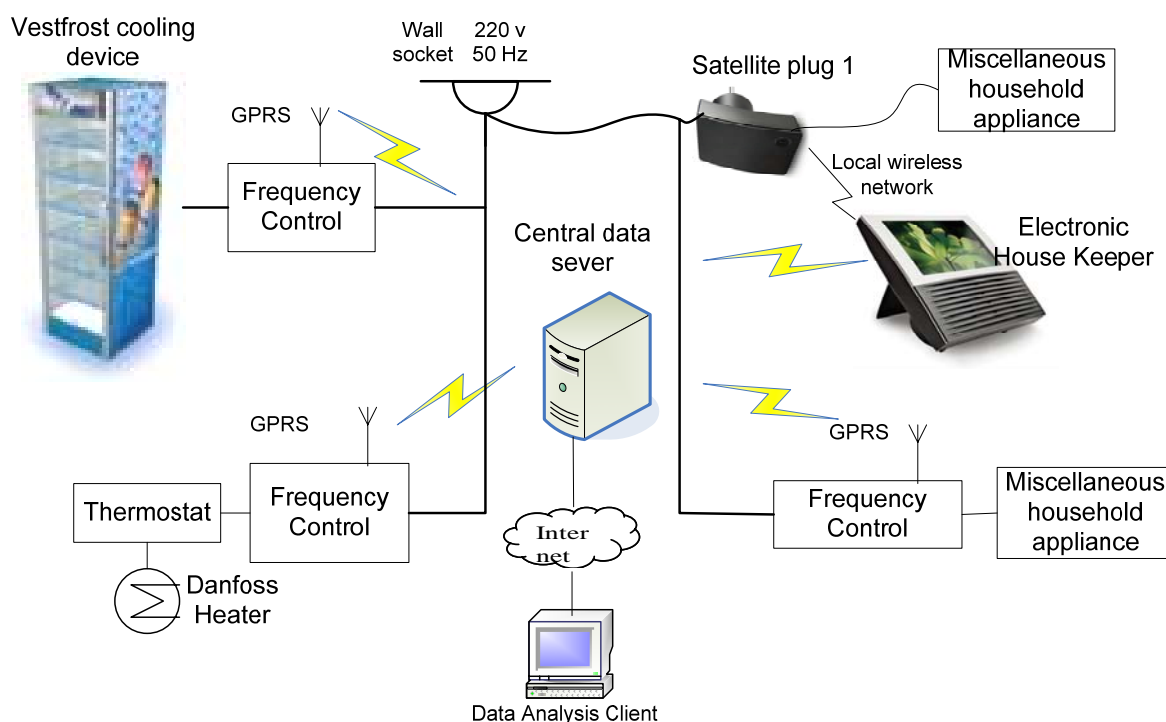


Figure 3 The setup of DFR appliances in the field test, including 50 end-users for the external and integrated control in relation to Danfoss electric heating respectively; 50 end users for Vestfrost cooling devices; 50 miscellaneous appliances with external control based on Electronic Housekeeper; and 50 miscellaneous appliances with external control

WP8. Field test of devices over a one year period. This includes a hot line for end users and monitoring of data collection system and quality control of data. Ea Energy Analyses is responsible for this work package in close cooperation with Østkraft.

WP9. Analyses of data. This includes comparing the predicted amount of reserves with actual delivered reserves. Ea Energy Analyses is responsible for this work package in close cooperation with CET.

WP10. Theoretical development. The project will be followed by a Post Doc study that will extend the activities from the previous work, including developing possible designs for more advanced system, e.g. including voltage control in combination with the frequency control of demand, and use of hot water tank of heating system as dump load. CET will be responsible for this work package. Analysis of applying DFR technology in other relevant appliances, e.g. heat pumps and circulation pumps will also be carried out. The Post Doc is 50% financed by DTU.

WP11. Reporting and project management will be done by Jacob Østergaard, CET in cooperation with Mikael Tøgeby, Ea Energy Analyses.

In addition to these work packages, various activities will be organised throughout the project to report and summarize the progress, disseminate the research outcomes, and communicate with relevant parties in the field. Three progress reports and two workshops are planned during the course of the project. An advisory group will be set up with representatives from utilities and manufactures to review and give inputs into the research work. In addition, writing of several conference and journal papers have been also planed. To support the project manager in managing and organising the project, a steering group will also be setup by important project participants who have the control of issues like staffing and resources allocation in their own organisations.

A number of similar research activities are taking places worldwide, including the Grid Friendly research program at PNNL [6, 7], and the Dynamic Demand and Responsive Load research in UK [8] [14]. The research team has contacts with these environments. Particularly, the team already has good collaborations with PNNL in previous project.

Reference List

- [1] Z. Xu, J. Østergaard, M. Tøgeby, and C. Marcus-Møller, "Design and Modeling of Thermostatically Controlled Loads as Frequency Controlled Reserve", Proc. of 2007 IEEE PES General Meeting, Tampa, Florida, USA, July 2007.
- [2] M. Bailey. "Provision of frequency responsive power reserve from disconnectable load". IEE Colloquium on Economic Provision Of A Frequency Responsive Power Reserve Service (98/190) 5 Feb. 1998 Page(s):5/1 - 5/5
- [3] A. Turner, T. N. Chan and A. N. Gibbs. "A Fast Reacting Power System Load Shedding Management System".. Proceedings of the 9th Conference on the Electric Supply Industry (CEPSI). Hong Kong. 1992
- [4] Fingrid, "Maintenance of frequency" online at www.fingrid.fi/portal/in_english/services/system_services/maintenance_of_frequency
- [5] F. C. Schwappe, "Frequency adaptive, power-energy re-scheduler (1979)", United States Patent 4317049 online at www.freepatentsonline.com/4317049.html
- [6] M. Kintner-Meyer. R. Guttromson. D. Oedingen. and S. Lang. "Final Report for California Energy Commission: Smart Load and Grid-Friendly Appliances". prepared by Architecture Energy Corporation and Battelle Memorial Institute. Oct. 2003;
- [7] PNNL, "Grid Friendly™ Controller Helps Balance Energy Supply and Demand" online at www.gridwise.pnl.gov/docs/pnnlsa36565.pdf
- [8] J. Short, and S. Leach, "Using smart appliances to provide peak-load management and increase the efficiency of the electricity network" EEDAL 06 International Energy Efficiency in Domestic Appliances Conference.
- [9] D. Hirst, "The Demand Side – Teaching an Old Dog New Tricks", Responsive Load Limited 2006.
- [10] B. J. Kirby. "Spinning reserve provided from Responsive Loads". Oak. Ridge National Laboratory. 2003;
- [11] Danish Ministry of Transport and Energy, "Energistrategi 2025", 2007.
- [12] Electronic Housekeeper homepage at <http://www.tellitonline.com/>

- [13] CET Research Project description, “Security of Supply for Bornholm - Integration of Fluctuating Generation using Coordinated Control of Demand and Wind Turbines” funding by Østkraft
- [14] ResponsiveLoad Ltd. Homepage at <http://www.rltec.com/>